Patterns of Bat Fatality at the Casselman Wind Project in south-central Pennsylvania

2008 Annual Report

Edward B. Arnett and Michael R. Schirmacher, Bat Conservation International

Manuela M. P. Huso
Oregon State University

John P. Hayes
University of Florida

Annual Report Prepared for the
Bats and Wind Energy Cooperative and the Pennsylvania Game Commission

June 2009

REPORT CITATION

Arnett, E. B., M. R. Schirmacher, M. M. P. Huso, and J. P. Hayes. 2009. Patterns of bat fatality at the Casselman Wind Project in south-central Pennsylvania. An annual report submitted to the Bats and Wind Energy Cooperative and the Pennsylvania Game Commission. Bat Conservation International. Austin, Texas, USA.

ACKNOWLEDGMENTS

This study was conducted under the auspices of the Bats and Wind Energy Cooperative and as part of the Pennsylvania Game Commission's cooperative agreement for wind energy development. We wish to thank the American Wind Energy Association (AWEA), Bat Conservation International (BCI), the National Renewable Energy Laboratory-Department of Energy (NREL), and the U.S. Fish and Wildlife Service (USFWS) for partnering to form the Bats and Wind Energy Cooperative (BWEC). Tom Gray (AWEA), Alex Hoar (USFWS), Bob Thresher (NREL), and Merlin Tuttle (BCI) provided oversight for the BWEC for this project.

We wish to thank numerous donors to BCI, member companies of AWEA, the National Fish and Wildlife Foundation, and Iberdrola Renewables for funding work conducted at the Casselman facility over the past several years. We are indebted to Holly McCready, Jeff Miller, Erica La More, Mario Dasilva, Brian Farless, Paula Shover, Ryan Claire, and Ann Zurbriggen for their dedication in the field and collecting and managing the data throughout the study. Allison Poe, Elizabeth van Stam, and Andrew Blaney also assisted with field work. We thank Iberdrola Renewables employees, in particular Andy Linehan, Sam Enfield, Scott McDonald, Dave DeCaro, and Chris Long, for their support and efforts to make this study happen and run smoothly. Zac Wilson (BCI) conducted all GIS analysis for the study. We thank staff from the Pennsylvania Game Commission for their help, oversight and support during the study. Finally, we appreciate the support and hospitality of the private landowners that graciously allowed access to their lands for this study; they should be commended for supporting proactive research for solving wildlife and wind energy issues.

BWEC
bats and wind energy cooperative

EXECUTIVE SUMMARY

We initiated a 5-year study in mid-summer 2005 to determine patterns of bat activity and evaluate the use of acoustic monitoring to predict fatality of bats at a proposed wind energy facility in south-central Pennsylvania. The primary objectives of this study are to 1) determine activity of different bat species and species groups using the Casselman Wind Project in south-central Pennsylvania prior to and after construction; 2) determine if indices of pre-construction bat activity can predict post-construction bat fatalities at turbine locations at the Casselman Wind Project (we also will combine data from this study with that from several facilities to determine if indices of pre-construction bat activity can predict post-construction bat fatalities at the wind facility-scale); 3) determine searcher efficiency and scavenger removal rates to adjust number of carcasses found and estimate bat fatality rates at the Casselman Wind Project; and 4) evaluate patterns of post-construction bat fatality in relation to wind speed, temperature, rotor speed, and other factors and assess the predictability of fatality based on these factors. This report focuses exclusively on the first year of post-construction fatality searches and estimates and patterns of bat fatality at the Casselman Wind Project in 2008.

We searched 10 of 23 turbines on 204 out of the total possible 211 days between 19 April and 15 November 2008 at the Casselman Wind Project. A total of 2,040 turbines searches were conducted at the 10 turbines during the 2008 field season.

We found 16 bird carcasses of 8 species (6 carcasses were of unknown species of birds) during searches between 19 April and 15 November 2008. Of 21 bird carcasses used for searcher efficiency trials, 5 of 7 placed in the easy class were found by searchers, while 4 of 7 and 2 of 7 were found in moderate and difficult classes, respectively. Average carcass persistence time was estimated to be 12.7 days (95% CI: 6.65, 24.37) for all birds. We estimated bat and bird fatality with three different estimators (two previous reported estimators [naïve and modified estimators] and a new estimator proposed and under review in the scientific literature [MH]; simulation studies suggest that the MH estimator is less biased than other estimators). The estimated number of bird fatalities per turbine was 4.69 (95% CI: 1.25, 14.31), 0.37 (95% CI: 0.07, 1.20), and 2.27 (95% CI: 0.88, 3.92) for the MH, naïve, and modified estimators, respectively.

We found 148 carcasses of 6 species of bats (1 carcasses was not identifiable to species) in the search plots from 19 April through 15 November 2009. Hoary bats, silver-haired bats, and eastern red bats were killed most frequently, representing 75% of estimated fatalities, and eastern pipistrelles and little brown bats represented 11 and 10% of estimated fatalities, respectively. Fatalities were found at all 10 turbines searched during the study. The total number of bat carcasses (all species and decay conditions combined) found at all turbines during searches on each day of the study increased in late summer and early fall (beginning around the middle of July), and no bat carcasses were found after 24 October 2008. One hundred-twenty-four (84%) of all bat carcasses were found between 15 July and 15 October 2009.

Data from 70 searcher efficiency trial carcasses were fit to a logistic regression model, and there was strong evidence of a difference in searcher efficiency among the visibility classes

(χ_2^2 = 14.32, p = 0.0002). All carcasses in the ‘easy’ class that persisted long enough to be observed were found by searchers, while 71% of carcasses in the ‘moderate’ class that persisted long enough to be observed were found. Only 13% of carcasses that persisted more than 2 weeks in the ‘difficult’ class were found. Data from 114 scavenger removal trial carcasses were fit to an interval-censored parametric failure time model and there was no difference among visibility classes (χ_2^2 = 1.78, p = 0.41). Average persistence time was estimated to be 31.9 days (95% CI: 17.4, 57.7 days).

The estimated number of bat fatalities per turbine was 32.30 (95% CI: 20.76, 51.43), 1.11 (95% CI: 0.50, 2.26), and 18.91 (95% CI: 15.27, 22.88) for the MH, naïve, and modified estimators, respectively. The average bat fatality estimate per turbine using the MH estimator was 1.7 times greater than that of the modified estimator and 29.1 times greater than estimates using the naïve estimator. Mean fatalities per turbine from the forested ridge portion of the project was 32.34 (n = 7, 95% CI: 22.39, 43.66), while mean fatalities per turbine from the strip mined ridge was 32.53 (n = 3, 95% CI: 24.53, 42.48), indicating no difference in fatalities between these two ridges and habitat conditions on the project site.

We will initiate a second year of post-construction fatality searches beginning 1 April and continuing through 15 November 2009 at the Casselman facility. A final report on the 3-years of pre-construction acoustic data is in preparation and will be distributed in early summer 2009. Also, we plan to correlate bat activity with fatality data for each turbine where these data were collected to determine if activity can predict turbine-scale fatality. That report will be prepared and distributed later in 2009.

Photo by: M. R. Schirmacher, Bat Conservation International.

INTRODUCTION

Although wind-generated electricity is renewable and generally considered environmentally clean, fatalities of bats and birds have been recorded at wind facilities worldwide (Erickson et al. 2002, Durr and Bach 2004, Johnson 2005, Kunz et al. 2007, Arnett et al. 2008, Baerwald 2008). Bat fatalities at wind energy facilities generally received little attention in North America until 2003 when 1,400–4,000 bats were estimated to have been killed at the Mountaineer Wind Energy Center in West Virginia (Kerns and Kerlinger 2004). High bat fatalities continued at the Mountaineer facility in 2004 (Arnett 2005) and large kills also have been reported at facilities in Pennsylvania (Arnett 2005) and Tennessee (Fiedler 2004). These fatalities raise concerns about potential impacts on bat populations at a time when many species of bats are known or suspected to be in decline (Racey and Entwistle 2003, Winhold and Kurta 2006) and extensive planning and development of wind energy is increasing worldwide (Kunz et al. 2007, EIA 2008).

Documenting patterns of bat fatality is fundamental to understanding bat interactions with turbines, the timing and predictability of fatality, and in developing solutions to reduce or eliminate fatalities. Few post-construction studies on bat fatalities had been conducted in North America prior to 2004 (Johnson 2005) and, unfortunately, the vast majority of empirical data from wind facilities around the world continue to reside in unpublished reports (Arnett et al. 2008). Post-construction fatality searches at wind facilities originally were designed to monitor annual or seasonal avian fatality rates, primarily for large raptors (Erickson et al. 2002). Since the recent discovery of high bat fatalities at wind facilities in the eastern U.S., however, post-construction monitoring has intensified and most permitting agencies now require inclusion of estimates of bat fatalities (Arnett et al. 2008). For example, the Pennsylvania Game Commission (PGC) enacted a voluntary agreement requiring all wind companies to conduct a minimum of two years of daily post-construction fatality searches. Past fatality search efforts usually were conducted on a systematic schedule of days ranging from 3 to as high as 28 days between searches at each turbine. Kerns et al. (2005) were the first researchers to conduct extensive daily searches at turbines, which are now required under Pennsylvania's voluntary agreement (PGC 2007).

