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Post-Construction Bat and Bird Fatality Study at the Blue Sky Green Field Wind Energy Center, Fond du Lac County, Wisconsin

July 21, 2008 – October 31, 2008 and March 15, 2009 – June 4, 2009

Jeff Gruver, Michelle Sonnenburg, Kimberly Bay and Wallace Erickson
Western **E**co**S**ystems **T**echnology**,** Inc.
2003 Central Avenue
Cheyenne, Wyoming

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WEST, Inc.

EXECUTIVE SUMMARY

The Blue Sky Green Field Wind Energy Center began commercial operation in May of 2008. The wind farm is located in the townships of Calumet and Marshfield in Fond du Lac County, Wisconsin. The wind farm consists of 88 Vestas V-80 wind turbines that rise to approximately 121 meters (397 feet) at the highest point at the top of a turbine blade. Each wind turbine is capable of generating 1.65 MW of electricity, and the wind farm as a whole is capable of generating 145 MW of electricity, or enough to provide power to 36,000 average residences. Here, we report results of fatality studies at Blue Sky Green Field that were conducted during the summer and fall of 2008 and spring of 2009.

From July 21 to October 31, 2008, and again from March 17 to June 4, 2009, we conducted studies designed to estimate the number of bird and bat fatalities attributable to wind turbine operation. These dates correspond with the fall and spring migration periods for birds and bats. These studies included systematic searches at a random sample of 30 turbines at daily and weekly intervals. We also conducted trials designed to estimate potential sources of bias, including searcher efficiency and scavenger removal rates. We used a statistical estimator designed to accurately estimate total fatalities. The estimator started with the total number of fatalities found during searches and added amounts associated with the bias rates, search interval and proportion of area searched. We generated estimates of fatalities for all birds and all bats, as well as separate estimates for migratory and non-migratory bat species.

For the entire study, we estimated 11.83 bird fatalities/turbine/year (9.08, 16.43; 90% C.I.) and 7.17 bird fatalities/MW/year (5.50, 9.94; 90% C.I.). We estimated 40.54 bat fatalities/turbine (30.98, 51.16; 90% C.I.) and 24.57 bat fatalities/MW (18.78, 31.03; 90% C.I.). This estimate includes 27 fatalities (12.2% of the total number used to generate fatality estimates) found on search plots outside of the scheduled searches and increased the overall estimate by at least 12% relative to excluding them. If the incidental finds are removed, the estimates would be 35.6 bat fatalities/turbine/year and 21.6 bat fatalities/MW/year. Fatality studies may not consistently include incidental finds of carcasses, or may not have any incidental fatalities to include, as the number of incidental finds likely depends heavily on total number of people active on site, number of inspections and/or visits to the turbine by other (non-study related) site personnel, number of visits to search plots for other activities, etc.

Daily and weekly searches yielded estimates of 12.9 (8.81, 17.57; 90% C.I.) and 11.32 (7.72, 17.21; 90% C.I.) bird fatalities per turbine, respectively. We estimated 39.97 (30.76, 50.70; 90% C.I.) and 40.82 (28.16, 54.29; 90% C.I.) bats per turbine during daily and weekly, respectively. Non-migratory bat fatalities were estimated to be 23.37 (13.51, 27.78; 90% C.I.) and 20.23 (12.17, 26.14; 90% C.I.) per turbine for daily and weekly searches, respectively. Migratory bat fatalities were estimated to be 16.60 (12.99, 21.12; 90% C.I.) and 20.59 (16.33, 32.71; 90% C.I.) per turbine based on daily and weekly searches. The estimates for birds and bats are within the range of others from the United States and Canada but are higher than others reported from the Midwest to date. It may also be noted that estimates based on daily and weekly search intervals did not differ, which may be useful to consider with other goals when designing future studies.

We investigated the relationship between the number of fresh (< 1 day old) bat fatalities found during searches and local meteorological conditions measured on-site and at a local airport. The AIC-ranked best models indicated significant positive relationships between number of fresh fatalities and average temperature and low visibility conditions, and negative effects of wind speed at 50 meters and low cloud ceiling. The models also indicated a significant positive correlation between bat pass rates measured with ground-based detectors and number of fresh fatalities.

This study represents one of the few currently available that we are aware of to estimate bird and bat fatalities from wind turbine operation in the Midwest and contributes to our understanding of wind energy impacts to birds and bats. As more wind power projects are built in the region, and additional studies become available, a clearer picture of the impacts to birds and bats will emerge.

STUDY PARTICIPANTS

Jeff Gruver	Project Manager
Kimberly Bay	Data Analyst / Report Manager
Wally Erickson	Senior Statistician
Michelle Sonnenberg	Statistician
JR Boehrs	GIS Technician
Matt Kesterke	Report Compiler
Andrea Palochak	Technical Editor
Noel Cutright	Field Supervisor
Nathan Kilger	Field Technician
Kelly Ryan	Field Technician
Brad Smith	Field Technician
Sam Theis	Field Technician

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INTRODUCTION

We Energies has developed a wind-energy facility of up to 145 megawatt (MW) capacity in Fond du Lac County, Wisconsin. The Blue Sky Green Field Energy Center (BSGF) is located approximately 15 miles (24 km) northeast of the city of Fond du Lac, Wisconsin in an area dominated largely by corn, soybean, and alfalfa fields. The wind energy project consists of 88 Vestas V82 wind turbines (Figure 1). This 1.65-MW turbine has a 80m (262 ft) hub height and a 82m (269 ft) rotor diameter. Total height at the tip of the blade is 121 m (397 ft). The BSGF project became fully operational in May 2008.

The following report presents results of the post-construction fatality monitoring at the BSGF project that was conducted between July 21 and October 31, 2008, and again from March 17 to June 6, 2009. This report summarizes the fatalities that were collected during the fall 2008 and spring 2009 study and estimates the total number of fatalities for bats and birds for the entire wind project for the fall and spring seasons. Preliminary estimates for the fall season were provided in a previous report (Gruver et al. 2009). This report uses additional data gathered during the spring sampling season to produce an estimated annual fatality rate, as well as comparisons of weather and bat activity data to patterns of bird and bat fatalities.

The mortality study plan for the BSGF site (Gruver et al. 2008) was designed primarily to estimate mortality caused by turbine impact to bats and birds in the project area. The study consisted of the following components: 1) standardized carcass searches in a square plot centered on select turbines; 2) searcher efficiency trials to estimate the percentage of carcasses found by searchers; and 3) carcass removal trials to estimate the length of time that a carcass remains in the field for possible detection.

The objective of the standardized carcass searches was to systematically search plots at the 30 selected turbines for bat and bird casualties that are attributable to collision with the turbines. All bird and bat fatalities during both transect surveys and incidental fatality observations (i.e. a fatality observed outside the 30 study locations) were recorded and are presented in this report.

The objective of the searcher efficiency trials was to estimate the percentage of casualties that are found by the observers. Searcher efficiency trials were conducted by placing "detection" carcasses in the same areas where carcass searches occur, and the efficiency trials were conducted periodically throughout both the fall 2008 and spring 2009 study season. Estimates of searcher efficiency were used to correct for detection bias by adjusting the total number of carcasses found for those missed by observers. Searcher efficiency trials occurred concurrently with carcass studies.

The objective of carcass removal trials is to estimate the likelihood a carcass is removed by scavengers as a function of time. Carcass removal includes removal by predation or scavenging, or removal by other means (e.g., cultivation, harvesting). Estimates of carcass removal were used to correct for removal bias by adjusting the total number of carcasses found by the relative rate at which carcasses are removed from the study area.

METHODS

This document reports results based on a protocol designed to estimate bat and bird fatality at BSGF and determine if environmental factors influence mortality rates. This report summarizes the monitoring that was conducted during the both the fall 2008 (July 21 – October 31) and spring 2009 (March 15 – June 6) migration seasons, the periods assumed to include the vast majority of fatalities (Johnson 2005). Searchers walked roads, crane pads, and bare areas around the sample turbines and crane pads from July 21 through July 25, 2008 while search plots were being prepared. Carcasses found while conducting these constrained searches were included in the summary tables and totals, but were not included in estimation of total fatalities.

Assumptions

Levels of mortality for the wind energy facility as a whole were estimated by searching in a predefined area around a sample of wind turbine generators on a periodic basis and recording all carcasses found. Decisions regarding the number of turbines to search and how to select them were based on the desire to extrapolate results from the sample to the wind farm as a whole. Decisions regarding the area to be searched around turbines and the interval across which turbines were searched were based on the statistical properties of the estimator used and on published guidelines (Kunz et al. 2007*a*). Some of the same factors were considered in the context of the statistical properties of our estimator. For instance, the estimator takes into account the proportion of area searched as a function of distance from the turbine, as well as the distance from a turbine a carcass was found. Standard statistical procedures allow us to understand and account for the variance associated with these choices. Another sampling decision that can influence mortality estimates is the size of the search plot. We selected search plot size based on recommendations in Kunz et al. (2007*a*), strengthened by evidence from other studies that suggested that the search distance was sufficient to capture most of the fatalities (e.g., Johnson et al. 2003, Jain 2005).

Factors independent of sampling choices also contribute to uncertainty and can introduce substantial bias into estimates of wind turbine-associated mortality. Therefore, these factors must be measured and accounted for to the extent possible. Chief among these are removal of carcasses (e.g., by scavengers) before searchers have opportunity to find them, and carcasses that are present during searches but missed by searchers. Rates of carcass removal by scavengers are likely to vary with time of year, scavenger density, conspicuousness of carcasses, and other factors. If carcass removal rates are high, then fewer carcasses are available to be found during searches, and mortality estimates would be biased low. We used trials designed to estimate the rate at which carcasses are removed by scavengers to account for this source of bias. Variation in searcher efficiency comes primarily from differences in vegetative condition in search plots, color and disposition of carcasses, and individual searcher skill. Searchers are never 100% efficient, so not accounting for this variability will result in mortality estimates that are biased low. We used trials designed to estimate searcher efficiency to account for this source of bias.

When establishing the survey dates, we assumed that most fatalities occur during the migration periods for birds and bats as has been the case at other wind energy facilities (Howe et al. 2002, Arnett et al. 2008), and therefore report estimated fatality rates per year. When calculating fatality estimates, we assumed that crippling bias (mortality of animals injured by turbines but that die from those injuries at a later time) and levels of background mortality (i.e., “natural” mortality not attributable to turbines) were small. Most fatality monitoring studies at wind-energy facilities used this approach because of the relatively high costs or improbability of obtaining accurate estimates (Smallwood 2007; also see Johnson et al. 2000). Accurate estimates of crippling bias, in particular, are very difficult to obtain because crippling bias represents negative data (i.e., it represents a population of fatalities that is not seen). If a large number of animals are injured from turbine collisions but die later away from the plot, then the estimated mortality will be biased low. If levels of background mortality are high, then some of the fatalities discovered during searches may erroneously be attributed to turbine collision, resulting in an estimate that is biased high.

Sample Size

Thirty wind turbine generators (WTG) were selected for study (Kunz et al. 2007*a*) using a systematic random sample to ensure that sampled plots were spread throughout the BSGF site and to allow inference to the project as a whole. Seven of the 88 turbines were considered unavailable for study *a priori,* due to landowner considerations. The remaining 81 turbines were selected by systematic randomization by ordering the turbines from northwest to southeast and randomizing the list. From that list, every 3rd turbine (81/30 ≈ 3) was selected without replacement. The first 30 turbines selected in this manner were chosen for study, while the 31st through 81st turbines on the list were available in the event that one or more of the original became unavailable.

Search Plots

Two different types of search plots were used (see Plot Condition below), but all search plots were defined by a square with sides 160 m long (25,600 m^2; 6.3 acres; 2.56 ha) centered on the turbine (Figure 3). Studies at wind farms with other large turbines (e.g., Johnson et al. 2003, Young et al. 2005) indicate that most fatalities are found within the area that is roughly equivalent to the height of the turbine hub. Most bat fatalities are generally found within an even smaller area around the turbine (Kunz et al. 2007*a*).

Plot Condition

All search turbines were located in cultivated cropland (corn, soybeans, and alfalfa), however, conditions on the ground differed between the 2 seasons. During the fall 2008 portion of the study, search plots, as defined, included the graveled access road and crane pad abutting the base of the turbine, but also extended well into standing crops (Figure 4). During the spring 2009 season, which occurred mostly prior to planting, search plots consisted primarily of bare tilled soil (Figure 4.1).

Because searcher efficiency in plots that extend into crops was expected to be quite low during the growing season (i.e., during the fall 2008 season), we mowed six strips in each of 27 turbine search plots (e.g., Jain 2005), and for the remaining three turbines, we kept the entire 6.3 acre plot in a low-vegetative state. In corn and soybeans, the mowing clipped vegetation to stems approximately six inches tall. Planting row spacing (approximately three feet) in the corn and soybean fields resulted in mowed strips of primarily bare soil in between the mowed stubble (Figure 4). Plant spacing and growth-form were denser in the alfalfa fields, and while mowing increased visibility for the searchers, it was not able to produce strips of primarily bare ground as in the other crops. Therefore, strips in alfalfa fields were re-mowed approximately every two weeks during the study.

Each mowed strip was 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 (see example in Figure 4). This scheme ensured that all distances from 0 to 80 m away from the turbine were sampled during searches. In addition, three randomly selected turbines had the entire 160 m by 160 m search plot maintained in a low-growth vegetative condition. This allowed us to estimate the percentage of carcasses missed by comparing the carcasses from the turbines with managed strips to the turbines whose turbine search plots are completely mowed. In addition to searching the managed strips, that portion of the turbine access road within 80 m of the turbine and the turbine pad were searched. This portion varied by turbine and was measured for each sample plot.

During the spring 2009 season, the strips that had been mowed the previous fall were re-established by demarcating strip edges with stakes and flagging tape so that search methods were consistent between seasons (Figure 4.1). At times, bare-ground, snowmelt, and rain combined to create waterlogged conditions in portions of plots. When transects passed through these areas, searching was very difficult. We initially attempted to complete transects through the muddy areas (Figure 4.2). However, by the beginning of April we made the decision to avoid these areas when they were encountered. If the area was too large to be visually searched (i.e., larger than about the width of a transect), technicians demarcated the area on plot maps, and we accounted for these small reductions in the search area estimates.

Carcass Searches

The objective of the standardized carcass searches was to systematically search plots at the 30 selected turbines for bat and bird casualties that are attributable to collision with the turbines. Personnel trained in proper search techniques conducted the carcass searches. The access road within 80m of the turbine, the turbine pad, and the managed transects were searched. The condition of each carcass found was recorded using the following categories:

<u>Intact</u> - a carcass that is completely intact, is not badly decomposed, and shows no sign of being fed upon by a predator or scavenger.

<u>Scavenged</u> - an entire carcass, which shows signs of being fed upon by a predator or scavenger, or a portion(s) of a carcass in one location (e.g., wings, skeletal remains, portion of a carcass, etc.), or a carcass that has been heavily infested by insects.

<u>Feather Spot</u> - ten or more feathers found at one location indicating predation or scavenging.

In addition to carcasses, any injured bats and birds observed in search plots were recorded and treated as a fatality. All carcasses found were labeled with a unique number, bagged, and frozen for future reference and possible necropsy. A copy of the original data sheet for each carcass was placed in the bag with the frozen carcass. For all casualties found, data recorded included species, sex and age when possible, date and time collected, GPS location, condition (intact, scavenged, feather spot), distance and bearing to turbine, and any comments that may indicate cause of death. All casualties located were photographed as found.

Bat and bird casualties found in non-search areas (e.g., near a BSGF turbine not included in the study) were coded as incidental discoveries and documented as much as possible in a similar fashion as those found during standard searches. While we include those finds in summary totals, they were not included in fatality estimates. Casualties discovered on search plots but outside the scheduled search period were included in fatality estimates under the assumption that they would have been discovered during the next scheduled search.

Appropriate wildlife salvage/collection permits were obtained from the Wisconsin Department of Natural Resources and the US Fish and Wildlife Service to facilitate legal transport of injured animals and/or carcasses. Deposition of carcasses is discussed in Disposition of Data section below.

Ancillary data that may be useful during analyses were also collected. Meteorological and climate data, including precipitation, cloud cover and ceiling level, temperature, wind speed and direction, and barometric pressure were also obtained from meteorological stations. Bat use data within the project area were collected using Anabat™ detectors (Titley Scientific™, Australia).

Search Schedule

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 searched daily, and 20 turbines (five per day) were searched on a four to six day interval (Figure 5). In this report, we refer to these turbines as "weekly turbines". The order that searches were done was randomized so that each plot was searched at various periods during the day. For plots that consist of managed strips, searchers walked at a rate of approximately 45-60 meters/min along each transect. Searchers scanned the area on both sides out to approximately 2.5m for casualties as they walked each transect. Everything within the search plot transects, including the turbine access road and turbine pad, was searched. For cleared plots, searchers walked parallel transects spaced 5m apart while searching 2.5 m on either side of the transect line.

Searcher Efficiency Trials

The objective of the searcher efficiency trials was to estimate the percentage of casualties that are found by the observers. Searcher efficiency trials were conducted by placing "detection" carcasses in the same areas where carcass searches occur. Estimates of searcher efficiency were used to correct for detection bias by adjusting the total number of carcasses found for those missed by observers. Searcher efficiency trials were conducted throughout the survey seasons.