Interactions between bats and wind turbines are poorly understood. The combination of nocturnal habits, volancy, small size, and variation in resource dependence (i.e., species vary in roost, water, and food resource dependence), have made even a rudimentary understanding of how bats interface with their environment difficult to establish (Gannon et al. 2003). Post-construction monitoring has provided most of what little information has been gathered on bat fatalities at wind farms. While patterns of fatality of bats at wind facilities allow for some conjecture about risk factors for some species, information on use of the area encompassing a facility are needed to place bat fatality in an appropriate context (Fiedler 2004). Pre-construction surveys at wind facilities have been conducted and most commonly employ mist nets and acoustic detectors to assess local bat species presence and activity (e.g., Reynolds 2006). However, using this information to predict bat fatality and thus risk at a site has proved to be challenging. The ability to generate reliable risk assessments prior to construction of wind facilities is greatly hampered by the lack of baseline data on bat population distributions and densities throughout much of North America (O'Shea et al. 2003, Reynolds 2006) and migratory patterns and behavior of bats (Larkin 2006).

Understanding bat activity levels prior to construction of wind facilities could assist in identifying habitats and features that may pose high risk of fatality and aid with decision-making, including specific placement of turbines (Fiedler 2004, Reynolds 2006). Unfortunately, past and current efforts to acoustically monitor bat activity prior to construction of turbines may suffer from flaws in study design, including small sample sizes and poor temporal and spatial replication (Hayes 1997, 2000), pseudoreplication (Hurlbert 1984), and inappropriate inference because limitations and assumptions were not understood or clearly articulated (Hayes 2000, Sherwin et al. 2000, Gannon et al. 2003). Also, there is a lack of information and lack of agreement among stakeholders, biologists, and scientists regarding what constitute different levels of risk in relation to bat activity and potential fatality of bats at wind facilities. Perhaps most importantly, we currently are unaware of any study that has correlated pre-construction monitoring data with post-construction fatality, a fundamental link necessary for understanding potential risk of wind facilities to bats.

We initiated a 5-year study in late summer 2005 to evaluate whether indices of bat activity gathered before construction using acoustic detectors can predict post-construction fatality of bats at the Casselman Wind Project in south-central Pennsylvania. This project occurred in 2 phases: the first phase used acoustic detectors to collect echolocation calls to develop indices of bat activity from August through October 2005 (Arnett et al. 2006) and from April through October 2006 and 2007. The second phase involves monitoring bat activity at the same sites after turbines are constructed, coupled with extensive fatality searches in 2008 and 2009. In this report, we present results from the first year of post-construction fatality searches in 2008.

OVERALL PROJECT OBJECTIVES

1. Determine activity of different bat species and species groups using the Casselman Wind Project in south-central Pennsylvania prior to and after construction.
2. Determine if indices of pre-construction bat activity can predict post-construction bat fatalities at turbine locations at the Casselman Wind Project (we also will combine data from this study with those from several facilities to determine if indices of pre-construction bat activity can predict post-construction bat fatalities at the wind facility-scale).
3. Evaluate temporal and spatial (both horizontal, i.e. sampling points across the turbine string, and vertically, i.e., multiple detectors at each sampling point at different heights) patterns of variability of bat species group activity at turbine locations and meteorological towers located across the Casselman facility.
4. Correlate bat activity prior to and after construction with weather and other environmental variables.
5. Determine searcher efficiency and scavenger removal rates to adjust number of carcasses found and estimate bat and bird fatality rates at the Casselman Wind Project.

6. Evaluate patterns of post-construction bat fatality in relation to wind speed, temperature, rotor speed, and other factors and assess the predictability of fatality based on these factors.
7. Evaluate study design, temporal and spatial variation, and sample size requirements and offer suggestions for standardizing protocols for future acoustic studies and fatality searches.

This report focuses exclusively on objectives 5 and 6. A final report on the 3-year activity data collected at Casselman is in preparation and will address objectives 1-3.

STUDY AREA and METHODS

Study Area

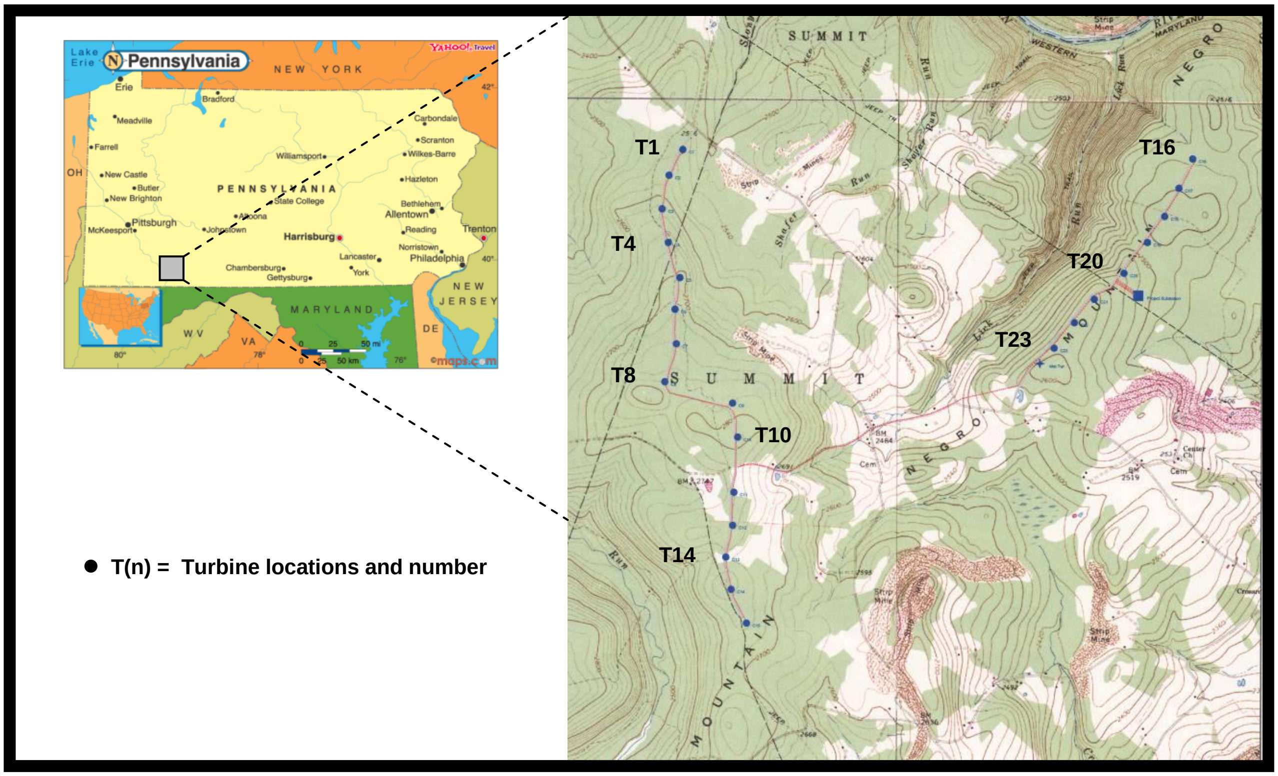
The Casselman Wind Project is located near the town of Rockwood in Somerset County, Pennsylvania. The facility lies within the Appalachian mixed mesophytic forests ecoregion and the moist broadleaf forests that cover the plateaus and rolling hills west of the Appalachian Mountains (Brown and Brown 1972, Strausbaugh and Core 1978). There are two "strings" of turbines at the Casselman site. The western string has 15 turbines and is mostly forested (herein referred to as the "forested ridge"; Figure 1). Eleven of the 15 turbines in this string occur in relatively dense, second-growth deciduous hardwood forest with a canopy height generally ranging from 15–20 m; 3 of the 15 turbines in this string occur in open hay pasture near second-growth forest and one occurs in a stand of young (<10 years old) regenerating forest. The eastern string has 8 turbines (herein referred to as "mine ridge"; Figure 1) and all turbines in this string occur in open grassland reclaimed after strip mining for coal.

METHODS

Delineation of Carcass Search Plots and Habitat Mapping

We attempted to delineate a rectangular plot 126 m east-west by 120 m north-south (60 m radius from the turbine mast in any direction; 15,120 m^2 total area) centered on each turbine sampled; this area represents the maximum possible search area for this study [see Figure 2 for an example]). Transects were set 6 m apart within each plot and observers searched 3 m on each side of the transect line; thus, the maximum plot in the east-west direction could be up to 126 m wide. However, dense vegetation and the area cleared of forest at this facility was highly varied and, thus, we eliminated unsearchable habitat (e.g., forest, tall and dense grassland) and usually did not search the entire possible maximum area. We used a global positioning system (GPS) to map the actual area searched at each turbine (see Figure 2 for an example, and Appendix 1 for plot maps). The density weighted area searched was used to standardize results and adjust fatality estimates (see methods). The number of transect lines and length of each line was recorded for each plot and habitat in each plot mapped with a GPS unit. We recorded the percent ground cover, height of ground cover (low [<10 cm], medium [11–50 cm], high [>50 cm]), type of habitat (vegetation, brush pile, boulder, etc), and the presence of extreme slope and collapsed these habitat characteristics into visibility classes that reflect their combined influence on carcass detectability (Table 1; following Arnett 2005 and PGC 2007).

Figure 1. Location of the Casselman Wind Project study area and its 23 turbines in Somerset County in south-central Pennsylvania.



Fatality Searches

We conducted daily searches at 10 of the 23 turbines (1, 3, 4, 8, 11, 13, 14, 16, 20, 23; Figure 1) 7 days/week from 19 April to 15 November 2008. These turbines were selected based on the amount and quality of acoustic data previously collected from 2005–2007 that will be correlated with turbine-specific fatality data in the future (see Arnett et al. 2006 for more details). Searchers walked at a rate of approximately 10–20 m/min. along each transect searching both sides out to 3 m on each side for casualties. Searches were abandoned only if severe or otherwise unsafe weather (heavy rain, lightning, etc) conditions were present and searches were resumed that day if weather conditions permitted. Searches commenced at sunrise and all turbines were searched within 8 hr after sunrise.

We recorded date, start time, end time, observer, and weather data for each search. When a dead bat or bird was found, the searcher placed a flag near the carcass and continued the search. After searching the entire plot, the searcher returned to each carcass and recorded information on a fatality data sheet, including date, species, sex and age (when possible), observer name, turbine number, perpendicular distance from the transect line to the carcass, distance from turbine, azimuth from turbine, habitat surrounding carcass, condition of carcass (entire, partial, scavenged), and estimated time of death (e.g., ≤1 day, 2 days). The field crew leader (M. R. Schirmacher) confirmed all species identifications at the end of each day.

Figure 2. Sample carcass search plot at a wind turbine depicting the maximum plot size of 126 m east-west and 120 m north-south, 6 m wide transect lines (searched 3 m on each side), unsearchable area (black), and area encompassed by easy (white), moderate (light tan), difficult (dark tan), and very difficult (brown) visibility habitat.

Table 1. Habitat visibility classes used during this study (following PGC 2007). Data for Classes 3 and 4 were combined during our final analyses.

% Vegetative Cover	Vegetation Height	Visibility Class
≥90% bare ground	≤15 cm tall	Class 1 (Easy)
≥25% bare ground	≤15 cm tall	Class 2 (Moderate)
≤25% bare ground	≤25% > 30 cm tall	Class 3 (Difficult)
Little or no bare ground	≥25% > 30 cm tall	Class 4 (Very Difficult)

Rubber gloves or an inverted plastic bag were used to handle all carcasses to reduce possible human scent bias for carcasses later used in scavenger removal trials. Carcasses were placed in a plastic bag and labeled. Fresh carcasses, those determined to have been killed the night immediately before a search, were redistributed at random points on the same day for searcher efficiency and scavenging trials.

Field Bias Trials

Searcher efficiency and removal of carcasses by scavengers were quantified to adjust the estimate of total bat and bird fatalities for detection bias. We conducted bias trials throughout the entire study period and searchers were never aware which turbines were used or the number of carcasses placed beneath those turbines during trials. Prior to the study's inception, we used EXCEL to generate a list of random turbine numbers and random azimuths and distances (m) from turbines for placement of each bat used in bias trials.

For bat trials, we used only fresh killed bats for searcher efficiency and carcass removal trials during the study. At the end of each day's search, the field crew leader gathered all carcasses and then redistributed fresh bats at predetermined random points within any given turbine plot's searchable area. Data recorded for each trial carcass prior to placement included date of placement, species, turbine number, distance and direction from turbine, and visibility class surrounding the carcass. We attempted to distribute trial bats equally among the different visibility classes throughout the study period and succeeded in distributing roughly one-third of all trial bats in each visibility class (easy, moderate, and difficult [difficult and very difficult were combined]). We attempted to avoid "over-seeding" any one turbine with carcasses by placing no more than 4 carcasses at any one time at a given turbine. Because we used fresh bats for searcher efficiency trials and carcass removal trials simultaneously, we did not mark bats with tape or some other previously used methods (e.g., Kerns et al. 2005) that could impart human or other scents on trial bat carcasses. Rather, we removed an upper canine tooth from each trial bat so as to distinguish them from other fatalities landing nearby or if animals moved the trial bat away from its original random location. Each trial bat was left in place and checked daily by the field crew leader or a searcher not involved with the bias trials at turbines where carcasses were placed. Thus, trial bats were available to be found by searchers on consecutive days during daily searches unless removed by a scavenger. We recorded the day that each bat was found by a searcher, at which time the carcass remained in the scavenger removal trial. If, however, a carcass was removed by a scavenger before detection by a searcher it was removed from the searcher efficiency trial and used only in the removal data set. When a bat carcass was found, the searcher inspected the canine teeth to determine if a bias trial carcass had been found. If so, the searcher contacted the field crew leader and the bat was left in place for the carcass removal trial. Carcasses were left in place until removed by a scavenger or they decayed and disintegrated to a point beyond recognition. Carcass condition was recorded daily up to 20 days, as present and observable (1) or missing or no longer observable (0).

For bird trials, we used a combination of previously frozen specimens and fresh killed carcasses found beneath turbines for searcher efficiency and carcass removal trials during the study. Because we had so few frozen bird carcasses available to us and found very few fresh carcasses, we were unable to conduct our field bias trials as described above for bats. Rather, we followed the general methods described above, but only used the first day of a searcher efficiency trial (i.e., searchers did not have multiple opportunities to detect trial bird carcasses), protocol typical of most other studies (e.g., Kerns et al. 2005). For bird carcass removal trials, we left all trial carcasses at its random location until it was scavenged or decayed beyond recognition. Trial birds were marked following methods described by Kerns et al. (2005).

Statistical Methods

Carcass persistence/removal. Estimates of the probability that a bat or bird carcass was not removed in the interval between searches were used to adjust carcass counts for removal bias. Removal included scavenging, wind or water, or decomposition beyond recognition. In most fatality monitoring efforts, it is assumed that carcass removal occurs at a constant rate that is not dependent on the time since death; this simplifying assumption allows us to estimate fatality when search intervals exceed one day. The length of time a carcass remains on the study area before it is removed is typically modeled as an exponentially distributed random variable. The probability that a carcass is not removed during an interval of length I can be *roughly* approximated as: $r = \exp(-0.5 * I / t)$. The multiplier of 0.5 is based on the assumption that fatality is approximately constant in the interval between searches and the probability of removal over the entire interval (when some animals died at the beginning of the interval, others near the end), can be approximated by the probability of removal half way through the search interval.

Data from 114 bat carcasses were used in our analysis, with carcass persistence time modeled as a function of visibility class. Thirteen bird carcasses were used in carcass persistence/removal trials, with 7 of these carcasses occurring in the difficult visibility class, 4 in the moderate class, and 2 in easy class. There were too few observations to model average carcass persistence time for each visibility class for birds, thus our estimates for birds represent all visibility classes. We fit carcass persistence/removal data for both bats and birds to an interval-censored parametric failure time model, with carcass persistence time modeled as a function of visibility class. We used an alpha of 0.05 to determine if there was a statistically significant effect among visibility classes for removal of bat carcasses.

Searcher efficiency for bats. Estimates of the probability that a carcass will be seen by an observer during a search were used to adjust carcass counts for observer bias. The failure of an observer to detect a carcass on the search plot may be due to its size, color, or time since death, as well as conditions in its immediate vicinity (e.g., vegetation density, shade). In most fatality monitoring efforts, because we cannot measure time since death, it is assumed that a carcass' observability is constant over the period of the search interval, which it likely is not. In this study, searches were conducted daily and carcass persistence times were long, providing an opportunity for a searcher to detect a carcass that was missed on a previous search. Searcher efficiency trial carcasses were placed on search plots and monitored for 20 days. The day on which a bat carcass was either observed or removed by a scavenger was noted. After accounting for carcasses removed before a searcher had the chance of observing them, data from 70 bat carcasses were fit to a logistic regression model, with odds of observing a carcass given that it persisted, modeled as a function of visibility class. We used an alpha of 0.05 to determine if there was a statistically significant effect among visibility classes.

Searcher efficiency for birds. For birds, we only used the first day of a trial and recorded if the carcass was found or not. After accounting for carcasses that were removed prior to an observer having the chance to detect it, our final data set used to bootstrap searcher efficiency for small and medium birds combined consisted of 21 observations. Because we had no large birds for our trials, we assumed that the probability of detecting a large bird was 100% in all visibility classes. The probability of selecting a bootstrapped sample with an estimated SE of 0 from extremely small sample sizes above was quite high, but it is not possible to estimate fatality when searcher efficiency is estimated to be 0. With these data, the minimum estimable SE was 1/7 or 0.14. When the bootstrapped sample estimated SE as 0, it was replaced with an estimate of 0.05, or about 1/3 the minimum, nonzero estimable SE, to acknowledge a small probability of detection, but to allow estimation of fatality. Totally eliminating these samples would have led to a distribution of estimated SE that was too high and consequent bootstrapped confidence limits that would have been too low.

Density of carcasses and proportion of area surveyed. The density of bat carcasses was modeled as a function of distance from the turbine. Only bat carcasses found in 'easy' visibility areas were used for this analysis and data from all turbines were used, yielding a total of 144 bat carcasses. The searcher efficiency in the 'easy' class was estimated to be 100% (see below in results) and we assumed that the carcass persistence time would be equal for all carcasses within this class and would not change as a function of distance from the turbine. Carcasses were "binned" into 2 m rings (Figure 3) extending from the turbine edge out to the theoretical maximum plot distance. We determined the total area among all search plots that was in the easy visibility class (m^2) and calculated carcass density from this. We combined data from all turbines to calculate carcass density (number of carcasses/m^2) in each ring. These data were modeled as a conditional cubic polynomial with the following estimated function:

$$\text{If distance} \leq 81\text{m, then density} = \exp(-2.8573 + 0.0849*\text{dist} - 0.0028*\text{dist}^2 + 0.00001858*\text{dist}^3) - 0.01\text{; otherwise, density} = 0.00137*\exp(-0.05*(\text{distance}-81))$$

The actual area surveyed within a plot differed among turbines and ranged from 41–96% of the delineated theoretical maximum search plot. Density of carcasses is known to diminish with increasing distance from the turbine (e.g., Kerns et al. 2005), so a simple adjustment to fatality based on area surveyed would likely lead to over estimates, because unsearched areas tend to be farthest from turbines. The calculated function (see above) relating density to distance from a turbine was used to weight each square meter in the plot. The density-weighted fraction of each plot that was actually searched was used as an area adjustment to per-turbine fatality estimates rather than using a simple proportion; the weighted density area of plots averaged 83% (range: 61–99%). In addition, using this density weight, we estimated that the search plots represented 94.7% of the total density weighted area, rather than only 83% of the actual surveyed area.