Observers conducting carcass searches did not know when the trials were being conducted, at which turbines "detection" carcasses were being placed, or the locations where the "detection" carcasses were placed in a search plot. An attempt was also made to place carcasses in each of the various habitats being searched and in some approximation of the habitat's aerial extent. Although many fatality studies must rely on non-native bird species such as House Sparrows, European Starlings, and Rock Pigeons, or farm-raised game bird species, Dr. Noel Cutright was able to procure sufficient numbers of a wide variety of native bird species that we were able to minimize or eliminate the need to rely on these other sources. Bird carcasses collected during the study were also used. During this study, bat carcasses collected during the study were mostly used in searcher efficiency trials. Preliminary searcher efficiency trials were conducted using bat carcasses generously provided by WDNR (D. Redell). All searcher efficiency trial carcasses were placed within the search plots being searched prior to the carcass search on the same day. Each trial carcass was discreetly marked so that it could be identified as a “detection” carcass after it was found. The number and location of the “detection” carcasses found during the carcass search were recorded. The number of carcasses available for detection during each trial was determined immediately after the trial by Dr. Cutright.

Carcass Removal Trials

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.

All removal trial carcasses were marked with small piece of colored tape on the bill or leg to avoid confusing a trial bird with a true casualty. Turbines not included in standardized searches were selected for inclusion in the removal trials, and trial carcasses were randomly located in a similar-sized plot as used to search turbines. Major habitats represented around the site’s turbines were included in these trials. Trial carcasses were placed in a variety of postures to simulate a range of conditions. For example, carcasses were: 1) placed in an exposed posture (tossed randomly to one side); 2) hidden to simulate a crippled bird (e.g., placed beneath a tuft of grass), and; 3) partially hidden. Field crews monitored the trial birds over a period of up to 30 days. Carcasses were checked every day for the first four days, and then on days seven, ten, fourteen, twenty, and thirty. Carcasses that remained at the end of the trial were removed from the field.

Fatality Estimation

The estimates presented below were calculated using the search periods July 21 to October 31, 2008, and March 17 to June 4, 2009, and most accurately represent number of fatalities per turbine for that period. Because fatalities outside that period are assumed to be very low, we refer to fatalities recorded during this period as yearly rates. In addition, we calculated four different fatality estimates for birds and bats. Each fatality estimate is based on the same equations (Shoenfeld 2004, Erickson et al. 2005) and used number of animals, searcher efficiency rates, carcass removal rates, search interval, and search area to generate estimates (see below for more detail). These estimates did not include carcasses found on non-search plots. Estimate One included all carcasses (and feather-spots for birds) that were found on the 30 scheduled search plots from the initiation of searches in July 2008 until the end the study in June 2009. Estimate Two included only those carcasses (and feather-spots for birds) found on the 30 scheduled search plots after the entire plot had been mowed and was searchable in 2008. That is, fatalities discovered before the entire search plot was mowed were not included. Estimate Three was similar to Estimate One, except feather spots (which may have resulted from predation rather than turbine collision) and three bird fatalities that may not have been turbine-related were excluded. Estimate Four was identical to estimate One, but in addition, we separated migratory and non-migratory bats.

Statistical Methods for Fatality Estimates

Estimates of facility-related fatalities are based on:

(1) Observed number of carcasses found during standardized searches during the monitoring period for which the cause of death was either unknown or was probably facility-related;
(2) Non-removal rates expressed as the estimated average probability a carcass is expected to remain in the study area and be available for detection by the searchers during removal trials; and
(3) Searcher efficiency expressed as the proportion of planted carcasses found by searchers during searcher efficiency trials.

The number of bat and bird fatalities attributable to operation of BSGF, based on the number of bat and bird fatalities found at BSGF whose death appears related to facility operation, is reported. All carcasses located within areas surveyed, regardless of species, were recorded and, if possible, a cause of death determined based on a cursory field necropsy. Total number of bat and bird carcasses was estimated by adjusting for removal and searcher efficiency bias.

Definition of Variables

The following variables are used in the equations below:

- c_i the number of carcasses detected at plot *i* for the study period of interest (e.g., one monitoring year), for which the cause of death is either unknown or is attributed to the facility
- n the number of search plots
- k the number of turbines searched (including the turbines centered within each search plot)
- $\bar{c}$ the average number of carcasses observed per turbine per monitoring year
- s the number of carcasses used in removal trials
- s_c the number of carcasses in removal trials that remain in the study area after 30 days
- se standard error (square of the sample variance of the mean)
- t_i the time (in days) a carcass remains in the study area before it is removed, as determined by the removal trials
- $\bar{t}$ the average time (in days) a carcass remains in the study area before it is removed, as determined by the removal trials
- d the total number of carcasses placed in searcher efficiency trials
- p the estimated proportion of detectable carcasses found by searchers, as determined by the searcher efficiency trials
- I the average interval between standardized carcass searches, in days
- A proportion of the search area of a turbine actually searched
- $\hat{\pi}$ the estimated probability that a carcass is both available to be found during a search and is found, as determined by the removal trials and the searcher efficiency trials
- m the estimated annual average number of fatalities per turbine per year, adjusted for removal and searcher efficiency bias

Observed Number of Carcasses

The estimated average number of carcasses ($\bar{c}$) observed per turbine per monitoring year is:

$$\bar{c} = \frac{\sum_{i=1}^{n} c_i}{k \cdot A} \qquad (1)$$

Estimation of Carcass Non-Removal Rates

Estimates of carcass non-removal rates are used to adjust carcass counts for removal bias. Mean carcass removal time ($\bar{t}$) is the average length of time a carcass remains in the study area before it is removed:

$$\bar{t} = \frac{\sum_{i=1}^{s} t_i}{s - s_c} \qquad (2)$$

Estimation of Searcher Efficiency Rates

Searcher efficiency rates are expressed as *p,* the proportion of trial carcasses that are detected by searchers in the searcher efficiency trials. These rates were estimated by carcass size and season.

Estimation of Facility-Related Fatality Rates

The estimated per turbine annual fatality rate (*m*) is calculated by:

$$m = \frac{\bar{c}}{\hat{\pi}} \qquad (3)$$

where $\hat{\pi}$ includes adjustments for both carcass removal (from scavenging and other means) and searcher efficiency bias. Data for carcass removal and searcher efficiency bias was pooled across the study to estimate $\hat{\pi}$.

$\hat{\pi}$ is calculated as follows:

$$\hat{\pi} = \frac{\bar{t} \cdot p}{I} \cdot \left[\frac{\exp\left(I/\bar{t}\right) - 1}{\exp\left(I/\bar{t}\right) - 1 + p} \right].$$

This formula has been independently verified by Shoenfeld (2004). The final reported estimates of *m* and associated standard errors and 90% confidence intervals were calculated using bootstrapping (Manly 1997). Bootstrapping is a computer simulation technique that is useful for calculating point estimates, variances, and confidence intervals for complicated test statistics.

For each bootstrap sample, $\bar{c}$, $\bar{t}$, p, $\hat{\pi}$, and m are calculated. A total of 5,000 bootstrap samples was used. The reported estimates are the mathematical means of the 5,000 bootstrap estimates. The standard deviation of the bootstrap estimates is the estimated standard error. The lower 5th

and upper 95th percentiles of the 5,000 bootstrap estimates are estimates of the lower limit and upper limit of 90% confidence intervals.

This formula has been used widely. Other approaches have been proposed and generally differ in assumptions. Recent estimators proposed have the assumption that a carcass that is missed cannot be found (Huso 2008), which is extremely conservative (overestimate), especially when search intervals are short relative to the carcass removal rates. The Huso (2008) estimator is currently in review and has not been provided with enough detail to implement.

Comparison of Weather and Bat Activity to Fatalities

Weather data from an on-site Met tower and an off-site local airport were used to assess mortality in relation to weather variables at Blue Sky Green Field (Table 1). Wind speed, temperature, and barometric pressure data were obtained from the anemometers on the met tower, while ceiling height, visibility, and cloud cover were recorded at the Fond du Lac County Airport, located approximately 19 km (12 mi) south-east of the wind project.

Definition of Variables

Predictor Variable	Description
Temperature	
[avg.temp]	Mean nightly (1930 to 0630 hrs) temperature
Barometric Pressure	
[avg.press]	Mean nightly barometric pressure
Wind Speed	
[mean.ws50m]	Average nightly wind speed at 50 m AGL
[ws50m.0to4p]	Proportion of night (10 min intervals) with wind speed of 0–4 m/s
[ws50m.4to6p]	Proportion of night (10 min intervals) with wind speed of 4–6 m/s
[ws50m.gt6p]	Proportion of night (10 min intervals) with wind speed of >6 m/s
Ceiling Height	
[clow]	Proportion of night (10 min intervals) with cloud ceiling height less than 1000 m
Visibility	
[vlow]	Proportion of night (10 min intervals) with visibility less than 5000 m
Cloud Cover	
[cclow]	Proportion of night (10 min intervals) with cloud cover less than or equal to 0.5

Associations between weather characteristics and fresh bat casualties were investigated using graphical methods (least squares regression lines, interaction plots), univariate association analyses (Pearson’s correlations, simple linear regression), and multiple regression (Neter et al. 1996). However, because the data under examination represented count data, Poisson and negative binomial models were better suited to fit the data than the linear models. Poisson, negative binomial, and zero-inflated Poisson models were also considered.

Several Poisson models were fit to predict the number of fresh bat casualties found at the site. The Poisson models all had log link and were all of the form:

$$log(\mu) = \beta_0 + \beta_1\chi_1 + \ldots + \beta_\rho\chi_\rho + \varepsilon$$

which related the behavior of the natural logarithm (log) of the mean number of fresh bat mortalities per turbine to a linear function of the set of predictor variables $x_1,\ldots,x_p$. The β_j's are the parameters that specify the nature of the relationship and ε is a random error term. The computer program R[1] was used to fit several alternative models. In particular, step-wise model selection methods based on AIC were used to determine the best fitting Poisson and negative binomial models. The correlation matrix was obtained for all continuous main effects listed above. Variables with pairwise correlations ≥ 0.6 were not allowed to be present in the selected models at the same time. The Poisson and negative binomial models were built using a forward and backward stepwise approach in which main effects entered or left the model based on the AIC value. The first step began with the full model containing all parameters. In the next step, covariates were added or subtracted from the model one at a time. If the model AIC decreased, the change in covariates was retained. If AIC increased, that change was discarded and the next covariate was tested. This procedure was repeated until none of the covariate changes produced a lower AIC. Poisson and negative binomial models with the same parameter sets were compared using a goodness-of-fit test (Vuong 1989) that determined there was no distinguishable difference between the best Poisson and best negative binomial model. Therefore, Poisson-based models were used.

Based on the presence of adequate weather data, a total of 72 nights during the Fall 2008 study were used in the analysis. None of the models selected were allowed to contain: (1) both proportion of night with a wind speed of <4 m/s and proportion of night with a wind speed of ≥ 6m/s; (2) both proportion of night with a wind speed ≥ 6 m/s and mean wind speed; (3) both mean wind speed and proportion of the night with a wind speed of <4 m/s; and (4) both low cloud cover and low ceiling height. These exceptions were due to perceived high correlations between the pairs of variables (Neter et al. 1996).

Similar methods were used to determine the relationship between Anabat data and fresh bat fatalities. Bat activity was measured concurrently with the fatality study using Anabat II™ and CF ZCAIM™ ultrasonic bat detection equipment (Titley Scientific™, Australia). Anabat II detectors use a broadband high-frequency microphone to detect the echolocation calls of foraging and commuting bats in real time. Detectors were set to Division Ratio of 16 and a sensitivity level of 6, which matched settings used during the pre-construction study (Gruver 2008).

Four detector units were used at two fixed stations and one unit was used at rotating stations. Fixed Anabat units were paired at the two met towers on site used during the pre-construction survey (Gruver 2008), with one detector at the base of the tower and one detector raised to a height of approximately 30 m on the met tower. To increase spatial coverage of acoustic detection of bats, we rotated one detector among search turbines. The rotating Anabat unit was placed near the base of a randomly selected turbine for a period of 3 consecutive nights.

Anabat units were placed inside plastic weather-tight containers with a hole cut in the side for the microphone to extend through. Microphones were seated into PVC tubing with drain holes that curve vertically outside the container to minimize the potential for water damage due to rain. Each detector unit was powered with a 12-volt external battery and programmed to turn on

[1] R Development Core Team (2009). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0. (http://www.R-project.org)

approximately ½ hour before sunset and turn off at approximately ½ hour after sunrise to conserve power and record only during periods when bats are most active. Detector recorded passively for approximately one week before data retrieval, except the rotating unit, which was serviced every three days.

The measure of activity was number of bat passes per detector-night. A pass was defined as a continuous series of ≥ 2 call notes produced by an individual bat with no pauses between call notes of > 1 second. A detector-night was defined as one detector the operated for an entire night. With five Anabat detectors deployed, each calendar night would have up to 5 detector-nights. Bat activity was determined by downloading the Anabat files to a computer, tallying the number of echolocation passes recorded each night and dividing by the number of detectors working that night. This metric was used as an index of bat activity in the project area. Because the vast majority of fatalities occurred during fall 2008, we used only data from that season in this part of the analysis.

Disposition of Data

During the study, raw data forms were housed with the contractor conducting the study, and individual carcasses collected during the study were housed in a marked freezer at the BSGF Project Office. Individual carcasses not used in trials in 2008 were left in the freezer and were used in trials during the 2009 field season. A total of 26 bat carcasses (19 that were collected at BSGF during fall 2008 searches and seven originally received from WDNR at the beginning of the study) were transferred at the end of the fall 2008 season to WDNR (D. Redell) for use in future studies. Carcasses not used during the study remain in a freezer on-site to possibly be used for future studies at other sites. Decomposed carcasses were discarded.

RESULTS

Search Area and Habitat

Total area searched (m^2), percent area searched as a function of the maximum search area (160 x 160-m plots or 25,600 m^2), and the proportion of detection types within each search plot were calculated for each plot. The proportion of area searched generally decreased as distance from the turbine increased (Table 1). Approximately 66% of possible search area between 0–10 m from the turbines was searched, while approximately 25% of the possible search area between 70–80 m from turbines was searched (Figure 6). In addition, the graveled crane pads and road surfaces within 80 m of the turbine were searched, regardless of whether they were within a search strip. Crane pad area averaged 405 m^2, while road area averaged 332 m^2.

Distance to Wooded Area

We measured the distance from each searched and unsearched turbine to the edge of the nearest wooded area. Four types of wooded areas were classified: Residential Woodlots (RW), Forested Area (FA), Field Strip (FS), and Small Tree Stand (SS); these differed in number, size, and shape. We calculated the area to perimeter ratio for each type. Field Strips and Small Tree Stands had smaller areas relative to their perimeters than Residential Woodlots and Forested Areas (Table 2). Therefore, we combined these four stand types into two types labeled Small (FS and SS) and Large (RW and FA) (Table 2.1).

Searched turbines tended to be closer on average to small woodlots than unsearched turbines, but the difference was not significant ($F_{1,86}$; P=0.166). Searched turbines tended to be farther from a large woodlot than unsearched turbines, but again the difference was not significant ($F_{1,86}$; P=0.203). Mean distance to any wooded area (irrespective of size or shape) also did not differ between searched and unsearched turbines ($F_{1,86}$; P=0.600).

Search Schedule

Searches at turbines began on July 21, 2008 while waiting for soils to dry following very rainy weather during the week of July 14, when searches were scheduled to begin. Due to the amount of precipitation, farm equipment was unable to enter fields to mow search plots and strips; however, we initiated regularly scheduled surveys at turbines but were restricted to searching essentially only the gravel road and pad areas. We searched as much area around each turbine as possible, including un-graveled and unseeded area, until search plots were mowed. Mowing was prioritized based on search schedule and condition of soils. By July 29, 2008 all strips and plots were mowed. Searches proceeded on schedule for the remainder of the study period.

During the fall 2008 study, daily search turbine A33 was inoperable from July 23 to September 1 due to mechanical failure of the electrical generator in the nacelle. Replacement of the generator required a large crane to be brought in and parked on the crane pad. Due to the recent amount of rain, the pad first had to be reconstructed to be able to support the crane. We continued to search the plot to the extent possible. From August 6 to August 24 an area estimated to be 1800 m^2 of the crane pad was blocked by the crane. None of the plot could be searched on August 7-8 for safety issues related to construction. Between August 25 and August 29, approximately 4200 m^2 (66%) of the plot could not be searched due to turbine blades and other equipment on the ground, and no search was conducted on August 29 due to construction. By our September 1 search, the turbine was operational, though some equipment remained on the pad blocking an area of approximately 1000 m^2. By the September 22 search, all equipment was cleared.

In 2008, WEST completed a total of 1,031 searches; 685 searches at daily turbines (mean 68.5 per turbine) and 346 searches at weekly turbines (mean 17.3 per turbine). In addition, we searched turbine B17 on weekly basis from August 26 to October 28. Turbine B17 was added to provide anecdotal information and is not included in the fatality estimates. Given that B17 was located on a knoll and partially surrounded by mature trees, whereas most turbines were completely surrounded by agricultural fields, we added searches at B17 to attempt to evaluate if the fatalities would be appreciably different. A total of three bats and zero birds was found during searches at this site, which suggests fatality rates on par with other turbines. Therefore, B17 was not searched during the spring 2009 survey.

In 2009, WEST completed a total of 838 searches; 558 searches at daily turbines (mean 55.8 per turbine) and 280 searches at weekly turbines (mean 14.0 per turbine). During the spring 2009 survey, bare-ground conditions combined with melting snow and rain turned some plots into muddy quagmires, making searching very difficult at times. In some cases, transects passed through low-lying areas that tended to remain saturated and at times threatened to swallow technicians (Figure 4.2). To our knowledge, all turbines in search plots operated correctly during the 2009 survey.

Bird Fatalities

Characteristics of Bird Fatalities

In total, 43 bird carcasses were recorded during scheduled searches, with one tree swallow, one unidentified bird, and one red-tailed hawk being recovered incidentally (Table 3). Of these, 42 were small birds (e.g., songbirds) and one was a large bird (e.g., crows). Twelve unique identifiable bird species were found at BSGF. Of these, golden-crowned kinglet (n=4; 9.4%), horned lark (n=3, 7.0%), and tree swallow (n=3; 7.0%) were most common, followed by two species with two observations each. Unidentified birds accounted for 44.2% of all carcasses found. Unidentified carcasses included feather-spots, carcasses that were very old and consisted of little more than bones, and those that were too scavenged to make a positive identification.

We calculated separate fatality estimates based on carcasses found during daily and weekly searches, and a total estimate. After accounting for searcher efficiency and scavenger removal, we estimate 11.83 (9.08, 16.43; 90% C.I.) bird fatalities/turbine/year and 7.17 (5.50, 9.94; 90% C.I.) fatalities/MW/year (Table 4).

On a per turbine basis, daily searches yielded an estimated 12.86 (8.81, 17.57; 90% C.I.) fatalities and weekly searches resulted in an estimate of 11.32 (7.72, 17.21; 90% C.I.) fatalities (Table 4.1). On a per MW basis, daily and weekly searches yielded estimates of 7.80 (5.35, 10.66; 90% C.I.) and 6.87 (4.69, 10.44; 90% C.I.), respectively.

Temporal Pattern of Bird Fatalities

Bird fatalities were found throughout the both the fall 2008 and spring 2009 study periods. Most days during which bird fatalities were found had one fatality present; three days had two bird fatalities found, though there is no apparent temporal trend associated with this slightly higher fatality rate (Figure 7).

Bird Fatalities across Turbines

Numbers of bird fatalities varied across turbines. Bird fatalities were found at 22 of 30 search turbines (Figure 8). For turbines searched weekly, bird fatalities ranged from zero to four at any turbine (Figure 8.1), while bird fatalities at turbines searched daily ranged from zero to eight fatalities. The highest number of bird fatalities at turbines searched weekly was at turbine B20 (four fatalities), and the highest number of bird fatalities at turbines searched daily was at turbine D43 (eight fatalities; Figures 8.1 and 8.2).

Distribution of Fatalities: Distance from Turbine

The majority of bird fatalities (40.5%) were found beyond 60m from the search turbine (Table 5). Sixteen of the bird fatalities were found between 60 and 90m from the search turbine, and 13 bird fatalities found between zero and 30m from the turbines (Figure 9). The locations of bird carcasses seemed to follow a bimodal distribution with most carcasses found either within about 30m or greater than 60m away from the turbine. Comparatively few carcasses were found at intermediate distances.

Distribution of Fatalities: Distance from Woodlots

We used linear regression to determine if there was a relationship between number of bird fatalities at a turbine and distance to nearest forest-type. Distance to wooded area, regardless of woodlot size, did not predict number of fatalities at a wind turbine (Table 9).

Bat Fatalities

Characteristics of Bat Fatalities

In total, 247 bat carcasses were found at the Blue Sky Green Field over the course of both study seasons (242 in 2008 and 5 in 2009) (Table 6; Figure 13). Of that total, 221 were found on search plots (194 during scheduled searches), and 26 were found on non-search plots (Table 6.1). Five different bat species were found at BSGF. Little brown bats were most commonly found, accounting for 28.7% of all carcasses found. Silver-haired bats (23.5%), big brown bats (19.0%), and hoary bats (16.6%) also contributed to the majority of total observed bat fatalities at the site. Only 18 eastern red bats were found, representing 7.3% of total bats found (Figure 10). This species composition differs from what has been reported at other midwestern wind farms, where hoary bat and eastern red bats comprise the majority of fatalities (Figure 10.1).

Of the 247 bats found, 72% were adults, 11% were juveniles, and 17% were unable to be aged (Table 6.2). Approximately equal numbers of males and females were found. Age and sex distributions were roughly equal between migratory and non-migratory species, though nearly twice as many of the bats identified as juveniles were migratory species (Table 6.3).

As with birds, we calculated fatality rate estimates based on carcasses found during daily searches, during weekly searches, and an overall estimate. After accounting for searcher efficiency and scavenger removal, we estimate 40.54 (30.98, 51.16; 90% C.I.**)** bat fatalities per turbine and 24.57 (18.78, 31.03; 90% C.I.) bat fatalities per MW (Table 4.1).

We also calculated estimates for migratory and non-migratory species. Big brown, little brown, and *Myotis* spp. bats were considered non-migratory bats, while eastern red, hoary, and silver-haired bats were considered migratory. For non-migratory species, we estimated 21.27 (14.20, 25.21; 90% C.I.) fatalities/turbine and 12.89 (8.61, 15.28; 90% C.I.) fatalities/MW. For migratory species, we estimated 19.26 (16.32, 28.05; 90% C.I.) fatalities/turbine and 11.67 (9.89, 17.00; 90% C.I.) fatalities/MW (Table 4.1)

On a per turbine basis, daily searches yielded an estimated 23.37 (13.51, 27.78; 90% C.I.) fatalities, and weekly searches resulted in an estimate of 20.23 (12.17, 26.14; 90% C.I.) for non-migratory species. The estimates for migratory species are 16.60 (12.99, 21.12; 90% C.I.) and 20.59 (16.33, 32.71; 90% C.I.) fatalities for daily and weekly searches, respectively (Table 4.1).

On a per megawatt (MW) basis, daily searches yielded an estimated 14.18 (8.20, 16.86, 90% C.I.) fatalities, and weekly searches resulted in an estimate of 12.28 (7.39, 15.86; 90% C.I.) for non-migratory species. The estimates for migratory species are 10.07(7.88,12.82; 90% C.I.) and 12.50 (9.91, 19.85; 90% C.I.) fatalities for daily and weekly searches, respectively (Table 4.1).

Distribution of Fatalities: Temporal Patterns

Bat fatalities were most common during the fall 2008 study season, with only 5 bat fatalities being found during scheduled searches during the spring 2009 season (Table 6; Figure 13). The most common bat species fatalities found (little brown and silver-haired bats) were distributed unevenly during the fall 2008 study period (Figures 14, 15). In general, little brown bats were found in the early portion of the fall period, whereas silver-haired bats were more common later in the study. The timing for big brown bats was similar to little brown bats, while hoary and red bats were found sporadically throughout the study period. During the fall season, no fresh bats were found after October 1, although an old carcass (unidentifiable) was found on October 24. The first bat fatality found during the spring 2009 study period was on May 8, 2009 (Figure 13).

Distribution of Fatalities: Spatial Patterns

Search plots were distributed throughout the study area, with 16 search plots (five daily, eleven weekly) in the north and 14 plots (five daily, nine weekly) in the south (Figure 2). Slightly more bat fatalities were found in the northern portion of the study area (Blue Sky; 54.2%) than were found at the southern portion (Green Field; 45.7%) project (Table 7).

Distribution of Fatalities: Turbines

Numbers of bat fatalities varied across turbines (Figures 11 and 11.1). Bat fatalities per turbine on weekly scheduled search plots ranged from one (Turbines B12 and D30) to 13 (Turbine A9), with an average of 5.55 bats found per turbine. For daily scheduled search plots, total bat fatalities per turbine ranged from four (Turbine A33) to 19 (Turbine B22), with an average of 10.90 bats found per turbine. Comparing searches across all turbines, Turbine A9 had the largest number of fatalities per search at 0.43. The minimum number of fatalities per search (0.03) occurred at Turbines B12 and D30. (Figure 11.2)

Distribution of Fatalities: Distance from Turbine

Bat fatalities were generally found closer to turbines than were bird fatalities. The majority of bat fatalities (58.2%) were found within 20m of the search turbine (Table 8), and the number of bat fatalities found declined smoothly as distance from turbine increased (Figure 12).

Distribution of Fatalities: Distance to Woodlot

We used linear regression to determine if there was a relationship between number of bat fatalities at a turbine and distance to nearest forest-type. Distance to wooded area, regardless of woodlot size, did not predict number of fatalities at a wind turbine. This was true when we considered all bat fatalities together and when we examined migratory and non-migratory species separately (Table 9).

Analysis of Fatalities and Meteorological Data

The best model for fresh bat fatality rates as a function of weather data was the zero-inflated Poisson model:

Log(mean(fresh bat fatalities per search) = – 298 + 0.005 avg.temp + 1.76 vlow - 0.01 mean.ws50m – 0.27 clow

This model indicates that the number fatalities found on any given day were positively related to average temperature and proportion of the night with low visibility during the previous night. Similarly, the number of fatalities found was negatively related to mean wind speed and proportion of the night with low ceiling conditions. Figure 16 shows how a change in a particular covariate corresponds to a change in the predicted numbers of bat fatalities, holding all other variables constant at their medians.

Analysis of Fatalities and Acoustic Activity Data

Modeling the Anabat data with the fresh bat fatality data produces a best zero-inflated Poisson model of:

Log(mean(fresh bat fatalities per search) = –2.49 + 0.023 ground.only

This model indicates that probability of finding fatalities on any given day were positively related to mean number of bat passes detected the previous night. Figure 17 shows how a change in mean bat pass rate corresponds to a change in the predicted numbers of bat fatalities.

Searcher Detection Probability

A total of 31 bat carcasses, 24 large bird carcasses, and 117 small bird carcasses were used in searcher efficiency trials (Table 10). Overall searcher efficiency for bat carcasses was estimated to be 51.6% for all trials, compared to 66.7% for large birds and 61.3% for small birds. These means were used to adjust total fatality estimates up by accounting for carcasses that were present but missed by searchers.

Carcass Removal Trials

In total, 120 carcass removal trials were conducted. We used 51 bat carcasses, 38 large birds, and 31 small birds. By day 5 of the trials, roughly 25% of the bat carcasses, 75% of the large bird carcasses, and 65% of the small bird carcasses remained (Figure 18). These trials were used to account for the probability that a carcass would be available to be found by searches during scheduled searches.

DISCUSSION

Fatality Estimation

The approach used for calculating adjusted fatality estimates is consistent with the approach outlined by Shoenfeld (2004) and Erickson et al. (2005), and accounted for search interval, total area searched, proportion of area searched at specific distances from the turbine, searcher efficiency rates, and carcass removal rates. At the BSGF site, red foxes, striped skunks, cats, dogs, American crows, and ring-billed gulls were observed in or near search plots, and these and other unobserved scavengers (e.g., raccoon, Virginia opossum, white-tailed deer) were likely responsible for carcass removal. It is hypothesized that scavenging could change through time at a given site and must be accounted for when attempting to estimate fatality rates. We accounted for this by conducting scavenging trials throughout search period. We also estimated searcher efficiency rates throughout the search period and in different plot conditions to account for any biases associated with changes in conditions.

The estimation approach assumed that the searcher efficiency rate was constant during the period of study, and we accounted for potential changes in searcher efficiency through time by conducting weekly efficiency trials during the study period. The estimation approach also assumed that detection probabilities for non-trial carcasses were not dependent on the time a carcass was in the field. The study was not designed to test this hypothesis. However, over time the detection probabilities of carcasses that are not found during previous searches may change. Initially, carcasses may increase in detection due to cues such as smell and insect presence due to decomposition. Detection may also increase if partially scavenged and feathers become spread out over a larger area. Over longer periods of time, carcass detection may decrease due to the weathering of carcasses. The assumption of uniform detectability is of most concern with larger search intervals than used in this study.

We calculated separate estimates for bird and bat fatality rates based on search interval. For both birds and bats, confidence intervals overlapped fatality means (see Tables 4 and 7), indicating that there was no difference in the estimates based on search interval. Thus, while daily search intervals can be more useful than weekly intervals for correlating weather events to temporal patterns of fatalities, our data suggest that essentially the same conclusions regarding fatality rates during this study were reached by searching turbines on a weekly interval. This information may be useful when considering the relative costs and goals of future studies in Wisconsin.

As noted in Methods, when calculating fatality estimates, we included all carcasses that were reported or found on search plots, even if those plots were not scheduled to be searched that day. We adopted this conservative approach and included the fatalities because we assumed that they would have been found during the next scheduled search. This approach produced an estimate for bat fatalities that was 10.5% higher than would have been the case had we excluded these fatalities (see Table 6.1). We cannot be sure that this assumption was valid in every case, or that all fatality studies incorporate this approach.

Bird Fatalities

Of the 40 birds that were found during scheduled searches or incidentally and which were identifiable, none were species protected under Threatened or Endangered Species legislation. Of bird carcasses that were identifiable, golden–crowned kinglet was most common, followed by horned lark and tree swallow (Table 3). One raptor, a red-tailed hawk, was found as an incidental fatality. During a concurrent study of bird use at BSGF (Cutright 2009), red-winged blackbird was the most common species observed at point-count stations at turbines, followed by ring-billed gull and Canada goose. None of these species were found during searches, although one of the feather-spots contained feathers from a ring-billed gull

The total number of birds found during this study was relatively low, but because of the distance they were found from the turbine and the area adjustment for distance, the estimates were inflated by a larger number, resulting in a relatively large estimate. When we removed records of feather-spots, and four other carcasses that may not have been attributable to wind turbine operation, the estimate for birds at BSGF fell to lower levels. Of the species of birds found during searches, none were among the most abundant during concurrent avian use study (Cutright 2009), and all were species that have been observed as fatalities at other wind energy projects (e.g., Erickson et al. 2001)

Bat Fatalities

During this study, the vast majority of bat fatalities occurred during the fall season, with only about 2% of total fatalities occurring during spring migration. This is consistent with other studies that have documented far higher fatality rates during the fall migration season than during the spring (Johnson 2005).

The fatality estimates for bats from this study are within the range of others reported for wind projects in North America (Arnett et al. 2008), yet they were higher than expected, based on either the regional average or the pre-construction acoustic surveys for bats (Gruver 2008). While it is unclear why the estimates for BSGF would be higher than others in the region, we provide possible explanations here, and place the bat fatality estimates in context with other wind energy facilities in North America.

To date, the highest fatality estimates for bats have come from the eastern US, particularly the Appalachian region where estimates have ranged from 20.8 to 69.6 bats per turbine (Arnett et al., 2008). In the Midwest, fatality estimates for bats from wind farms studied between 1998 and 2004 range between 0.1 and 7.8 bats per turbine (Arnett et al. 2008, Kerlinger et al. 2007). Although the regional data pool of similar studies for the Midwest is relatively small (four sites: Howe et al. 2002, Johnson et al. 2003, Jain 2005, Kerlinger et al. 2007), it represents both a range of habitats (e.g., southwestern Minnesota to northern Wisconsin), and a range of survey effort and methodology. For instance, while three of the four fatality monitoring studies from the Midwest were conducted primarily in a matrix of corn, soybeans, and hay, similar to conditions at BSGF, only Jain (2005) attempted to maintain a portion of the search plot in a low- or no-vegetative condition as we did in this study. During the growing season, searching in un-mowed fields becomes progressively more difficult physically, and progressively less effective from a searcher efficiency standpoint (see Figure 4, which shows a mowed transect next to an un-mowed area). Thus the most ready comparison of results from BSGF, based on similarity of methods and habitat, is to Top of Iowa Wind Farm in north-central Iowa (Jain 2005). Interestingly, both Jain (2005) and this study reported higher numbers of fatalities than any of the other midwestern studies that did not clear crops. Our estimate is also slightly higher due in part to the number of incidental finds on scheduled plots that were reported, and which we included in the fatality estimation total (see *Assumptions* above). These incidentals increased our fatality estimate by at least 12% compared to not having included them (Table 6). However, even if we excluded those fatalities our estimates would still be higher than others from the Midwest.

Landscape and habitat context have both been proposed as hypotheses to explain bat fatalities at wind farms. For example, in the eastern US, clearings cut into the forested ridges that some wind farms are built on are thought to contribute to the relatively high numbers of bat fatalities at these sites, as clearings create potential foraging habitat, and ridges may serve as attractive linear features during foraging, commuting or migration (Kunz et al. 2007*b*). None of those features are present at BSGF. In addition, distance to nearest wooded area was not a predictor of bat fatalities in this study.

As has been seen in other studies (see e.g., Arnett et al. 2008), weather variables were correlated with increased fatalities at BSGF. Wind speed and temperature, in particular, were significant predictors of bat fatalities, and it is generally accepted that bats are more active on warm, calm nights than on cool, windy nights. Pre-construction surveys at BSGF found reduced levels of bat activity as the season progressed and on windy nights (Gruver 2008). It seems likely that the correlation of fatalities with temperature may reflect the general decrease in abundance as the fall season progressed, while windy nights may keep bats from flying at heights at which they are likely to encounter spinning turbine blades.

Species composition of fatalities at BSGF differed substantially from three previous midwestern studies (Figures 10, 10.1). The migratory bats (hoary, eastern red, and silver-haired bats) that seem to dominate fatalities at nearly every North American wind farm study published to date, were represented in relatively low numbers as a group at BSGF. An exception was the silver-haired bat, which was the second most abundant bat fatality at BSGF during the Fall 2008 season. Based on the timing of fatalities for hoary and eastern red bats during fall, it seems that they are either resident during the summer, or they migrate through the area in relatively small waves over a longer period. Silver-haired bats on the other hand, may not be resident in the area (or at least may not be present in large numbers), but may migrate through the area during a relatively discrete period during fall. All but one of the silver-haired bats were found during fall were found in the month of September, making it the most punctuated species in terms of timing. Silver-haired bats were also the most abundant species (3/5) found during spring searches.