There were too few bird carcasses found to model the density of carcasses as a function of distance from turbines, and assuming the same relationship for birds as bats was not tenable due to small sample size. Therefore, no adjustments were made for searchable area of the plots for birds. This will likely result in slight overestimates of actual fatality of birds, but we were unable to determine by how much.

Fatality estimates. We adjusted the number of bat and bird fatalities found by searchers by estimates of searcher efficiency and of the proportion of carcasses expected to persist unscavenged during each interval using the following equation:

$$\hat{f}_{ijk} = \frac{c_{ijk}}{\hat{a}_i * \hat{p}_{jk} * \hat{r}_{jk} * \hat{e}_{jk}}$$

Where:

$\hat{f}_{ijk}$ is the estimated fatality in the k^{th} visibility class that occurred at the i^{th} turbine during the j^{th} search;

c_{ijk} is the observed number of carcasses in the k^{th} visibility class at the i^{th} turbine during the j^{th} search;

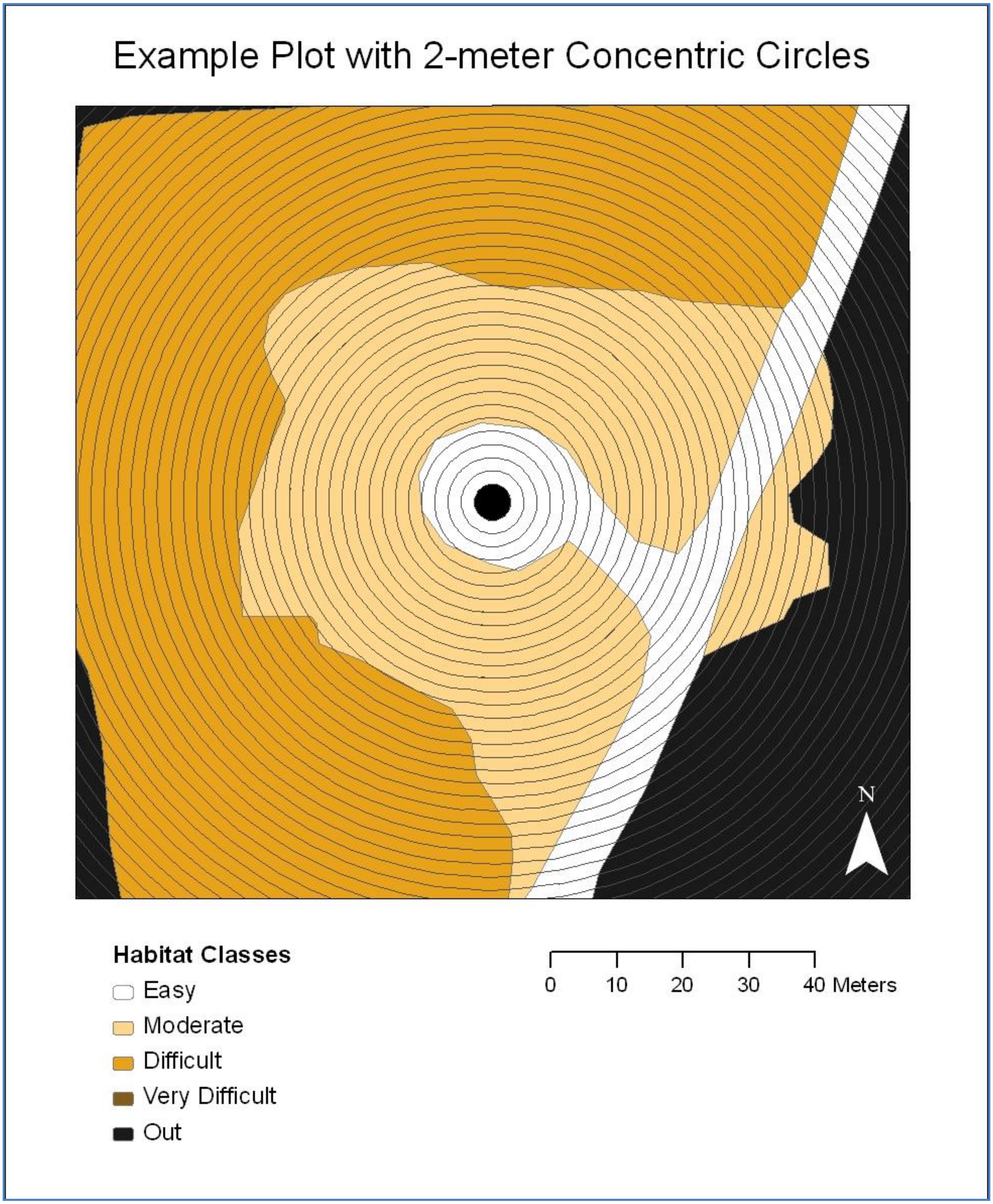
a_i is the density-weighted proportion of the area of the i^{th} turbine that was searched;

$\hat{p}_{jk}$ is the estimated probability that a carcass in the k^{th} visibility class that is on the ground during the j^{th} search will actually be seen by the observer;

$\hat{r}_j$ is the probability than an individual bird or bat that died during the interval preceding the j^{th} search will not be removed by scavengers; and

$\hat{e}_j$ is the effective interval (i.e., the ratio of the length of time before 99% of carcasses can be expected to be removed to the search interval).

Figure 3. Hypothetical carcass search plot for a wind turbine illustrating 2 m rings extending from the turbine edge out to the theoretical maximum plot distance and a depiction of "easy" searchable area (shaded area within line drawing) in the plot, used to develop weights for adjusting fatalities.



The value for $\hat{p}_{jk}$ was estimated through searcher efficiency trials with estimates given above; $\hat{r}_j$ is a function of the average carcass persistence rate and the length of the interval preceding the j^{th} search; and $\hat{r}_j$, $\hat{e}_j$ and $\hat{p}_{jk}$ are assumed not to differ among turbines, but differ with search interval (*j)* and visibility class (*k*).

The estimated annual per turbine fatality for bats and birds was calculated using three different estimators: an estimator used by Johnson et al. (2003) and Fiedler et al. (2007; herein referred to as the Naïve estimator), a modified version of the naïve estimator (P. Shoenfeld, unpublished data) used by Erickson et al. (2004), Kerns and Kerlinger (2004) and Kerns et al. (2005) (herein referred to as the modified estimator, which is the current estimator required by PGC 2007), and a newly derived estimator by M. Huso, Oregon State University (unpublished data, manuscript in press; herein referred to as the MH estimator). The equation for the MH estimator for this study is:

$$\hat{f} = \frac{\sum_{i=1}^{10}\sum_{j=1}^{n_i}\sum_{k=1}^{3}\hat{f}_{ijk}}{10}$$

where n_i is the number of searches carried out at turbine *i*, 1= 1, …, 10, and $\hat{f}_{ijk}$ is defined above. The per turbine estimate and confidence limits were divided by 0.947 to adjust for actual density-weighted area searched and multiplied by 23, the total number of turbines, to give total annual fatality estimates (Cochran 1977). This estimate assumes that no fatalities occurred during the winter, i.e. prior to April and after November. No closed form solution is yet available for the variance of this estimator, so 95% confidence intervals of this estimate were calculated by bootstrapping (Manly 1997) . Searcher efficiency was estimated from a bootstrap sample (with replacement) of searcher efficiency data, carcass persistence estimated from a bootstrap sample of carcass persistence data, and these values were applied to the carcass data from a bootstrap sample of turbines to estimate average fatality per turbine. This process was repeated 1000 times. The 2.5th and 97.5th quantiles from the 1,000 bootstrapped estimates formed the 95% confidence limits of the estimated fatality.

Fatalities in relation to weather and turbine operation. We used weather data (e.g., temperature, wind speed) collected from wind turbine anemometers to correlate the number of bat fatalities determined to have occurred the previous night with weather variables for that night. The data used in this analysis spanned the period from 12 July through 11 October, the time period when 82% of bat fatalities were found. The number of fresh bat kills at a turbine was modeled as a Poisson distributed variable using a generalized mixed model with turbine as a random effect and explanatory variables as fixed effects. The autoregressive parameter indicating correlation from day-to-day was estimated to be 0.055, so data from consecutive days within turbine were assumed to be independent, allowing use of AIC to compare models with different explanatory variables (Burnham and Anderson 2002). We compared the following univariate models using AIC: percent of night when wind speed was <3.5, <5.0, <6.5, and between 3.5 and 6.5 m/s, mean wind speed, mean total rotations (blade revolutions) per night, mean temperature, percent of the night when revolutions per minute was >11 m/s, and the null model. We did not model bird fatalities in relation to weather variables or turbine operation due to small sample sizes.

RESULTS

We searched on 204 out of the total possible 211 days between 19 April and 15 November 2008; we were unable to search on 7 days (20 and 31 May, 4 June, 9 September, 29 and 30 October, and 11 November) due to extreme weather conditions (severe thunderstorms, dense fog, and snow). Our fatality estimates were able to adjust for intermittent changes in search interval. A total of 2,040 turbines searches were conducted at the 10 turbines during the 2008 field season. Time required searching a plot ranged from 35–90 minutes.