It is unclear why little brown and big brown bats would appear as fatalities in such high numbers at this site, considering they have generally been only minor contributors to fatality totals at other projects. Numbers of non-migratory bat fatalities were higher than expected at BSGF, with little brown and big brown bats contributing nearly half of the total fatalities found and more than half the estimated fatalities. In total, 71 little brown bats were found during fatality searches. Little brown bats comprised 28.7% of all fatalities recovered, a percentage that is similar to Top of Iowa (Jain 2005) and to a study from Alberta Canada (Brown and Hamilton 2002), though higher than most other published results (Arnett et al. 2008). Similarly, big brown bats comprised 19% of fatalities, which is nearly double the relative proportion found in other studies (Arnett et al. 2008). To our knowledge, non-migratory species have not been found to constitute a large proportion of fatalities at other sites (but see Brown and Hamilton 2002, and Jain 2005 where proportions of little brown bats were similar to those from this study). These are species with continent-wide distributions and are generally abundant throughout their range. As the overwhelming majority were found during the fall 2008 portion of the study, it is possible that the existence of a large regional hibernaculum in the Neda Mine may play a role in concentrating species such as little brown and big brown bats. However, BSGF is located some 30 miles away from the mine, so it seems unlikely that BSGF experiences large increases in numbers of these species as a result of seasonal movement toward the mine, unless the project is located along a migratory route traveled by bats headed to the mine. This study was not designed to address that question, and information on migratory routes by bats (assuming they exist) has proven to be an intractable question to date (Arnett et al. 2008), although a recent study from Alberta Canada provided some evidence of increased migratory activity nearer to the foothill of the Rocky Mountains relative to the prairies (Baerwald and Barclay 2009). A potentially elucidating comparison would be to contrast estimates of fatalities of these species between BSGF and other recently constructed wind farms that are located closer to the mine, and will require meta-analysis of several regional wind projects.

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Table 1. Proportion of the area searched in 10 m distance bands at Blue Sky Green Field.

Distance from Turbine (m)	Acres Searched (daily)	Total Acres (daily)	Acres Searched (weekly)	Total Acres (weekly)	Acres Searched (cleared)	Total Acres (cleared)
0 to 10	18.72	27.57	11.26	11.74	13.58	20.08
10 to 20	41.61	82.72	34.01	35.61	30.26	60.24
20 to 30	47.10	138.05	57.02	60.33	32.71	100.54
30 to 40	42.06	193.64	80.13	85.94	31.40	141.02
40 to 50	49.10	249.04	103.00	112.24	34.25	181.38
50 to 60	56.47	304.51	125.89	139.35	41.93	221.77
60 to 70	73.67	359.89	148.87	167.19	49.68	262.10
70 to 80	80.00	415.34	169.78	195.84	58.99	302.49
80 to 90	98.05	470.79	122.46	225.27	70.74	342.87
90 to 100	56.15	526.24	64.53	255.47	40.23	383.26
100 to 110	35.65	581.59	28.26	286.41	26.56	423.56

Table 2. Summary statistics for four categories of wooded areas at Blue Sky Green Field.

	N	Mean Ratio (A:P)	SE mean
Field Strip	65	8.4	0.645
Forested Area	88	35.8	2.52
Small Tree Stand	9	5.8	0.732
Wood Residential	16	18.6	1.53

Table 2.1. Summary statistics for 2 categories of wooded area at Blue Sky Green Field. Large Stands include Forested Areas and Wood Residential. Small Stands include Field Strips and Small Tree Stands. See Methods section for detail.

	N	Mean Ratio (A:P)	SE mean
Large Stand	104	33.15	2.23
Small Stand	74	8.12	0.851

Table 3. Summary of bird species found during fatality studies at Blue Sky Green Field.

Species	Fatalities found at scheduled search plots		All Fatalities	
	Total	**% Composition**	**Total**	**% Composition**
unidentified bird	18	45.0	19	44.2
golden-crowned kinglet	4	10.0	4	9.3
horned lark	3	7.5	3	7.0
brown-headed cowbird	2	5.0	2	4.7
ruby-crowned kinglet	2	5.0	2	4.7
tree swallow	2	5.0	3	7.0
black-throated green warbler	1	2.5	1	2.3
cedar waxwing	1	2.5	1	2.3
eastern meadowlark	1	2.5	1	2.3
European starling	1	2.5	1	2.3
savannah sparrow	1	2.5	1	2.3
unidentified meadowlark	1	2.5	1	2.3
unidentified sparrow	1	2.5	1	2.3
unidentified swallow	1	2.5	1	2.3
warbling vireo	1	2.5	1	2.3
red-tailed hawk	0	0.0	1	2.3
Overall	**40**	**100**	**43**	**100**

Table 4. Summary of fatalities estimates for birds and bats, including bats by migration status. Fatalities are presented as mean and 90% lower and upper confidence limits.

Taxa	Fatalities/Turbine/Year	Fatalities/MW/Year
All Birds	11.83 (9.08, 16.43)	7.17 (5.50, 9.94)
All Bats	40.54 (30.98, 51.16)	24.57 (18.78, 31.03)
Migratory Bats	19.26 (16.32, 28.05)	11.67 (9.89, 17.00)
Non-migratory Bats	21.27 (14.20, 25.21)	12.89 (8.61, 15.28)

Table 4.1. Summary of adjusted fatality estimates for the fall and spring seasons. Mean and 90% lower (ll) and upper (ul) confidence limits are bootstrap point estimates for daily, weekly and total fatality rates at Blue Sky Green Field during the fall and spring seasons. See Appendix 1 for detail on fatality estimate components.

Per Turbine Fatality Estimates	Daily Searches			Weekly Searches		
	mean	*ll*	*ul*	*mean*	*ll*	*ul*
All Birds Fall08	11.77	7.76	16.55	8.77	5.63	13.8
All Birds Spring09	1.09	0	2.29	2.55	0.9	4.66
All Birds Overall	**12.86**	**8.81**	**17.57**	**11.32**	**7.72**	**17.21**
All Bats Fall08	38.32	29.46	49.24	39.83	30.02	53.74
All Bats Spring09	1.64	0.16	3.8	0.99	0	3.24
All Bats Overall	**39.97**	**30.76**	**50.7**	**40.82**	**28.16**	**54.29**
Migratory Bats Fall08	*15.69*	*12.15*	*19.9*	*20.1*	*14.95*	*27.28*
Migratory Bats Spring09	*0.91*	*0*	*2.6*	*0.5*	*0*	*1.97*
Migratory Bats Overall	***16.6***	***12.99***	***21.12***	***20.59***	***16.33***	***32.71***
Non-migratory Bats Fall08	*22.63*	*13.61*	*28.13*	*19.73*	*13.61*	*28.13*
Non-migratory Bats Spring09	*0.74*	*0*	*2.25*	*0.5*	*0*	*1.92*
Non-migratory Bats Overall	***23.37***	***13.51***	***27.78***	***20.23***	***12.17***	***26.14***
Per MW Fatality Estimates						
All Birds Fall08	7.14	4.71	10.04	5.32	3.42	8.38
All Birds Spring09	0.66	0.00	1.39	1.55	0.55	2.83
All Birds Overall	**7.80**	**5.35**	**10.66**	**6.87**	**4.69**	**10.44**
All Bats Fall08	23.26	17.88	29.88	24.17	18.22	32.61
All Bats Spring09	1.00	0.10	2.31	0.60	0.00	1.97
All Bats Overall	**24.26**	**18.67**	**30.77**	**24.77**	**17.09**	**32.95**
Migratory Bats Fall08	*9.52*	*7.37*	*12.08*	*12.20*	*9.07*	*16.56*
Migratory Bats Spring09	*0.55*	*0.00*	*1.58*	*0.30*	*0.00*	*1.20*
Migratory Bats Overall	***10.07***	***7.88***	***12.82***	***12.50***	***9.91***	***19.85***
Non-migratory Bats Fall08	*13.73*	*8.26*	*17.07*	*11.97*	*8.26*	*17.07*
Non-migratory Bats Spring09	*0.45*	*0.00*	*1.37*	*0.30*	*0.00*	*1.17*
Non-migratory Bats Overall	***14.18***	***8.20***	***16.86***	***12.28***	***7.39***	***15.86***

Table 5. Distribution of bird fatalities by distance from turbines at Blue Sky Green Field.

Distance to Turbine (m)	% Bird Fatalities
0-10	16.7
10-20	9.5
20-30	9.5
30-40	7.1
40-50	7.1
50-60	9.5
>60	40.5

Table 6. Summary of bat species found during fatalities studies at Blue Sky Green Field by season. All fatalities found during the study are represented, including those discovered by facility maintenance personnel.

	Fatalities found, fall 2008		Fatalities found, spring 2009		All Fatalities	
Species	**Total**	**% Total**	**Total**	**% Total**	**Total**	**% Total**
little brown bat	69	28.5	2	40.0	71	28.7
silver-haired bat	55	22.7	3	60.0	58	23.5
big brown bat	47	19.0	0	0	47	19.0
hoary bat	41	16.9	0	0	41	16.6
eastern red bat	18	7.4	0	0	18	7.3
unidentifiable bat	12	4.9	0	0	12	4.9
Overall	**242**	**100**	**5**	**100**	**247**	**100**

Table 6.1. Summary of bat species found during fatalities studies at Blue Sky Green Field. All fatalities found on search plots (scheduled and incidental) were included for the fatality estimation. All Fatalities includes casualties found on both search plots and non-search areas.

	Fatalities found during scheduled searches		Incidental fatalities found on search plots		All Fatalities	
Species	**Total**	**% Total**	**Total**	**% Total**	**Total**	**% Total**
little brown bat	60	30.9	8	29.6	71	28.7
silver-haired bat	51	26.3	4	14.8	58	23.5
big brown bat	33	17.0	8	29.6	47	19.0
hoary bat	29	14.9	5	18.5	41	16.6
eastern red bat	11	5.7	2	7.4	18	7.3
unidentified bat	5	2.6	0	0.0	7	2.8
unknown myotis	4	2.1	0	0.0	4	1.6
unidentified large bat	1	0.5	0	0.0	1	0.4
Overall	**194**	**100**	**27**	**100**	**247**	**100**

Table 6.2. Summary of bat fatalities by age and sex at Blue Sky Green Field.

Age/Sex	Number of Bats	Proportion of Total (Proportion of Group)
Adult	178	0.72
Female	61	0.25 (0.34)
Male	57	0.23 (0.32)
Unknown	60	0.24 (0.34)
Juvenile	26	0.11
Female	10	0.04 (0.38)
Male	8	0.03 (0.31)
Unknown	8	0.03(0.31)
Unknown	43	0.17
Female	5	0.02 (0.11)
Male	4	0.02 (0.09)
Unknown	34	0.14 (0.79)
Total	**247**	

Table 6.3. Summary of bat fatalities by age, sex, and migratory status at Blue Sky Green Field.

	Migration Status		
Age/Sex	**Migratory**	**Non-migratory**	**Total**
Adult	88	90	178
Female	34	27	61
Male	26	31	57
Unknown	28	32	60
Juvenile	17	9	26
Female	6	4	10
Male	5	3	8
Unknown	6	2	8
Unknown	13	30	43
Female	1	4	5
Male	NA	4	NA
Unknown	12	22	34
Total	**118**	**129**	**247**

Table 7. Distribution of fatalities by migration category and Project. Totals include bats found on both search plots and non-search plots.

Project	Migratory	Non-migratory	Unknown	All Bats
Blue Sky	63	68	3	134
Green Field	56	54	3	113
Total	**119**	**122**	**6**	**247**

Table 8. Distribution of bat fatalities by distance from turbines at Blue Sky Green Field.

Distance to Turbine (m)	% Bat Fatalities
0-10	32.4
10-20	25.8
20-30	18.4
30-40	13.5
40-50	4.9
50-60	2.5
>60	2.5

Table 9. Summary of P-values for linear regressions testing number of bat and bird fatalities at a turbine against distance to woodlot. See Methods for descriptions of woodlot types and bat migration status.

Migration Status	Distance to Large Wood	Distance to Small Wood	Distance to Nearest Wood
Migratory[1]	0.77[a]	0.41 [a]	0.849 [a]
Non-migratory[2]	0.13 [b]	0.57 [b]	0.65 [b]
All Bats	0.22[c]	0.63 [c]	0.69 [c]
Birds	0.86[d]	0.99[d]	0.84[d]

[1]. Hoary, red and silver-haired bats
[2]. Little brown and big brown bats
[a]. $F_{1,39}$
[b]. $F_{1,32}$
[c]. $F_{1,44}$
[d]. $F_{1,22}$

Table 10. Searcher efficiency at Blue Sky Green Field as a function of date and size.

Date	Type	# Placed	# Available	# Found	% Found
7/31/2008	BAT	1	1	1	100
8/29/2008	BAT	7	7	6	85.7
9/3/2008	BAT	2	2	1	50.0
9/10/2008	BAT	3	3	2	66.7
9/23/2008	BAT	3	3	1	33.3
9/25/2008	BAT	2	2	2	100
10/22/2008	BAT	2	2	1	50.0
3/27/2009	BAT	3	3	0	0
4/7/2009	BAT	3	3	1	33.3
4/17/2009	BAT	2	2	1	50.0
4/24/2009	BAT	3	3	0	0
Overall	**BAT**	**31**	**31**	**16**	**51.6**
8/6/2008	SB	8	7	5	71.4
8/12/2008	SB	8	7	4	57.1
8/20/2008	SB	9	9	4	44.4
8/29/2008	SB	2	1	1	100
9/3/2008	SB	6	5	1	20.0
9/10/2008	SB	6	6	5	83.3
9/23/2008	SB	5	5	3	60.0
9/25/2008	SB	6	6	4	66.7
10/7/2008	SB	9	9	7	77.8
10/21/2008	SB	10	10	5	50.0
10/22/2008	SB	7	7	5	71.4
10/23/2008	SB	10	10	5	50.0
3/27/2009	SB	7	5	1	20.0
4/2/2009	SB	8	8	8	100
4/7/2009	SB	6	6	2	33.3
4/17/2009	SB	5	5	5	100
4/24/2009	SB	5	5	3	60.0
Overall	**SB**	**117**	**111**	**68**	**61.3**
8/6/2008	LB	2	2	1	50.0
8/12/2008	LB	2	2	1	50.0
8/20/2008	LB	1	1	1	100
8/29/2008	LB	1	1	1	100
9/3/2008	LB	2	2	1	50.0
9/10/2008	LB	3	3	2	66.7
9/23/2008	LB	2	2	1	50.0
9/25/2008	LB	1	1	0	0.0
10/7/2008	LB	1	1	1	100
10/22/2008	LB	1	1	0	0.0
4/2/2009	LB	2	2	2	100
4/7/2009	LB	1	1	1	100
4/17/2009	LB	3	3	2	66.7
4/24/2009	LB	2	2	2	100
Overall	**LB**	**24**	**24**	**16**	**66.7**

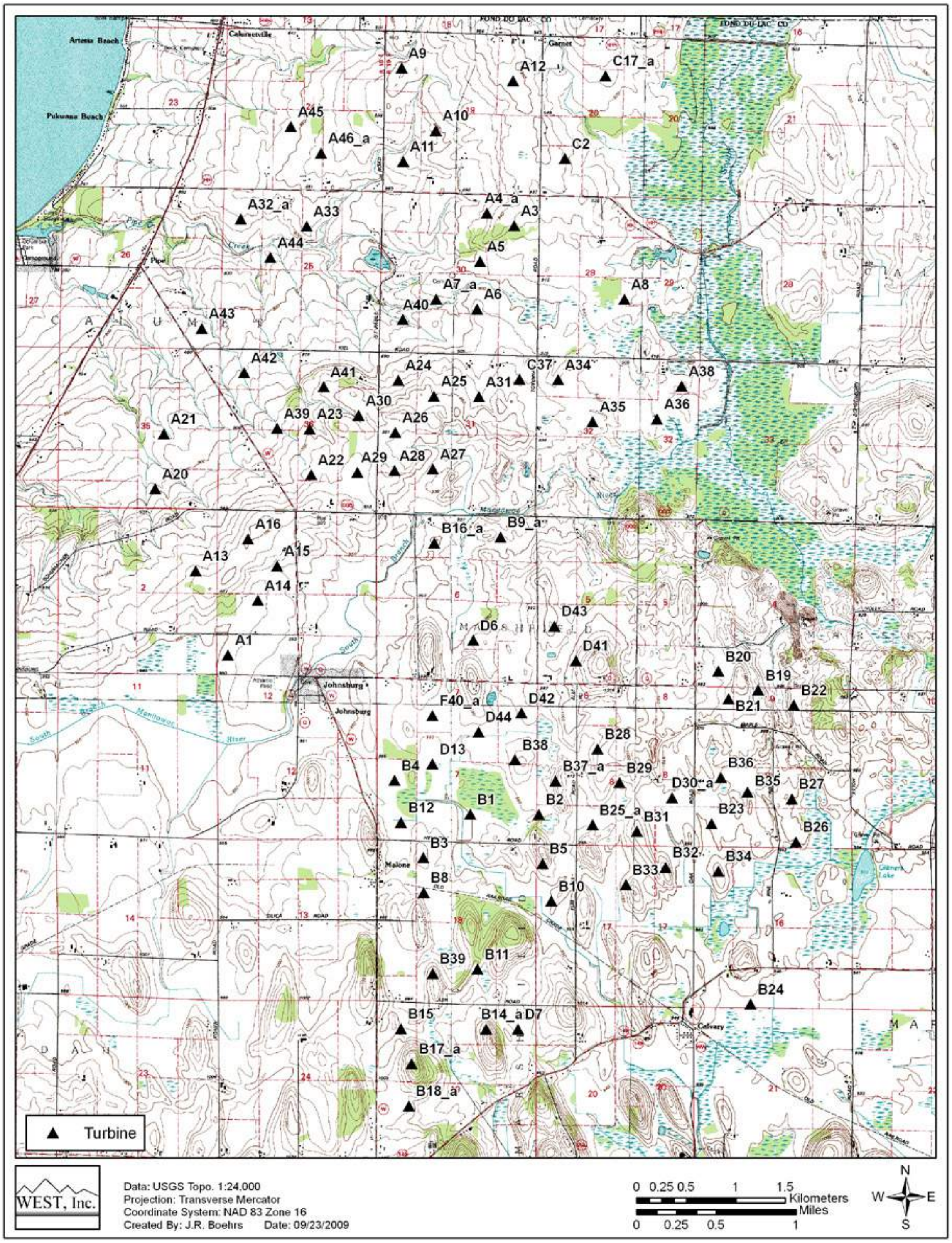

Figure 1. Map of the Blue Sky Green Field turbine locations.

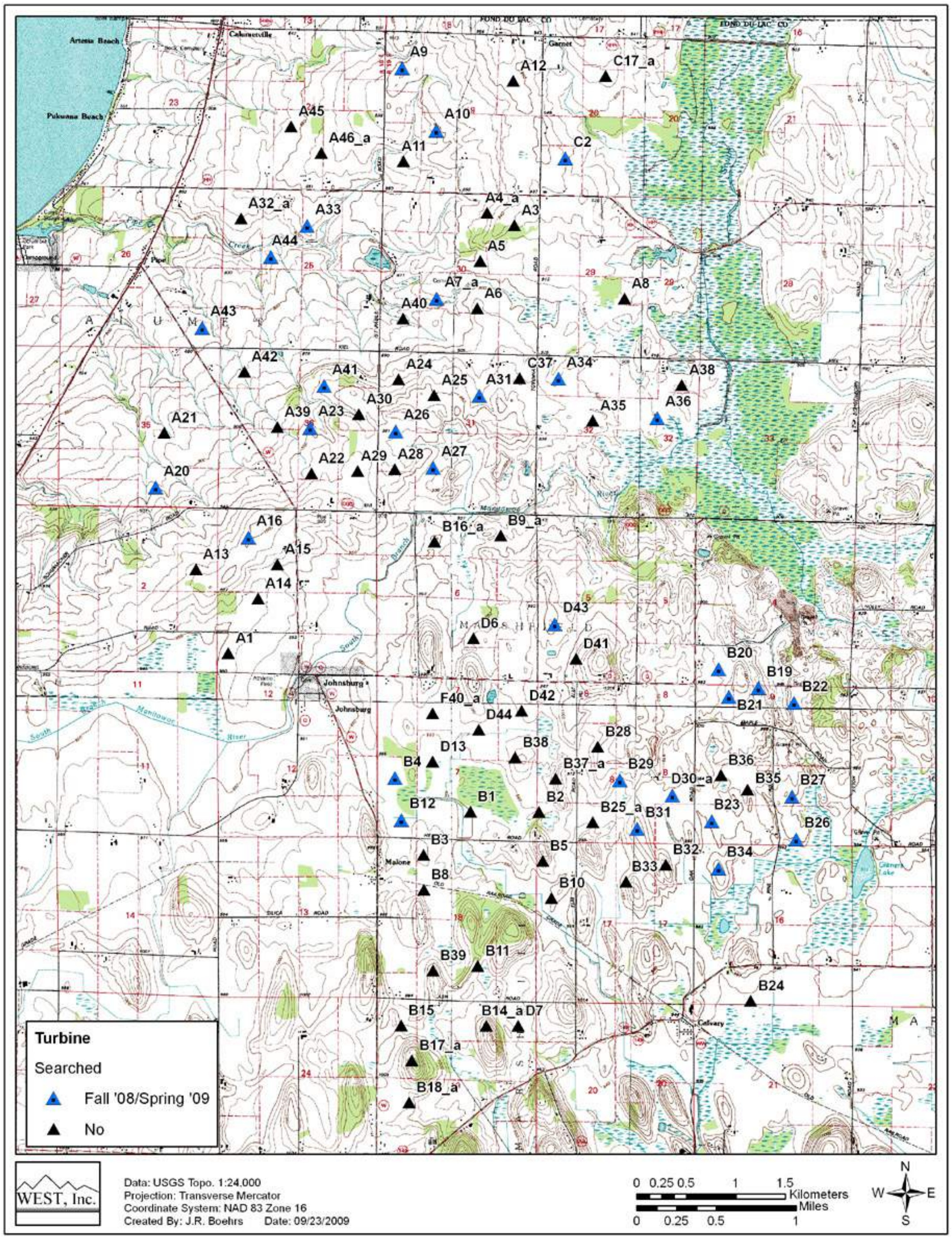

Figure 2. Map of Blue Sky Green Field turbines sampled for fatality studies. Solid circles represent turbines with the entire plot cleared. Non-solid circles represent plots with search strips mowed into the crops.

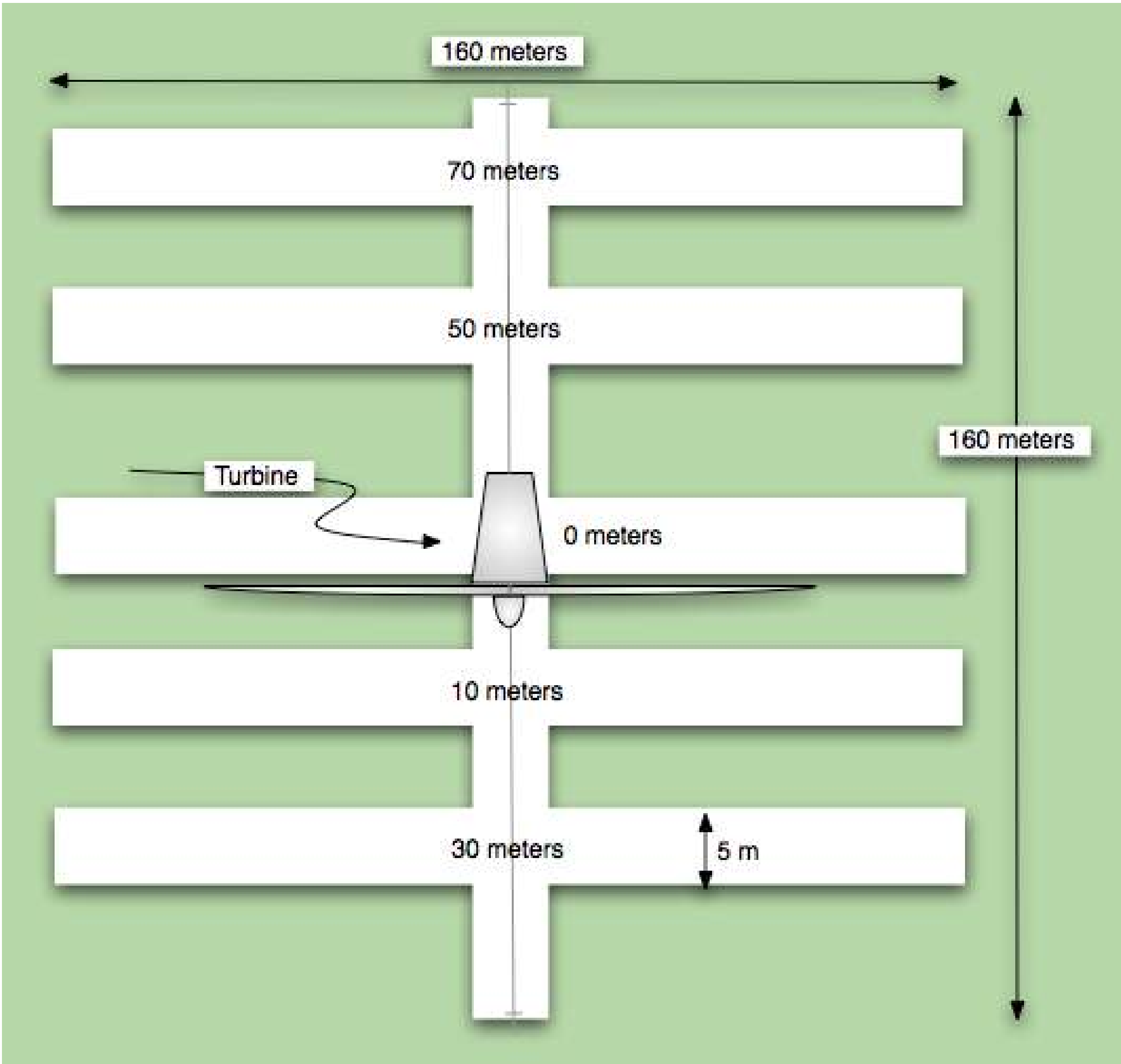

Figure 3. Example of layout of carcass search transects. Turbine pad and access road (not shown) were also searched. The area covered by road and pad varied, but was measured at each turbine searched.

Figure 4. View of a typical search strip and plot condition during the fall survey. Photo was taken on August 19, 2008, approximately 3 weeks after mowing.

Figure 4.1. View of a typical search strip and plot condition during the spring survey. Photo was taken on April 22, 2009.

Figure 4.2. Difficult search plot conditions during the spring survey. Photo was taken on April 1, 2009.

Week	M	T	W	R	F
1	a	a	a	a	a
	b1				
		b2			
			b3		
				b4	
					b1
2	a	a	a	a	a
	b2				
		b3			
			b4		
				b1	
					b2
3	a	a	a	a	a
	b3				
		b4			
			b1		
				b2	
					b3
.					
.					
.					
K	a	a	a	a	a
	b4				
		b1			
			b2		
				b3	
					b4

Figure 5. Example of search schedule. Group ‘a’ turbines (n=10) are searched daily during the week. Group ‘b’ turbines (n=20) are searched on a 4-6 day interval.

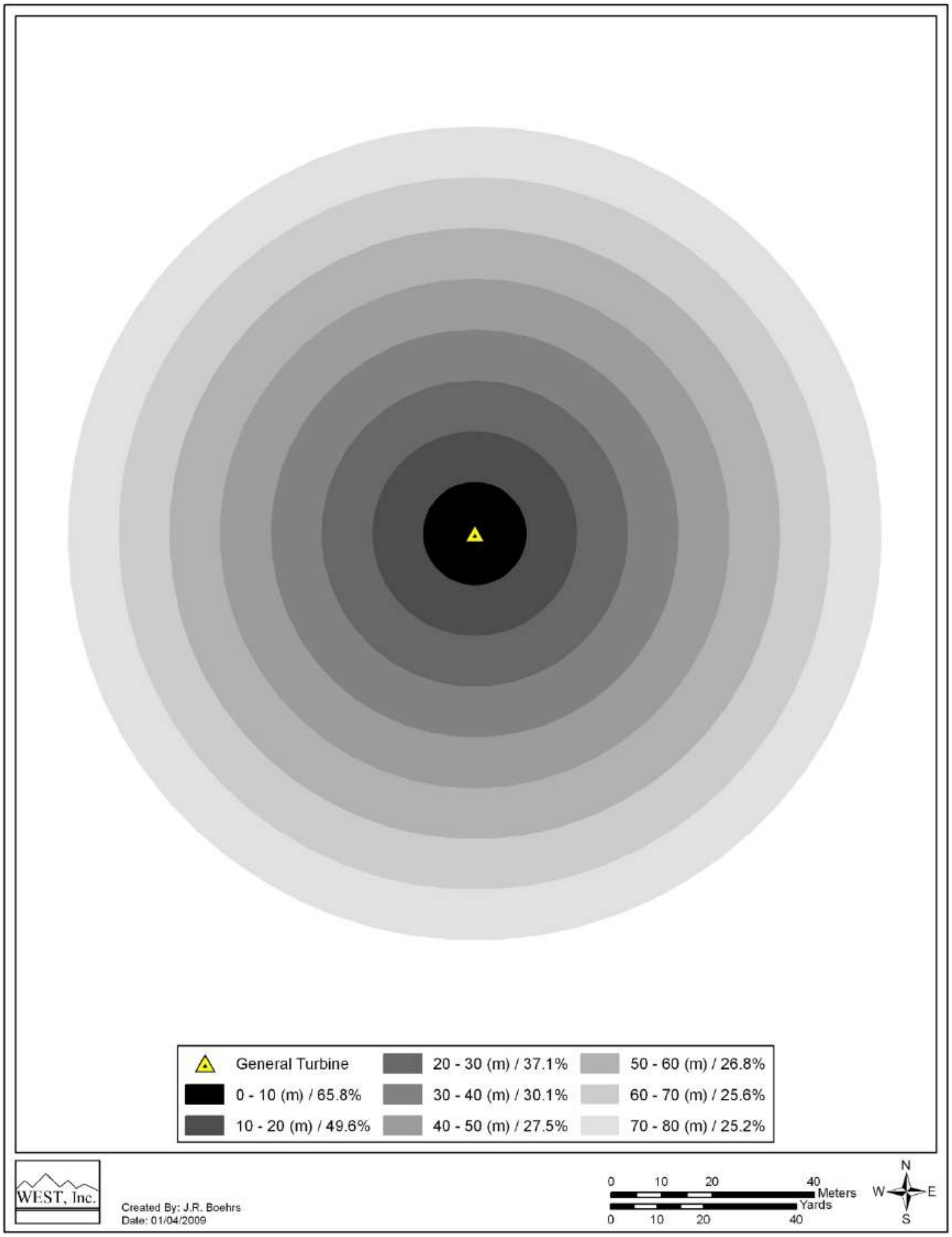

Figure 6. Fatality search area efficiency at Blue Sky Green Field.

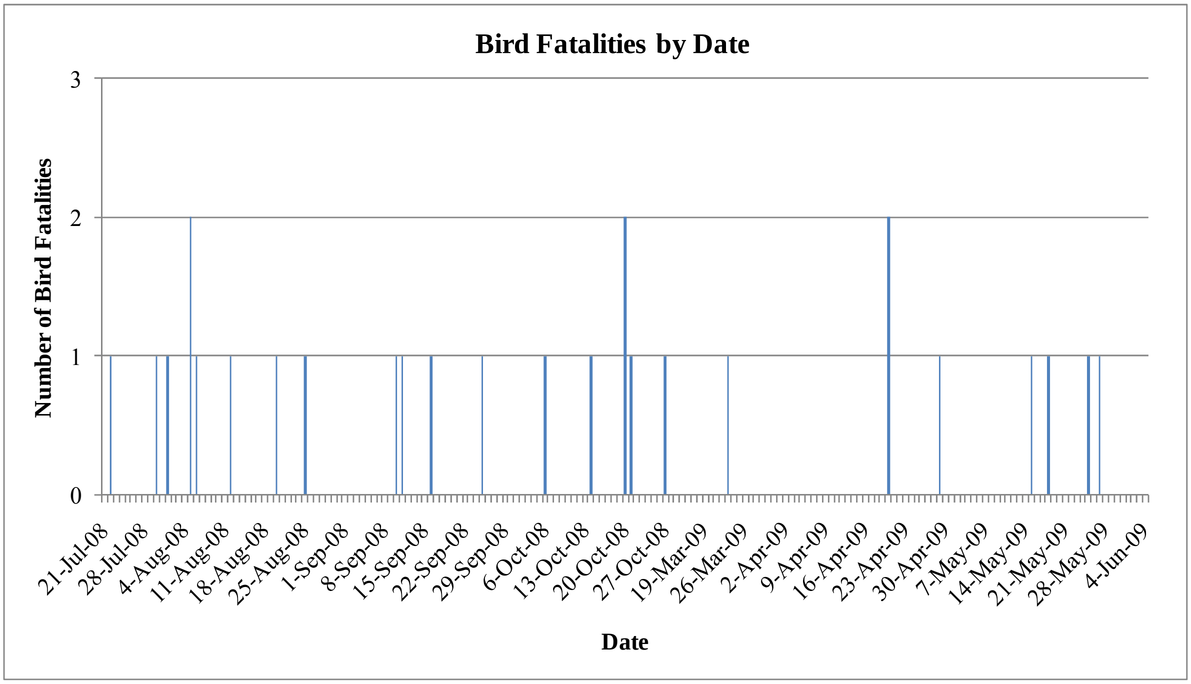

Figure 7. Bird fatalities through time at Blue Sky Green Field. This figure excludes feather spots and carcasses that were too old to reliably estimate time since death.