Bird Carcasses

We found 16 bird carcasses of 8 species (6 carcasses were of unknown bird species) during searches between 19 April and 15 November 2008 (Table 2). Of the 21 bird carcasses used to correct fatality estimates for searcher efficiency, 7 were placed in each visibility class: easy, moderate, and difficult. Five of the 7 bird carcasses placed in the easy class were found by searchers, while 4 of 7 and 2 of 7 were found in moderate and difficult classes, respectively. Average carcass persistence time was estimated to be 12.7 days (95% CI: 6.65, 24.37) for all birds. The estimated number of bird fatalities per turbine was 4.69 (95% CI: 1.25, 14.31), 0.37 (95% CI: 0.07, 1.20), and 2.27 (95% CI: 0.88, 3.92) for the MH, naïve, and modified estimators, respectively (Table 3).

Table 2. Number and species of birds found during scheduled searches at the Casselman Wind Project, 19 April through 15 November 2008.

Species	**Total No.**
American crow	1
Golden-crowned kinglet	3
Magnolia warbler	1
Palm warbler	1
Red-eyed vireo	1
Ruby-crowned kinglet	1
Yellow-billed cuckoo	1
Yellow-bellied sapsucker	1
Unknown bird	6
Total	**16**

Table 3. Estimated bird fatalities (mean and 95% confidence intervals [CI]) per turbine and for the site total, adjusted for searcher efficiency and carcass removal for the Casselman Wind Project in Somerset County, Pennsylvania, using three different estimators (MH estimator (M.Huso, Oregon State University, unpublished data [manuscript in press]); Naïve estimator (e.g., Johnson et al. 2003, Fiedler et al. 2007); and Modified estimator (from P. Shoenfeld, unpublished data, and Erickson et al. 2004; e.g., Kerns and Kerlinger 2004, Kerns et al. 2005; estimator currently required by PGC 2007).

		MH Estimator			**Naïve Estimator**			**Modified Estimator**		
	No. turbines	**Mean**	**Lower 95% CI**	**Upper 95% CI**	**Mean**	**Lower 95% CI**	**Upper 95% CI**	**Mean**	**Lower 95% CI**	**Upper 95% CI**
Per Turbine	10	4.69	1.25	14.31	0.37	0.07	1.20	2.27	0.88	3.92
Site Total	23	107.87	28.65	329.18	8.56	1.61	27.56	52.25	20.24	90.15

Bat Carcasses

We found 148 bat carcasses of 6 species and 1 carcass of an unknown species during searches from 19 April through 15 November 2008 (Table 4). We found carcasses of 46 hoary bats, 39 silver-haired bats, 27 eastern red bats, 17 eastern pipistrelles, 14 little brown bats, and 4 big brown bats during searches (Table 4). Hoary bats, silver-haired bats, and eastern red bats had the highest estimated kills, representing 75% of estimated fatalities (Figure 4). Eastern pipistrelles and little brown bats represented 11and 10% of the estimated fatalities, respectively (Figure 4).

Fatalities were found at all 10 turbines. Turbine 13 on the forested ridge and turbine 20 on the mined ridge had the highest total estimated fatalities of all turbines searched (Figure 5). The total number of bat carcasses (all species and decay conditions combined, unadjusted) found at all turbines during searches on each day of the study increased in late summer and early fall (beginning around the middle of July), and no bat carcasses were found after 24 October 2008 (Figure 6). Eighty-four percent of all bat carcasses were found between 15 July and 15 October.

Field Bias Trials. Seventy searcher efficiency trial carcasses were used to correct estimates of fatality in this study. All 30 carcasses in the ‘easy’ class that persisted >7 days were found by searchers, while 17 of the 24 carcasses in the ‘moderate’ class that persisted long enough to be observed were found (Table 5). Only 2 of 16 carcasses that persisted more than 2 weeks in the ‘difficult’ class were found. Because there was no variability in the estimated searcher efficiency for the easy class (all carcasses were found within 7 days,) the logistic regression model of the odds of detection given persistence was fit only to the moderate and difficult visibility classes and there was strong evidence of a difference in searcher efficiency between these two classes (χ^2 = 14.32, p = 0.0002).

Data from 114 carcasses used in scavenger removal trials were fit to an interval-censored parametric failure time model, and no statistically significant effect was found among visibility classes (χ^2 = 1.78, p = 0.41). Average persistence time was estimated to be 31.9 days (95% CI: 17.4, 57.7 days; Table 5).

Fatality Estimates. The estimated number of bat fatalities per turbine was 32.3 (95% CI: 20.76, 51.43), 1.11 (95% CI: 0.50, 2.26), and 18.91 (95% CI: 15.27, 22.88) for the MH, naïve, and modified estimators, respectively (Figure 5, Table 6). The average bat fatality estimate per turbine using the MH estimator was 1.7 times greater than that of the modified estimator and 29.1 times greater than estimates using the naïve estimator. Mean fatalities per turbine from the forested ridge portion of the project was 32.34 (n = 7, 95% CI: 22.39, 43.66), while mean fatalities per turbine from the strip mined ridge was 32.53 (n = 3, 95% CI: 24.53, 42.48), indicating no difference in fatalities between these two ridges and habitat conditions on the project site. The estimated number of fatalities for each species of bat per turbine and for the site, using the MH estimator, is presented in Table 7.

Table 4. Total number of bats found during scheduled searches by each species, sex and age class at the Casselman Wind Project, Somerset County, Pennsylvania, 19 April through 15 November 2008.

	Adult			Juvenile			
Species	**M**	**F**	**UNK**	**M**	**F**	**UNK**	**TOTAL**
Hoary bat	21	16	5	3	1	0	46
Silver-haired bat	21	11	3	3	1	0	39
Red bat	13	3	6	3	1	1	27
Eastern pipistrelle	9	3	4	1	0	0	17
Little brown bat	9	2	2	1	0	0	14
Big brown bat	1	1	1	0	1	0	4
Unidentified bat	0	0	1	0	0	0	3
Total	**74**	**36**	**22**	**11**	**4**	**1**	**148**

Table 5. Mean and 95% confidence intervals (CI) for searcher efficiency and carcass persistence for bats in each habitat visibility class from the Casselman Wind Project in Somerset County, Pennsylvania, 19 April to 15 November 2008. Difficult and very difficult classes (classes 3 and 4) were combined for the final analysis.

	Searcher Efficiency			Carcass Persistence		
Visibility Class	**Mean**	**Lower CI**	**Upper CI**	**Mean**	**Lower CI**	**Upper CI**
easy	1.00	1.00	1.00	31.9	17.4	57.7
moderate	0.71	0.50	0.85	31.9	17.4	57.7
difficult	0.13	0.03	0.39	31.9	17.4	57.7

Figure 4. Percent of estimated bat fatalities, adjusted for area and field biases (MH estimator), for each species at the Casselman Wind Project, Somerset County, Pennsylvania, 19 April to 15 November 2008. EPFU = big brown bat, LABO = eastern red bat, LACI = hoary bat, LANO = silver-haired bat, MYLU = little brown bat, PISU = eastern pipistrelle, UNKN = unknown species.

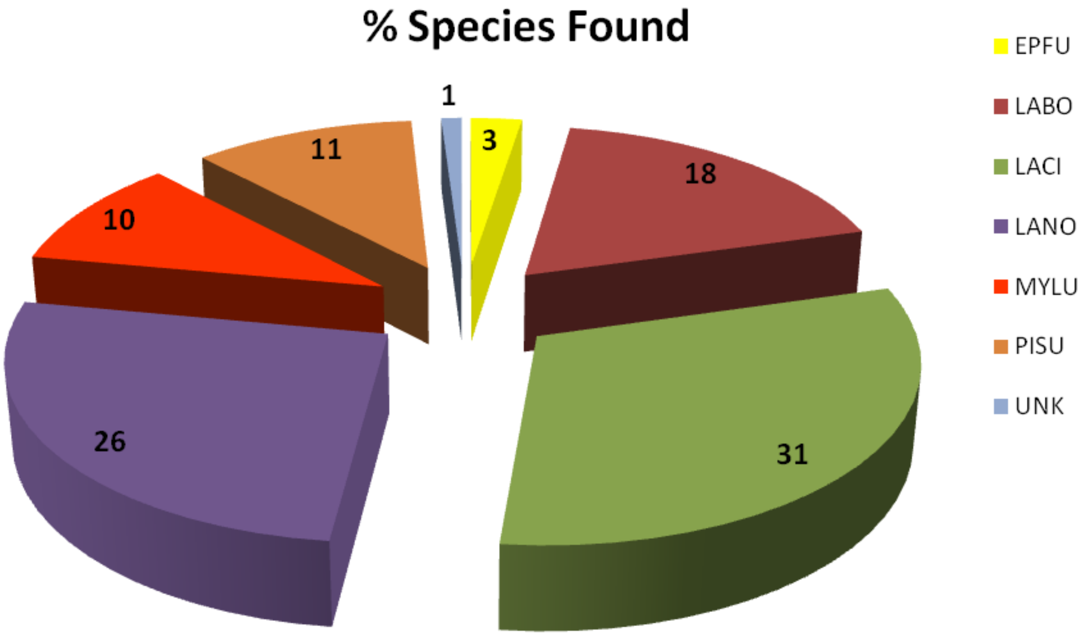


Figure 5. Mean number of bat carcasses estimated to have been killed, adjusted for area and field biases (MH estimator), and 95 % confidence intervals (CI) for all turbines (95% CI represented by dashed lines) and for each turbine during the study period at the Casselman Wind Project, Somerset County, Pennsylvania, 19 April to 15 November 2008.

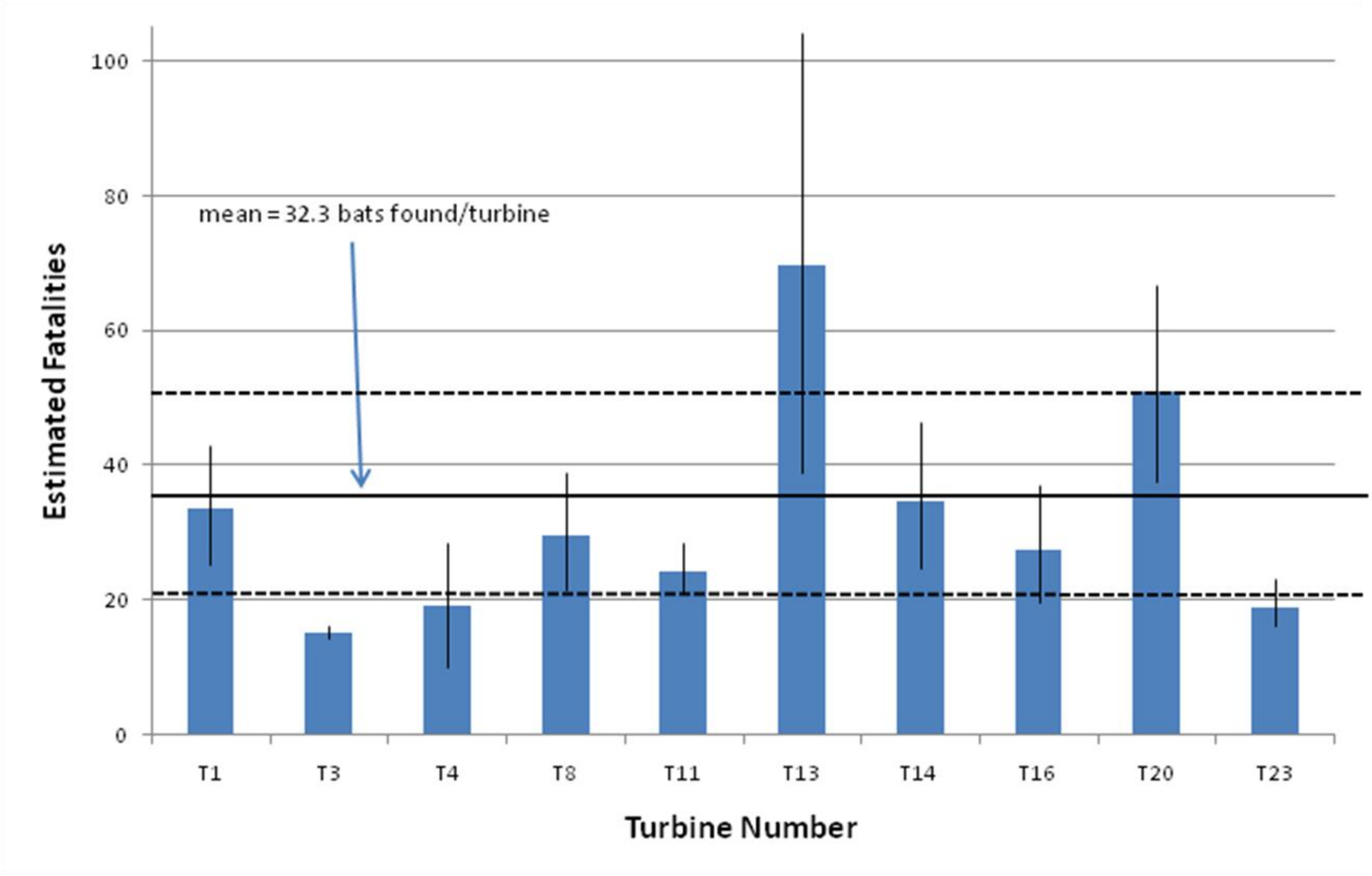


Figure 6. Total number of bat carcasses (all species and decay conditions combined; unadjusted) found at all turbines during daily searches at the Casselman Wind Project, Somerset County, Pennsylvania, 19 April to 15 November 2008.

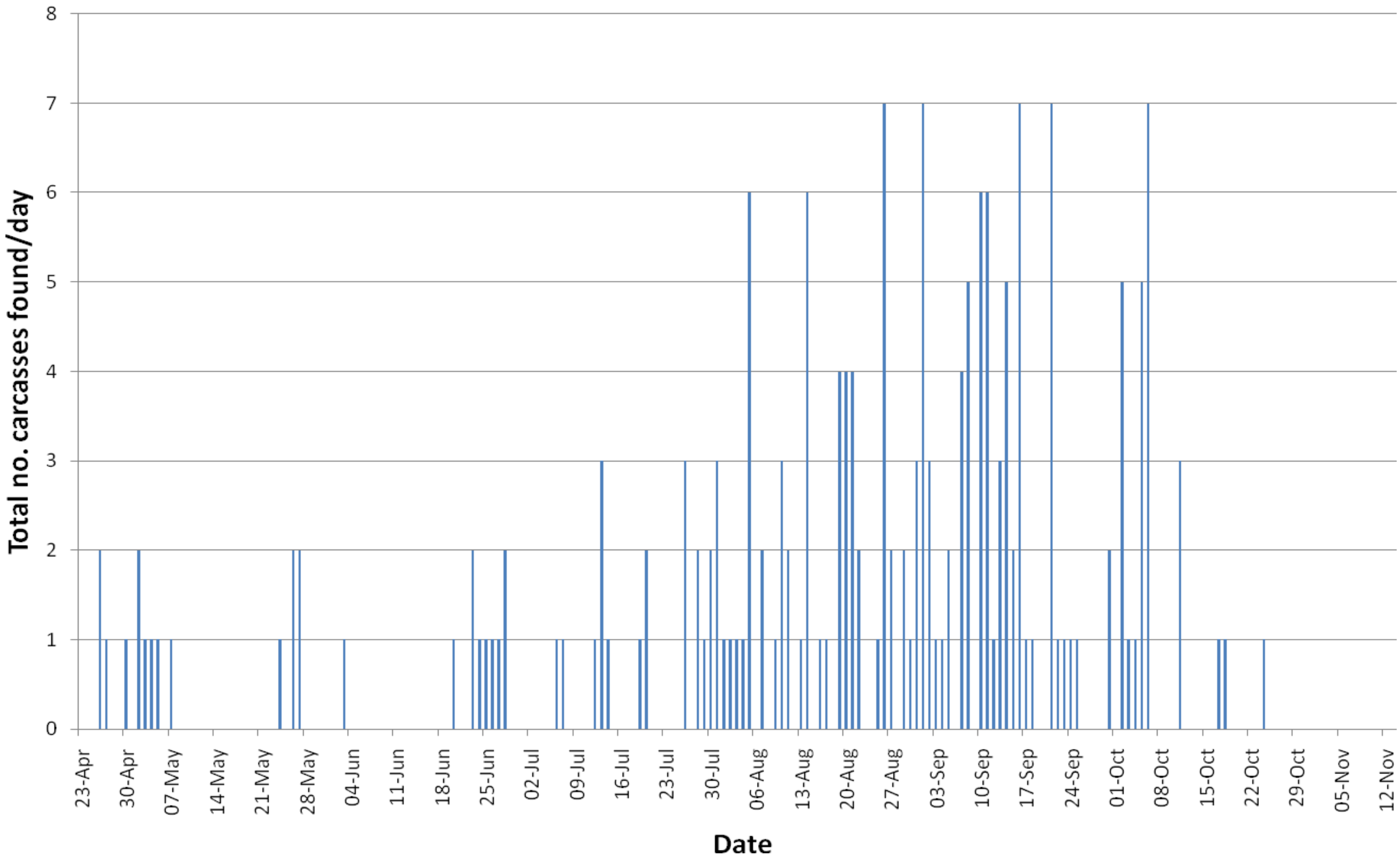


Table 6. Estimated bat fatalities (mean and 95% confidence intervals [CI]) per turbine and for the site total, adjusted for searcher efficiency, carcass removal, and area, for the Casselman Wind Project in Somerset County, Pennsylvania using three different estimators (MH estimator (M.Huso, Oregon State University, unpublished data [manuscript in press]); Naïve estimator (e.g., Johnson et al. 2003, Fiedler et al. 2007); and Modified estimator (from P. Shoenfeld, unpublished data, and Erickson et al. 2004; e.g., Kerns and Kerlinger 2004, Kerns et al. 2005; estimator currently required by PGC 2007).

		MH Estimator			**Naïve Estimator**			**Modified Estimator**		
	No. turbines	**Mean**	**Lower 95% CI**	**Upper 95% CI**	**Mean**	**Lower 95% CI**	**Upper 95% CI**	**Mean**	**Lower 95% CI**	**Upper 95% CI**
Per Turbine	10	32.3	20.76	51.43	1.11	0.50	2.26	18.91	15.27	22.88
Site Total	23	784.22	503.96	1,248.75	26.96	12.19	54.90	459.14	370.69	555.59

Table 7. Estimated bat fatalities (mean and 95% confidence intervals [CI]) for each species of bat per turbine and for the site total, adjusted for searcher efficiency, carcass removal, and area, based on the MH Estimator for the Casselman Wind Project in Somerset County, Pennsylvania, 19 April to 15 November 2008. EPFU = big brown bat, LABO = eastern red bat, LACI = hoary bat, LANO = silver-haired bat, MYLU = little brown bat, PISU = eastern pipistrelle, UNKN = unknown species. The species per turbine estimates are not likely reliable for either UNKN or EPFU due to the small number of turbines at which they were found; all other species were found at no fewer than 7 turbines, but results should still be interpreted with some caution.