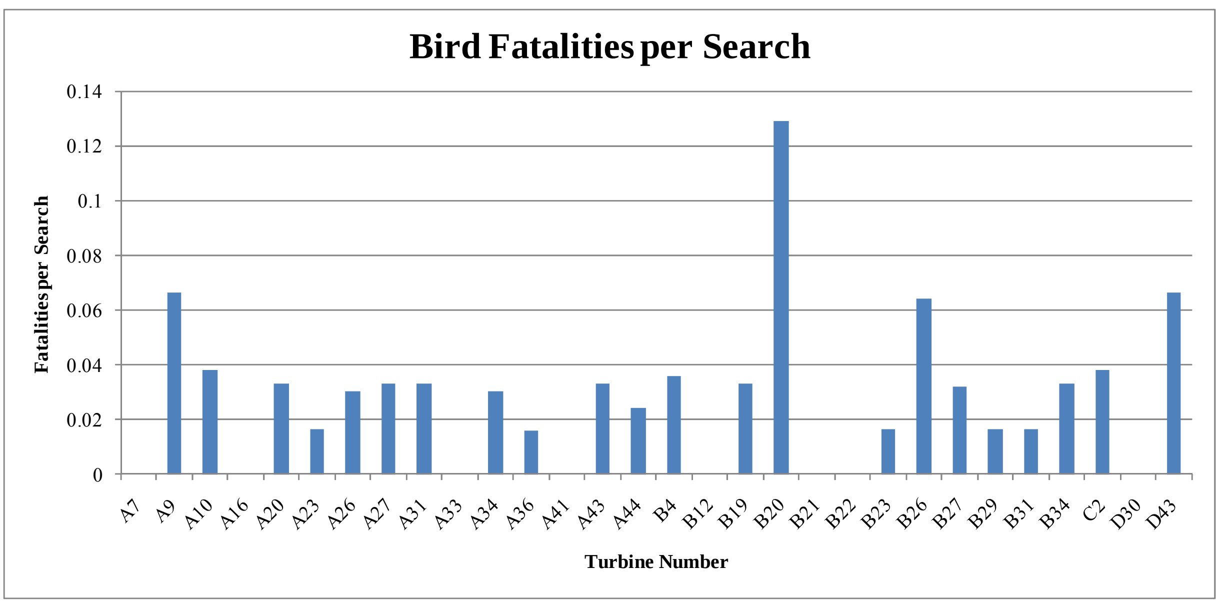

Figure 8. Bird fatalities per search for scheduled search turbines at Blue Sky Green Field.

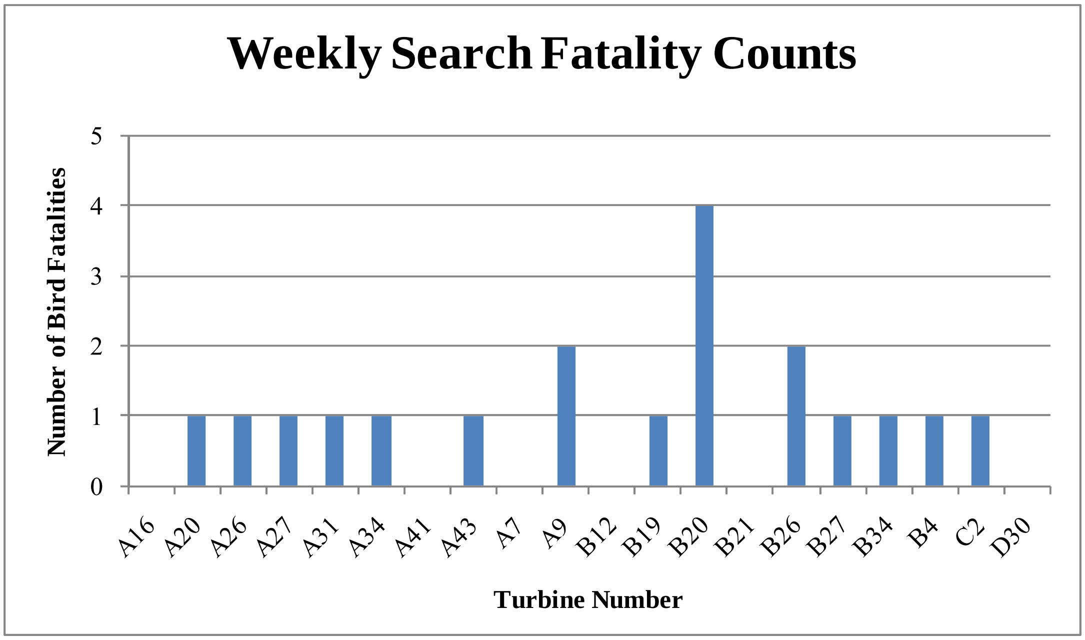

Figure 8.1. Bird fatalities per turbine for turbines searched weekly at the BSGF facility.

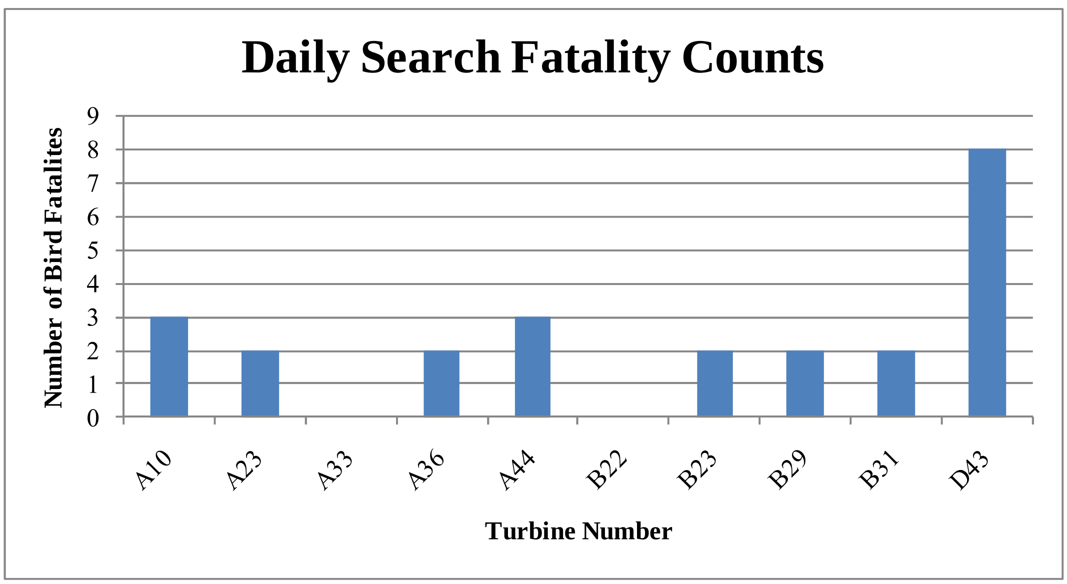

Figure 8.2. Bird fatalities per turbine for turbines searched daily at the BSGF facility.

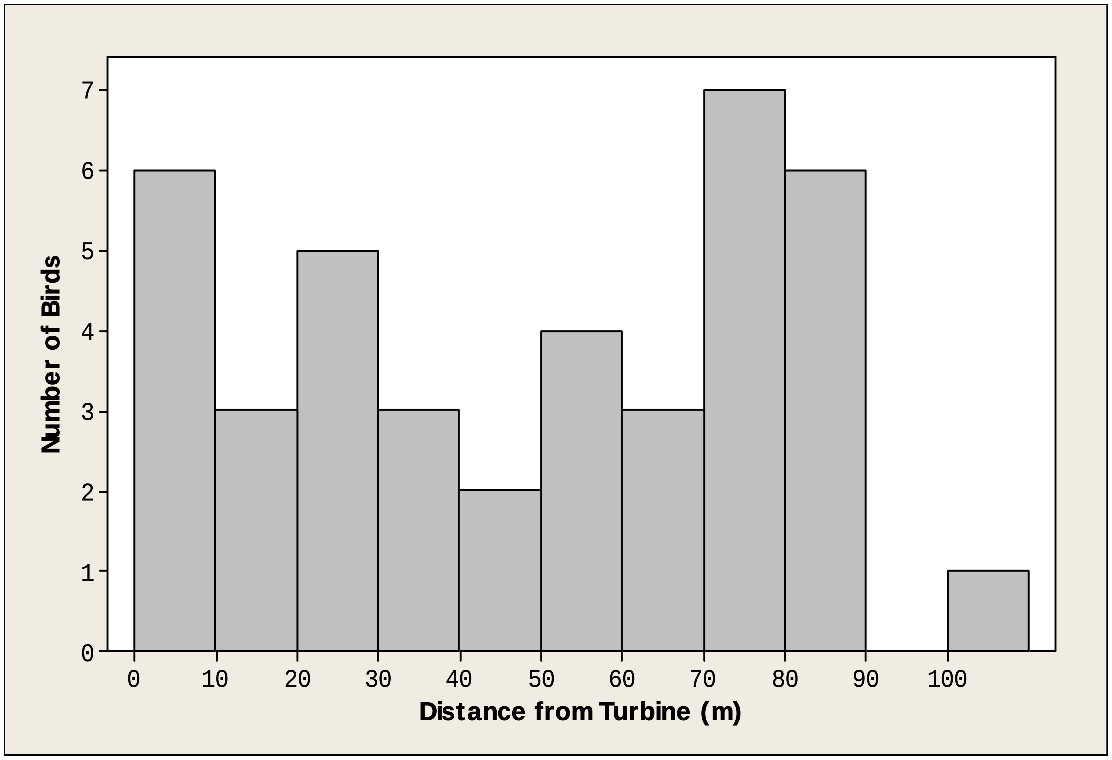

Figure 9. Distance from turbine for bird fatalities at BSGF.

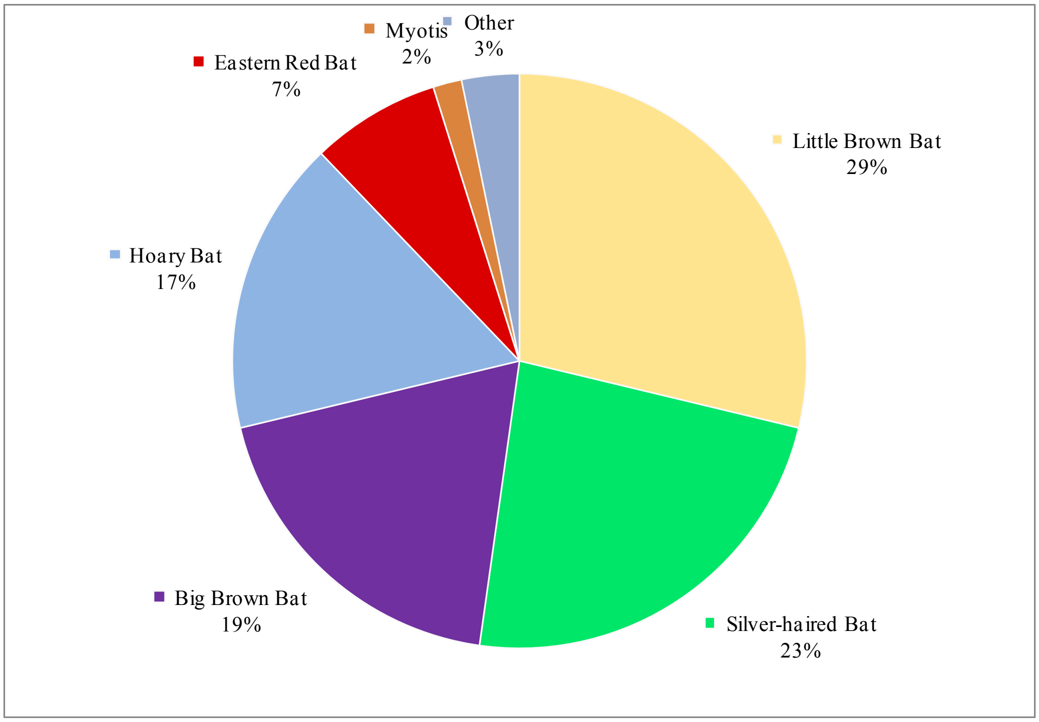

Figure 10. Distribution of bat fatalities during fall 2009 at the BSGF facility.

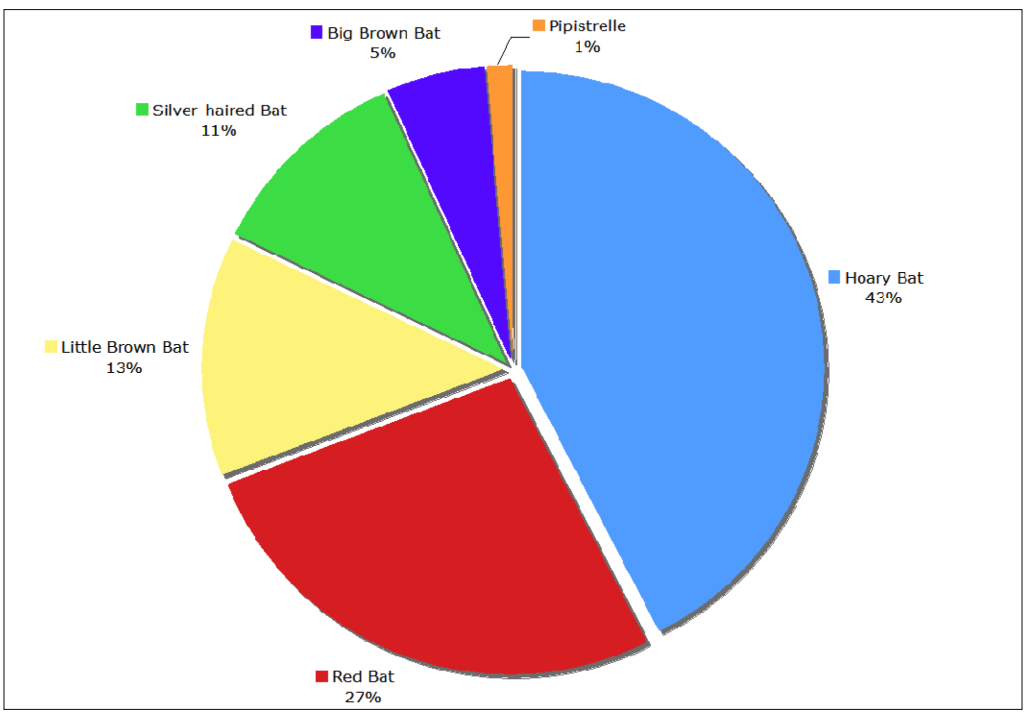

Figure 10.1. Distribution of bat fatalities at three midwestern wind farms with published results (adapted from Arnett et al. 2008).

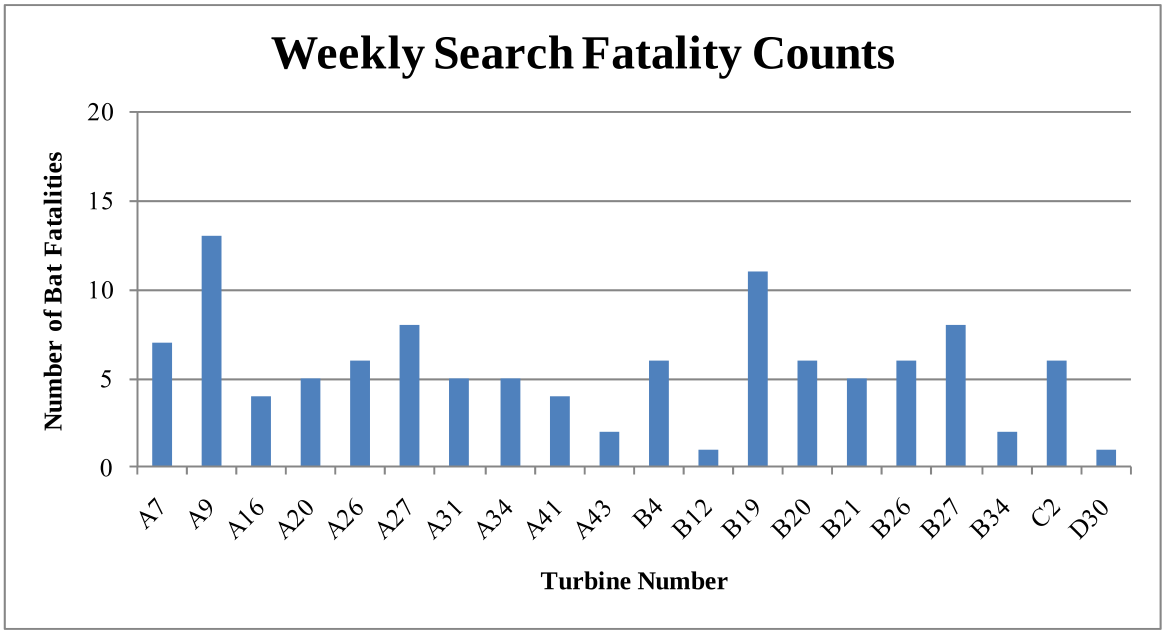

Figure 11. Bat fatalities per turbine for turbines searched weekly at the BSGF facility.