		Per Turbine			**Site Total**		
Species	**N turbines**	**Mean**	**Lower 95% CI**	**Upper 95% CI**	**Mean**	**Lower 95% CI**	**Upper 95% CI**
EPFU	3	1.48	0.16	4.17	35.89	3.89	101.25
LABO	9	5.73	2.29	12.07	139.16	55.57	293.05
LACI	10	9.57	5.19	16.91	232.42	126.06	410.67
LANO	9	8.71	4.58	15.78	211.44	111.12	383.14
MYLU	8	3.11	1.33	6.38	75.59	32.33	154.82
PISU	7	2.60	1.03	4.50	63.03	24.96	109.34
UNKN	1	1.73	0.48	5.77	42.01	11.70	140.13

Fatalities in Relation to Weather and Turbine Operation. Of the hypothesized models, two were highly competing models and comprised more than 90% of the Akaike weight: the percent of the night in which wind speed was <5.0 m/s and percent of night in which the wind speed was <6.5 m/s (Table 8). For each 10% increase in these variables, fresh bat fatalities were estimated to increase by 6–21% (mean = 13%) and 6–28% (mean = 16%), respectively (Table 9). Although percent of the night in which the wind speed was <3.5 m/s was not a highly competitive model relative to the two best models, the estimates of change in fatality were comparable (2–15%, mean = 9%, Table 9). Although the effect of percent of night with low wind speeds is fairly strong, Nagelkerke's R^2 value was quite low for all models and never exceeded 4%, indicating that there remains a large amount of unexplained variation in the observed fatalities.

Table 8. Results of AIC model selection for single variable models of fresh killed bats and the previous night's weather and turbine rotations. K = number of estimated parameters, QAICc = small sample size corrected AIC based on Quasi-likelihood, delta = difference in QAICc units between the given model and the 'best' model, weight = Akaike weight for the model, R^2 = Nagelkerke's R^2. Wind percent (%) is the percent of the night when wind speed was either <3.5 m/s, <5.0 m/s, <6.5 m/s, or between 3.5 and 6.5 m/s. Percent (%) rotations is percent of the night when rotations per minute (RPM) was >11 (the RPM at cut-in speed for turbines we studied is 12).

Model	**k**	**LogLikelihood**	**QAICc**	**delta**	**weight**	**R^2**
Wind % <5.0 m/s	11	-228.863	480.022	0.000	0.669	0.037
Wind % <6.5 m/s	11	-229.876	482.047	2.026	0.243	0.031
Mean wind speed	11	-231.312	484.919	4.897	0.058	0.024
Wind % <3.5 m/s	11	-232.378	487.051	7.029	0.020	0.018
Mean total rotations	11	-233.965	490.225	10.204	0.004	0.009
Mean temperature	11	-234.595	491.486	11.464	0.002	0.006
Null	10	-235.665	491.574	11.552	0.002	0.000
% >11 RPM	11	-234.95	492.195	12.173	0.002	0.004
Wind % 3.5–6.5 m/s	11	-235.574	493.443	13.421	0.001	0.000

Table 9. Parameter estimates, standard errors and Wald 95% confidence intervals for model variables. Because the natural log is the canonical link function in a Poisson regression, the coefficient estimates were transformed for interpretation. For variables that represent the percent of the night (*) beta represents the proportional change in fatality for each increase of 10 percent in the explanatory variable. For mean wind speed, beta represents the proportional change in fatality for each 1 m/s increase in wind speed. For mean temperature, beta represents the proportional change in fatality for each increase of 1 degree centigrade in the mean temperature. For mean total rotations, beta represents the proportional change in fatality for each increase of 1,000 rotations during the night.

Parameter	**Estimate**	**StdErr**	**Lower Wald 95% CI**	**Upper Wald 95% CI**	**X_1^2**	**$P > X_1^2$**	**Beta**	**Lower 95% CI**	**Upper 95% CI**
*Wind % <5.0 m/s	0.0122	0.0034	0.0055	0.0188	12.84	0.0003	1.13	1.06	1.21
*Wind % <6.5 m/s	0.0152	0.0049	0.0056	0.0249	9.59	0.002	1.16	1.06	1.28
Mean wind speed	-0.1698	0.0589	-0.2852	-0.0545	8.33	0.0039	0.84	0.75	0.95
*Wind % <3.5 m/s	0.0082	0.0031	0.002	0.0143	6.72	0.0095	1.09	1.02	1.15
Mean total rotations	-0.0731	0.0399	-0.1512	0.005	3.36	0.0667	0.93	0.86	1.01
Mean temperature	-0.0408	0.0286	-0.0968	0.0152	2.04	0.153	0.96	0.91	1.02
*% >11 RPM	-0.0042	0.0036	-0.0113	0.0029	1.35	0.245	0.96	0.89	1.03
*Wind % 3.5–6.5 m/s	0.0009	0.0045	-0.0079	0.0097	0.04	0.8393	1.01	0.92	1.10

Figure 7. BCI field biologists Holly McCready and Mario Dasilva processing bat fatalities at the Casselman Wind Project in Somerset County, Pennsylvania (Photos by E. B. Arnett, Bat Conservation International).

DISCUSSION

Estimates of bat and bird fatalities are strongly conditioned on field biases, how those biases are quantified, and estimators used to calculate the estimates. The naïve estimator is known to be strongly biased low, with magnitude of bias dependent on average carcass persistence time. In this study, the naïve estimator produced an unrealistic estimate of total site fatality that was far less than the actual number of bat carcasses counted (naïve 95% CI: 12.2–54.9 when 151 actual carcasses were found). Because its bias depends on average carcass persistence times, estimated fatality using this estimator is not comparable across sites and this estimator should not be used in the future. The modified estimator also is known to produce biased fatality estimates under many circumstances; however its bias depends greatly on searcher efficiency as well as average carcass persistence time. In this study, estimates of bat fatality are biased low by about 40% using this estimator based on the field biases we quantified at the Casselman site. We included the modified estimator here to satisfy reporting requirements (PGC 2007), and our discussion in this report is based on interpretation of the MH estimates of fatality.

Our estimates of bird fatality generally reflect the pattern observed in the eastern U.S. (e.g., Erickson et al. 2002, Kerns and Kerlinger 2004, Jain et al. 2007). Our estimates must be viewed with caution as we had poor sample sizes to estimate parameters used to adjust carcass data to estimate actual fatality.

The most consistent theme regarding bat fatalities from wind facilities currently studied, including our study, is that fatalities are heavily skewed toward migratory bats and a dominance of *Lasiurus* species killed during mid-summer through fall in North America, coinciding with bats' southward migration patterns (Cryan 2003, Arnett et al. 2008, Baerwald 2008). Of 15 species of bats that were reported as fatalities at wind facilities in Europe (10 sites in Germany alone), most were migratory species such as 2 species of *Nyctalus* and *Pipistrellus nathussi* and most were killed in mid-summer and fall (Dürr and Bach 2004, Brinkmann 2006), a pattern that coincides with records of migrating bats striking other anthropogenic structures and their arrival at migration stopovers (Cryan and Brown 2007). Movement of migratory bats into new areas during late summer and early autumn may be partially the result of exploratory activity (Cryan 2003) and the temporal pattern of bat fatality could simply be related to increased bat activity prior to and during migration. Some migratory species may summer in areas where they are colliding with turbines as well. Higher fatalities during migration also could be related to reduced echolocation, but little is known about use of echolocation during migration and available evidence suggests that bats are somehow attracted to turbines and that fatality is not a random event (Horn et al. 2008).

Kunz et al. (2007) discussed several hypotheses as to why bats may be attracted to and killed by turbines. It is possible that migrating tree roosting species perceive turbines as possible roost trees and investigate them upon encounter (Arnett 2005, Kunz et al. 2007, Horn et al. 2008). Thermal images of bats attempting to land or actually landing on stationary blades and the turbine mast generally support the roost attraction hypothesis (Kunz et al. 2007), but the ultimate attraction to ridge top sites where turbines are located might be the availability of insect prey (Horn et al. 2008). Cryan and Brown (2007) presented evidence that migrating hoary bats rely on vision to navigate across landscapes and are drawn to visual stimuli during migration, although it is unknown how far bats may visually perceive such stimuli. Once in proximity, bats may misconstrue turbines as suitable day or night roosts or as perches to facilitate feeding, although *Lasiurus* species do not exhibit such feeding behavior and the perch tree attraction hypothesis conforms only to those species that utilize such a strategy. Alternatively, the initial attraction for migrating bats moving across a landscape might be the prominence of turbines and the possibility of a suitable roost worth investigating. Video images of bats chasing turbine blades rotating at slow speeds offer further insight to possible attraction and bats may investigate moving blades simply out of curiosity because movement is mistaken as evidence of prey, or because of attractive sounds (Horn et al. 2008). Also, audible sounds emitted from turbines may attract bats from considerable distances (Kunz et al. 2007).

Cryan (2008) hypothesized that mating behavior of *Lasiurus* species may influence bat fatalities at wind turbines. Cryan (2008) suggested that *Lasiurus* spp. use the tallest trees in a landscape as rendezvous points or possibly lekking sites during the mating period and they may mistake turbines for the tallest trees, thus increasing their risk of being killed by turbines. Baerwald (2008) suggested that if the mating behaviour hypothesis is correct, then we would expect similar timing of adult male and adult female migration, as measured by the timing of fatalities at wind turbines. However, Baerwald (2008) reported asynchronous migration of adult male and adult female *L. cinereus* in south-western Alberta and suggested that, at least in this region, mating behaviour was not likely associated with *L. cinereus* fatalities at wind turbines. However, Baerwald (2008) did report relatively concurrent timing of adult male and female *L. noctivagans* migration and suggested that courtship and mating behaviour may be associated with *L. noctivagans* fatalities. Clearly, this hypothesis warrants further investigation.