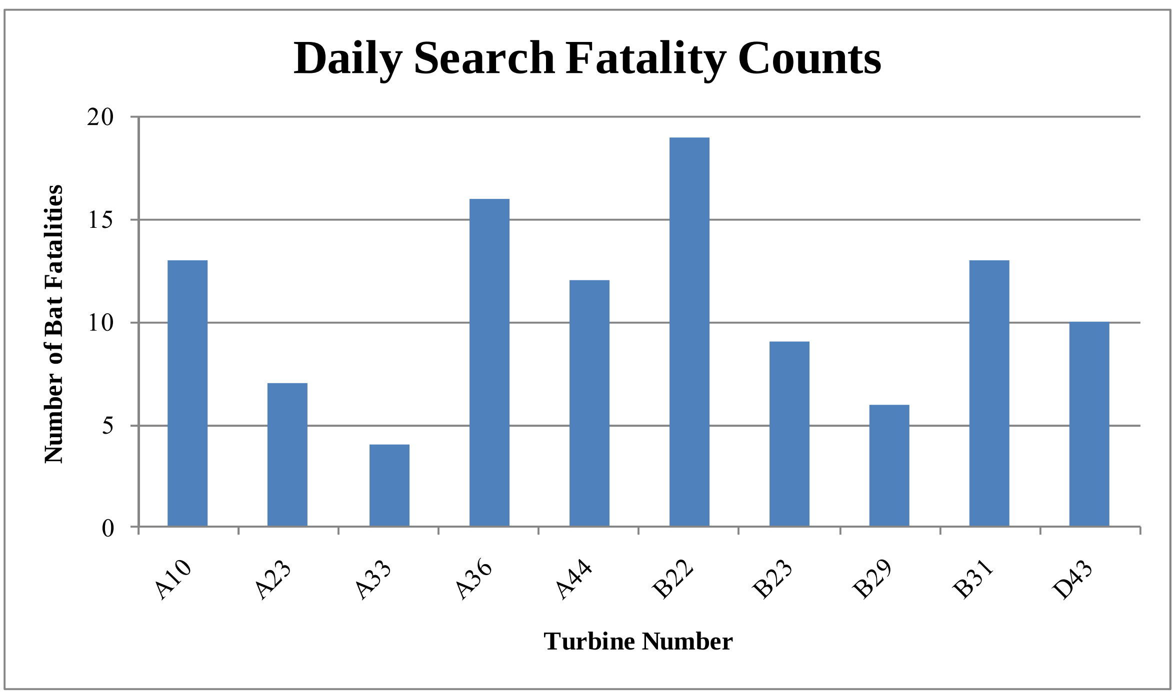

Figure 11.1. Bat fatalities per turbine for turbines searched daily at the BSGF facility.

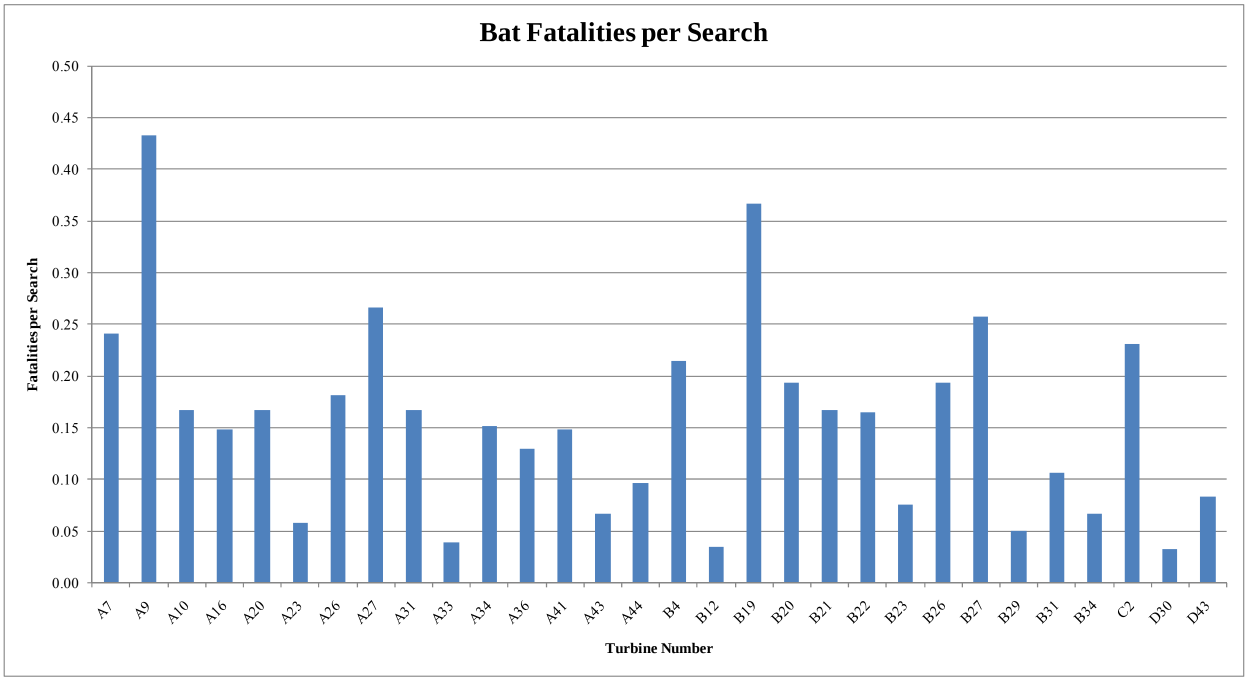

Figure 11.2. Bat fatalities per Search for scheduled search turbines at the BSGF facility.

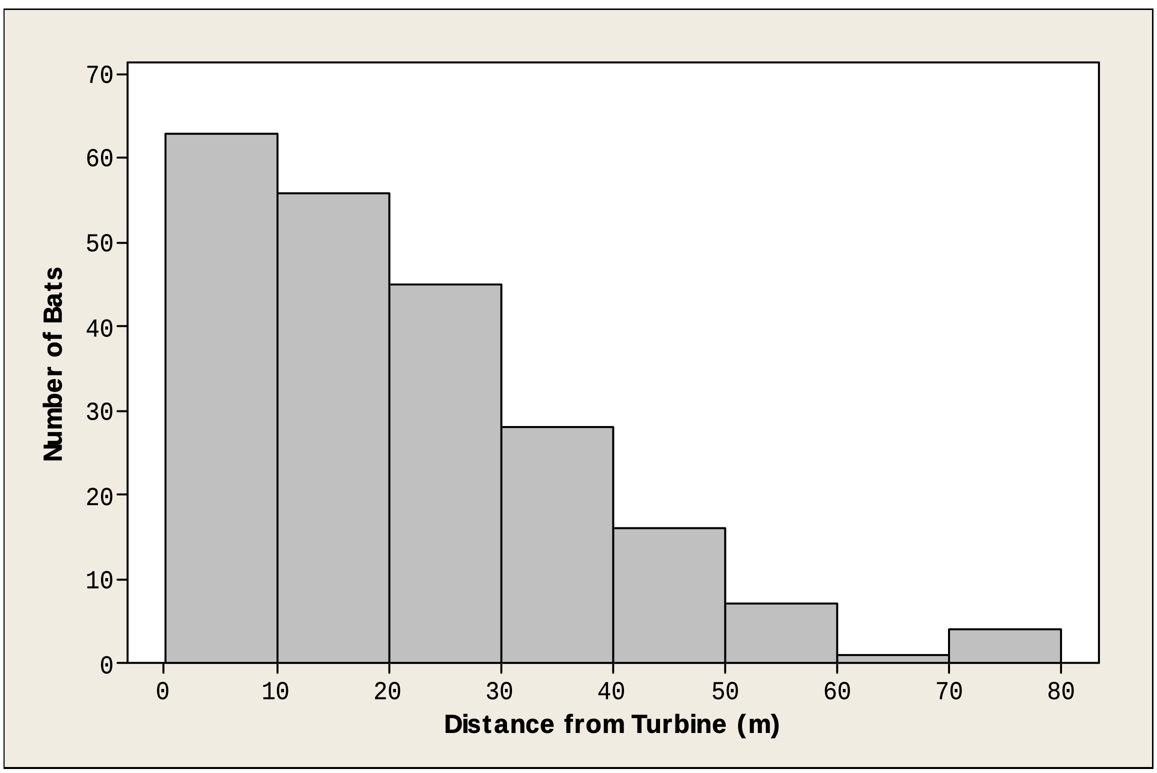

Figure 12. Distance from turbine for bat fatalities at BSGF.

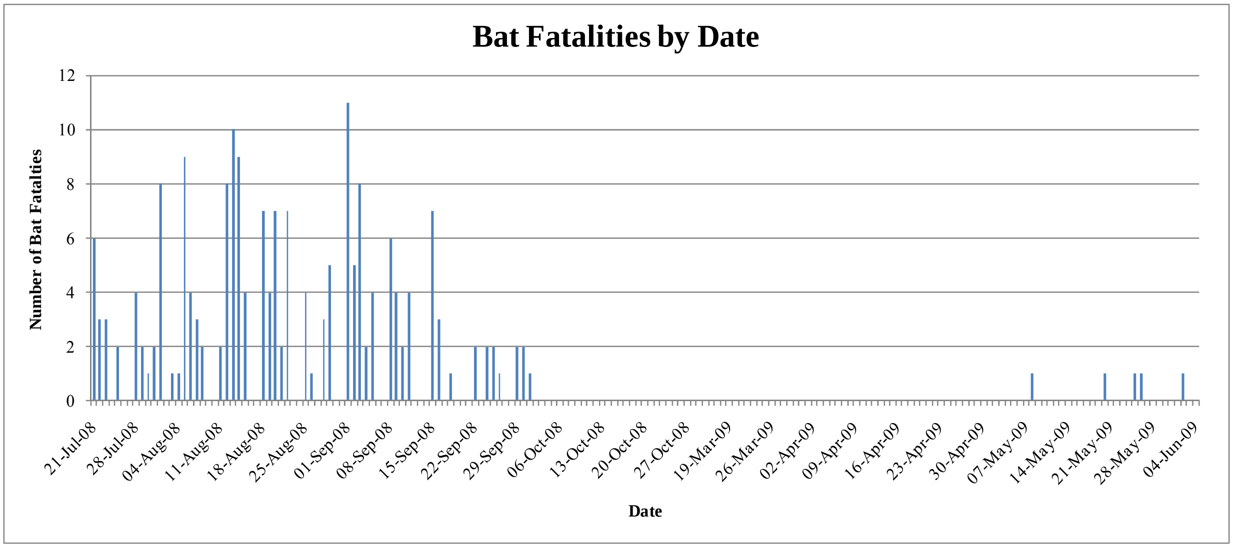

Figure 13. Bat fatalities through time at the BSGF facility.

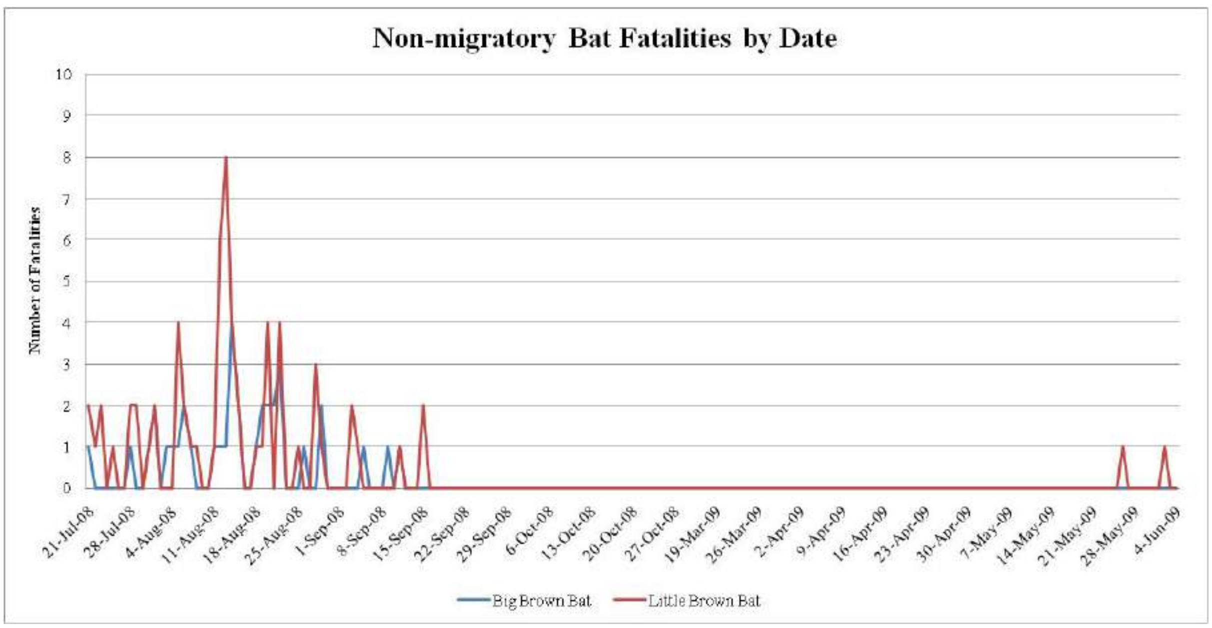

Figure 14. Little brown and big brown bat fatalities through time at the BSGF facility.

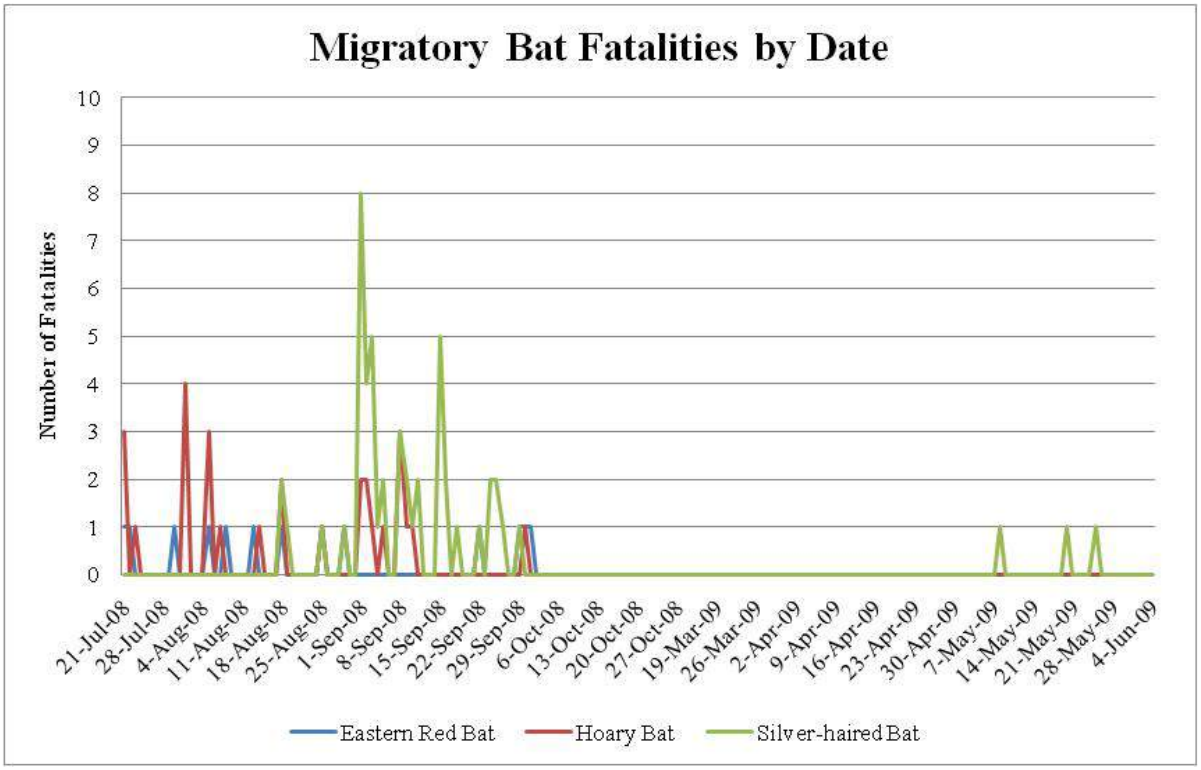

Figure 15. Migratory bat fatalities through time at the BSGF facility.

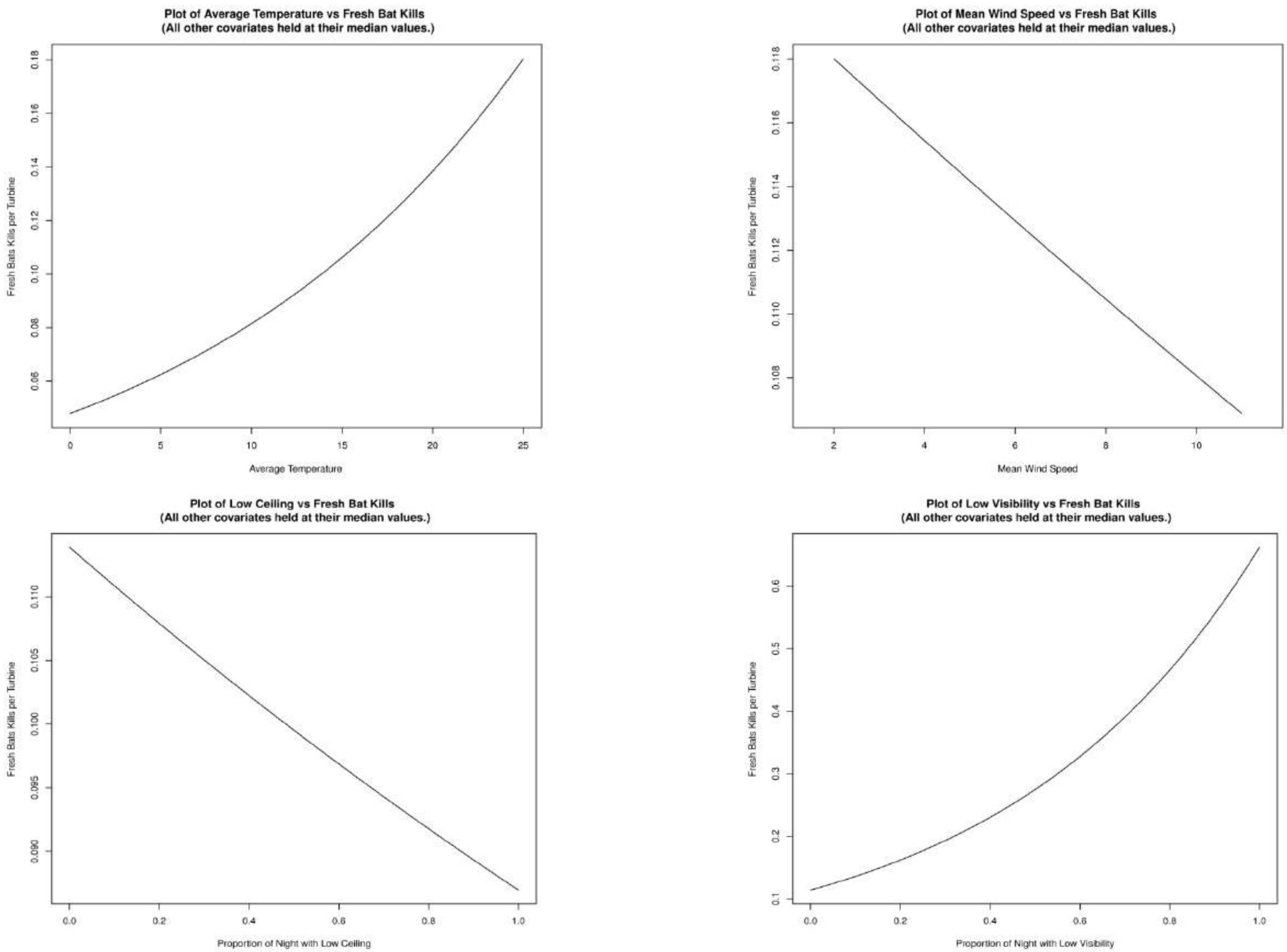

Figure16. Relationship between covariates in the zero-inflated Poisson model and fresh fatalities found the following day.

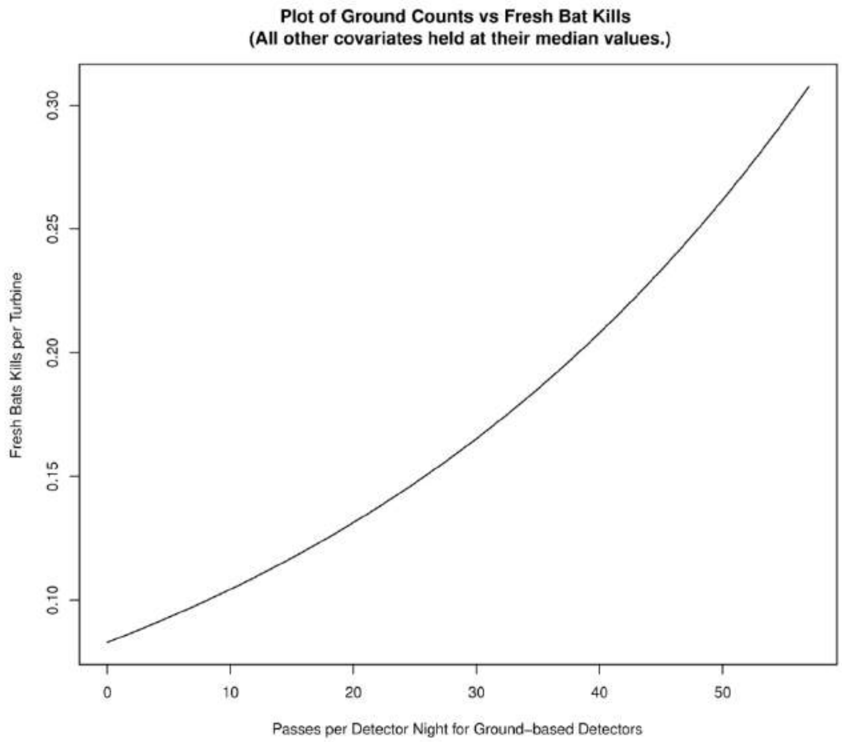

Figure 17. Relationship between mean passes per detector-night recorded at ground-based detectors and fresh fatalities found the following day.

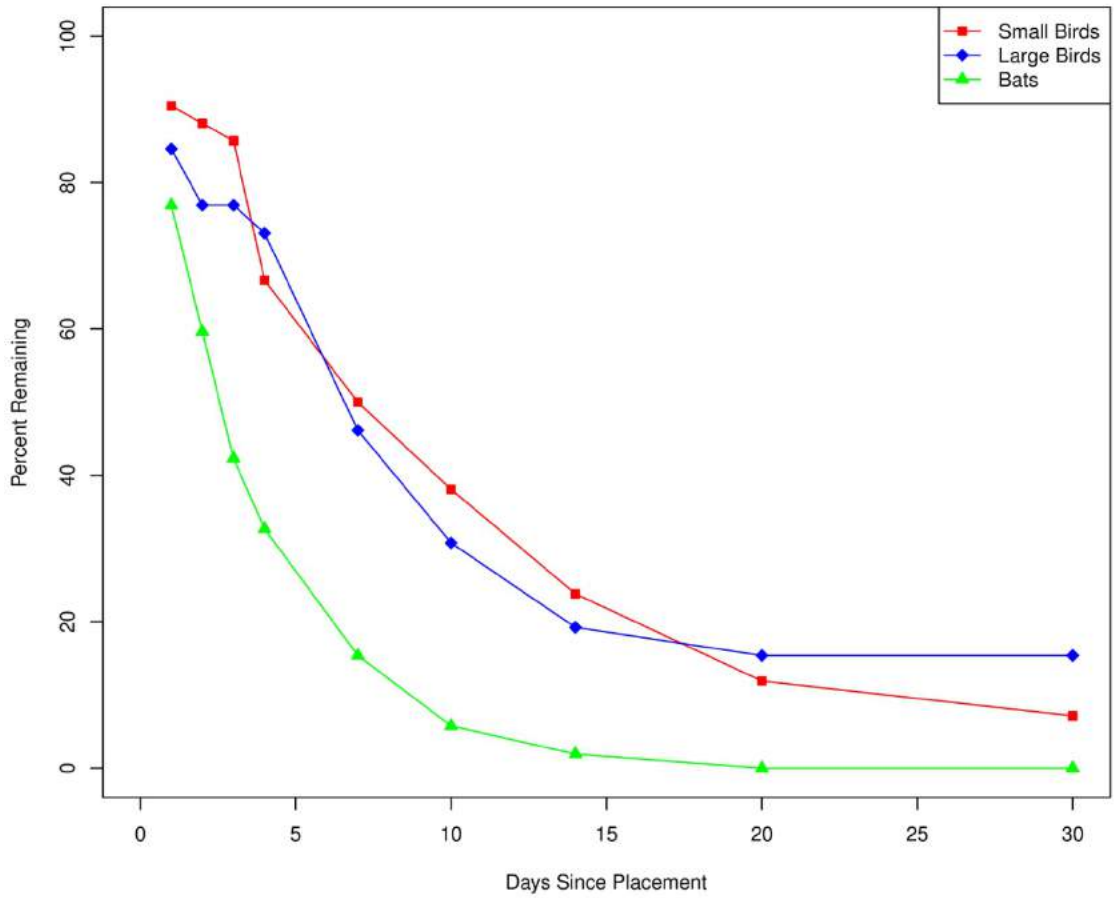

Figure 18. Scavenging trial results for bats, large birds, and small birds at Blue Sky Green Field.

APPENDIX 1. Summary of components used to calculate fatality estimates for daily and weekly searches during the fall and spring seasons at Blue Sky Green Field. Means, standard errors (se), and lower (ll) and upper (ul) 90% confidence limits are bootstrap point estimates.

Table A-1. Fall 2008 fatality estimates and components for birds. Dataset included observations before mowing was complete.

	Daily Searches				Weekly Searches			
			90% C.I.				90% C.I.	
Parameter	***mean***	***se***	***ll***	***ul***	***mean***	***se***	***ll***	***ul***
Search Area Adjustment								
A (small)	6.33							
A (large)	2.11							
Observer Detection								
p (small)	0.60	0.11	0.40	0.75				
p (large)	0.56	0.11	0.40	0.75				
Observed Fatality Rates (Fatalities/turbine)								
Small birds								
c_i	1.4	0.30	0.90	1.90	0.65	0.13	0.45	0.85
Large birds								
c_i	0.20	0.12	0	0.40	0	0	0	0
Average Probability of Carcass Availability and Detected								
$\hat{\pi}_i$ (small)	0.79	0.06	0.66	0.86	0.47	0.08	0.32	0.59
$\hat{\pi}_i$ (large)	0.82	0.07	0.69	0.90	0.52	0.10	0.34	0.68
Adjusted Fatality Estimates (Fatalities/turbine)								
All birds								
m_i	11.90	2.70	7.76	16.55	8.77	2.57	5.63	13.80
Daily Fatality Rates (Fatalities/turbine/day)								
All birds								
d_i	0.11	0.03	0.07	0.15	0.08	0.02	0.05	0.13

Table A-1.1. Fall 2008 fatality estimates and components for birds. Observations in dataset began when the plot was mowed for the first time.

	Daily Searches				Weekly Searches			
			90% C.I.				90% C.I.	
Parameter	***mean***	***se***	***ll***	***ul***	***mean***	***se***	***ll***	***ul***
Search Area Adjustment								
A (small)	6.78							
A (large)	2.11							
Observer Detection								
p (small)	0.60	0.11	0.40	0.75				
p (large)	0.56	0.11	0.40	0.75				
Observed Fatality Rates (Fatalities/turbine)								
Small birds								
c_i	1.34	0.31	0.85	1.89	0.60	0.14	0.37	0.83
Large birds								
c_i	0.21	0.13	0	0.44	0	0	0	0
Average Probability of Carcass Availability and Detected								
$\hat{\pi}_i$ (small)	0.79	0.06	0.66	0.86	0.47	0.08	0.32	0.59
$\hat{\pi}_i$ (large)	0.82	0.07	0.69	0.90	0.52	0.10	0.34	0.68
Adjusted Fatality Estimates (Fatalities/turbine)								
All birds								
m_i	12.11	2.96	7.94	17.56	8.62	2.96	4.96	14.63
Daily Fatality Rates (Fatalities/turbine/day)								
All birds								
d_i	0.11	0.03	0.07	0.16	0.08	0.03	0.05	0.14

Table A-2. Fall 2008 fatality estimates and components for all bats and bats by migratory status. Dataset included observations before mowing was complete.

	Daily Searches				Weekly Searches			
			90% C.I.				90% C.I.	
Parameter	***mean***	***se***	***ll***	***ul***	***mean***	***se***	***ll***	***ul***
Search Area Adjustment								
A	2.58							
Observer Detection								
p	0.70	0.07	0.57	0.81				
Observed Fatality Rates (Fatalities/turbine)								
All bats								
$\bar{c}_i$	10.5	1.45	8.10	13.00	5.45	0.65	4.40	6.50
Non-migratory bats								
$\bar{c}_i$	6.2	1.13	4.28	8.10	2.70	0.51	2.91	3.61
Migratory bats								
$\bar{c}_i$	4.30	0.56	3.40	5.30	2.75	0.35	2.15	3.35
Average Probability of Carcass Availability and Detected								
$\hat{\pi}_i$	0.71	0.04	0.63	0.77	0.35	0.04	0.28	0.42
Adjusted Fatality Estimates (Fatalities/turbine)								
All bats								
m_i	38.32	5.92	29.46	49.24	39.83	7.21	30.02	53.74
Non-migratory bats								
m_i	22.63	4.43	15.61	30.48	19.73	4.57	13.61	28.13
Migratory bats								
m_i	15.69	2.28	12.15	19.90	20.10	3.79	14.95	27.28
Daily Fatality Rates (Fatalities/turbine/day)								
All bats								
d_i	0.35	0.05	0.27	0.46	0.37	0.07	0.28	0.50
Non-migratory bats								
d_i	0.21	0.04	0.14	0.28	0.18	0.04	0.13	0.26
Migratory bats								
d_i	0.15	0.02	0.11	0.18	0.19	0.04	0.14	0.25

Table A-2.1. Fall 2008 fatality estimates and components for all bats and bats by migratory status. Dataset began when the plot was mowed for the first time.

	Daily Searches				Weekly Searches			
			90% C.I.				90% C.I.	
Parameter	***mean***	***se***	***ll***	***ul***	***mean***	***se***	***ll***	***ul***
Search Area Adjustment								
A	2.65							
Observer Detection								
p	0.70	0.07	0.57	0.81				
Observed Fatality Rates (Fatalities/turbine)								
All bats								
$\bar{c}_i$	10.20	1.55	7.68	12.82	5.21	0.66	4.17	6.35
Non-migratory bats								
$\bar{c}_i$	5.82	1.06	4.09	7.60	2.49	0.53	1.69	3.43
Migratory bats								
$\bar{c}_i$	4.38	0.67	3.31	5.50	2.72	0.37	2.12	3.31
Average Probability of Carcass Availability and Detected								
$\hat{\pi}_i$	0.71	0.04	0.63	0.77	0.35	0.04	0.28	0.42
Adjusted Fatality Estimates (Fatalities/turbine)								
All bats								
m_i	38.23	6.40	28.69	49.52	39.11	7.29	28.95	53.13
Non-migratory bats								
m_i	21.81	4.28	15.37	29.29	18.68	4.73	11.92	28.03
Migratory bats								
m_i	16.41	2.75	12.25	21.24	20.42	4.01	15.03	27.78
Daily Fatality Rates (Fatalities/turbine/day)								
All bats								
d_i	0.35	0.06	0.27	0.46	0.36	0.07	0.27	0.49
Non-migratory bats								
d_i	0.20	0.04	0.14	0.27	0.17	0.04	0.11	0.26
Migratory bats								
d_i	0.15	0.03	0.11	0.20	0.19	0.04	0.14	0.26

Table A-3.1. Spring 2009 fatality estimates and components for birds.

Parameter	*mean*	*se*	90% C.I. *ll*	90% C.I. *ul*
Observer Detection				
p (small birds)	0.67	0.06	0.56	0.78
p (large birds)	0.89	0.07	0.78	1

	Daily Searches (not fully cleared)	**Daily Searches (fully cleared)**	**Weekly Searches**
Search Area Adjustment			
A (small)	5.39	1.13	6.45
A (large)	---	---	4.49

			90% C.I.				90% C.I.				90% C.I.	
Parameter	*mean*	*se*	*ll*	*ul*	*mean*	*se*	*ll*	*ul*	*mean*	*se*	*ll*	*ul*
Observed Fatality Rates (Fatalities/turbine)												
Small birds												
$\bar{c}_i$	0.14	0.13	0	0.43	1.33	1.09	0	2.67	0.25	0.12	0.05	0.45
Large birds												
$\bar{c}_i$	0	0	0	0	0	0	0	0	0.05	0.05	0	0.15
Average Probability of Carcass Availability and Detected												
$\hat{\pi}_i$ (small)	0.91	0.02	0.86	0.94	0.91	0.02	0.86	0.94	0.70	0.05	0.61	0.78
$\hat{\pi}_i$ (large)	0.96	0.02	0.91	0.99	0.96	0.02	0.91	0.99	0.87	0.08	0.70	0.95
Adjusted Fatality Estimates (Fatalities/turbine)												
All birds												
m_i	0.85	0.80	0	2.53	1.66	1.37	0	3.48	2.55	1.15	0.90	4.66
Daily Fatality Rates (Fatalities/turbine/day)												
All birds												
d_i	0.01	0.01	0	0.03	0.02	0.02	0	0.04	0.03	0.02	0.01	0.06

Table A-3.2. Spring 2009 fatality estimates and components for all bats and bats by migratory status

			90% C.I.	
Parameter	*mean*	*se*	*ll*	*ul*
Observer Detection				
p (small birds)	0.67	0.06	0.56	0.78
p (large birds)	0.89	0.07	0.78	1

	Daily Searches (not fully cleared)	Daily Searches (fully cleared)	Weekly Searches
Search Area Adjustment			
A	4.74	1.07	2.99

	Daily Searches (not fully cleared)				Daily Searches (fully cleared)				Weekly Searches			
			90% C.I.				90% C.I.				90% C.I.	
Parameter	*mean*	*se*	*ll*	*ul*	*mean*	*se*	*ll*	*ul*	*mean*	*se*	*ll*	*ul*
Observed Fatality Rates (Fatalities/turbine)												
All bats												
$\bar{c}_i$	0.29	0.17	0	0.57	0.33	0.27	0	0.67	0.1	0.07	0	0.2
Migratory bats												
$\bar{c}_i$	0.14	0.14	0	0.43	0.33	0.27	0	0.67	0.05	0.05	0	0.15
Non-migratory bats												
$\bar{c}_i$	0.14	0.13	0	0.43	0	0	0	0	0.05	0.05	0	0.15
Average Probability of Carcass Availability and Detected												
$\hat{\pi}_i$	0.64	0.12	0.38	0.78	0.64	0.12	0.38	0.78	0.30	0.10	0.13	0.46
Adjusted Fatality Estimates (Fatalities/turbine)												
All bats												
m_i	2.11	1.59	0	5.07	0.56	0.52	0	1.48	0.99	1.16	0	3.24
Migratory bats												
m_i	1.05	1.19	0	3.33	0.56	0.52	0	1.48	0.50	0.76	0	1.97
Non-migratory bats												
m_i	1.05	1.17	0	3.21	0	0	0	0	0.50	0.77	0	1.92
Daily Fatality Rates (Fatalities/turbine/day)												
All bats												
d_i	0.03	0.02	0	0.06	0.01	0.01	0	0.02	0.01	0.01	0	0.04
Migratory bats												
d_i	0.01	0.01	0	0.04	0.01	0.01	0	0.02	0.01	0.01	0	0.02
Non-migratory bats												
d_i	0.01	0.01	0	0.04	0	0	0	0	0.01	0.01	0	0.02