The estimated fatality rates we observed are consistent with those reported for other facilities in the eastern U.S. (ranging from 15 to 53 bats killed per installed MW over the study period of each effort, and averaging 21.5/MW in this study), which represent the highest bat kills reported throughout North America (Arnett et al. 2008). The number of bats killed at wind energy facilities likely depends on several factors and at different scales. At the facility-scale, configuration of the turbines (e.g., linear, nonlinear, single row, double row), orientation of a ridge where turbines might be located or simply the turbines themselves (e.g., N-S, E-W, NE-SW, etc.; e.g., Baerwald 2008), dominant ecotype (e.g., open prairie, deciduous forest, cropland), abundance of bats in the area, landscape configuration, and proximity to key features such as maternity roosts or hibernacula all could explain observed fatality rates. Other variables associated with fatality may depend on features of the individual turbine, such as the model of turbine used, its height (Barclay et al. 2007), and proximity of a turbine to habitat features (e.g., open water, forest edge), although few studies have demonstrated a consistent relationship for any of these variables (Arnett et al. 2008). Some empirical data exist that demonstrate a landscape-scale relationship between fatalities and proximity to geologic features like mountain ranges (Baerwald 2008). It has been suggested that habitat differences may influence bat fatality (e.g., forested versus non-forested sites; Arnett 2005). However, we did not find a difference in fatality rates between the forested and strip mined ridges during our study. Although we did not analyze data to determine relationships between bat kills and proximity of turbines to resources, such as water, obvious patterns were not apparent to us.

Past studies that quantified field biases often did so by using small birds as surrogates for bats, which may not provide a reliable assessment of scavenging (Arnett et al. 2008). Kerns et al. (2005) reported significantly lower scavenging rates on birds compared to both fresh and frozen bat carcasses at the Mountaineer Wind Energy Center in West Virginia. Additionally, poor sample sizes have plagued field bias estimates that likely bias the estimates of fatality (Arnett et al. 2008). Our study is unique in that we conducted the first bias trials for searcher efficiency and carcass removal simultaneously and allowed observers more than one day to find trial carcasses. This yielded dramatically different results than had we only used one-day trials that are typical of virtually every study of post-construction fatality conducted to date (Arnett et al. 2008). We calculated searcher efficiency based on just the first day of trials and determined that the efficiency of searchers in easy habitat was only 50% (compared to 100% when given multiple days to discover carcasses). Thus, had we used the traditional approach for estimating searcher efficiency, our estimates of bat fatalities essentially would have doubled. More investigation regarding approaches to quantifying field biases is warranted, but we believe our methodology more accurately reflects efforts needed to best estimate actual fatality rates at wind facilities when daily searches are employed. Of course our findings, and those of any study, are conditioned on removal rates of carcasses by scavengers and variation among habitats. We observed low scavenging rates at the Casselman facility during its first year of operation, a finding similar other sites in the region (e.g., Kerns et al. 2005). Differences in scavenging rates between the Mountaineer, West Virginia and Meyersdale, Pennsylvania sites studied by Kerns et al. (2005) suggest that scavenging must be determined on a site-specific basis and should not be assumed to be similar between sites even in close proximity and in similar habitat conditions between years. Thus, future post-construction studies should account for temporal patterns of scavenging among different visibility classes, and researchers should expect scavenging to change over time as scavengers become aware of and develop search images for novel sources of food beneath turbines (Arnett 2005).

We found that bat fatalities were related to nights when wind speeds generally were low (<6.5 m/s), which corroborates other studies (Fiedler 2004, Kerns et al. 2005, Fiedler et al. 2007). Our findings further support the contention that bat fatality may be predictable and that operational curtailment during low wind periods may substantially reduce bat fatality at wind facilities (Kunz et al. 2007, Arnett et al. 2008), at least in areas similar to the Casselman site. Although we did not quantify the relationship between passage of storm fronts and bat kills, our anecdotal observations suggest that kills were related to storms and lead us to believe this hypothesis is realistic and warrants further investigation. Autumn arrivals of hoary bats on Southeast Farallon Island are related to periods of low wind speed, dark phases of the moon, and low barometric pressure (Cryan and Brown 2007), supporting the view that migration events may be predictable. Low barometric pressure can coincide with passage of cold fronts that may be exploited by migrating birds and bats (Cryan and Brown 2007). The positive correlation in timing of fatalities between the Meyersdale, Pennsylvania and Mountaineer, West Virginia facilities support the hypothesis that fatalities may be related to broad landscape, and perhaps regional patterns, movements which may be influenced by weather and insect abundance (Kerns et al. 2005). Erickson and West (2002) reported that regional climate patterns as well as local weather conditions can predict activity of bats. On a local scale, strong winds can influence abundance and activity of insects, which in turn influences bat activity. Bats are known to suppress their activity during periods of rain, low temperatures, and strong winds (Erkert 1982, Erickson et al. 2002). Episodic hatches of insects that are likely associated with favorable weather and flight conditions may periodically increase local bat activity (Erickson and West 2002). More studies incorporating daily fatality searches are needed so that patterns such as those described above can be determined at multiple sites across regions. These data will be critical for developing robust predictive models of environmental conditions preceding fatality events and, thus, prescribing possible mitigation (e.g., curtailment of operations; Kunz et al. 2007, Arnett et al. 2008).

NEXT STEPS

We will initiate a second year of post-construction fatality searches beginning 1 April and continuing through 15 November 2009 at the Casselman facility. A final report on the 3-years of pre-construction acoustic data gathered at Casselman is in preparation and will be distributed in spring 2009. Also, we plan to correlate bat activity with fatality data for each turbine where these data were collected to determine if activity can predict turbine-scale fatality. That report will be prepared and distributed later in 2009.

LITERATURE CITED

Arnett, E. B., editor. 2005. Relationships between bats and wind turbines in Pennsylvania and West Virginia: an assessment of bat fatality search protocols, patterns of fatality, and behavioral interactions with wind turbines. A final report submitted to the Bats and Wind Energy Cooperative. Bat Conservation International, Austin, Texas, USA.

Arnett, E. B., J. P. Hayes, and M. M. P. Huso. 2006. Patterns of pre-construction bat activity at a proposed wind facility in south-central Pennsylvania. An annual report submitted to the Bats and Wind Energy Cooperative. Bat Conservation International. Austin, Texas, USA.

Arnett, E. B., K. Brown, W. P. Erickson, J. Fiedler, T. H. Henry, G. D. Johnson, J. Kerns, R. R. Kolford, C. P. Nicholson, T. O'Connell, M. Piorkowski, and R. Tankersley, Jr. 2008. Patterns of fatality of bats at wind energy facilities in North America. Journal of Wildlife Management 72: 61–78.

Baerwald, E. F. 2008. Variation in the activity and fatality of migratory bats at wind energy facilities in southern Alberta: causes and consequences. Thesis, University of Calgary, Calgary, Alberta, Canada.

Barclay, R. M. R., E. F. Bearwald, and J. C. Gruver. 2007. Variation in bat and bird fatalities at wind energy facilities: assessing the effects of rotor size and tower height. Canadian Journal of Zoology 85: 381–387.

Brinkman, R. 2006. Survey of possible operational impacts on bats by wind facilities in southern Germany. Report for Administrative District of Freiburg – Department 56, Conservation and Landscape Management. Ecological Consultancy, Gundelfingen, Germany.

Brown, R. G., and M. L. Brown. 1972. Woody Plants of Maryland. Port City Press, Baltimore, Maryland, USA.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach, second edition. Springer-Verlag, New York, New York, USA.

Cochran, W. G. 1977. Sampling techniques, 3rd edition. John Wiley & Sons, New York, New York, USA.

Cryan, P. M. 2003. Seasonal distribution of migratory tree bats (*Lasiurus* and *Lasionycteris*) in North America. Journal of Mammalogy 84:579–593.

Cryan, P. M. 2008. Mating behavior as a possible cause of bat fatalities at wind turbines. Journal of Wildlife Management 72: 845–849.

Cryan, P. M., and A. C. Brown. 2007. Migration of bats past a remote island offers clues toward the problem of bat fatalities at wind turbines. Biological Conservation 139: 1–11.

Dürr, T., and L. Bach. 2004. Bat deaths and wind turbines – a review of current knowledge, and of the information available in the database for Germany. Bremer Beiträge für Naturkunde und Naturschutz 7: 253–264.

Energy Information Administration (EIA). 2008. Annual energy outlook 2008 with projections to 2030. U.S. Department of Energy, Energy Information Administration, Washington, D.C., USA.

Eckert, H.G. 1982. Ecological aspects of bat activity rhythms. Pages 201–242 in T. H. Kunz, editor. Ecology of bats. Plenum Press, New York.

Erickson, J. L., and S. D. West. 2002. The influence of regional climate and nightly weather conditions on activity patterns of insectivorous bats. Acta Chiropterologica 4: 17–24.

Erickson, W. P., G. D. Johnson, D. Young, M. D. Strickland, R. Good, M. Bourassa, K. Bay, and K. Sernka. 2002. Synthesis and comparison of baseline avian and bat use, raptor nesting and mortality information from proposed and existing wind developments. Unpublished report prepared for Bonneville Power Administration, Portland, Oregon, USA.

Fiedler, J. K. 2004. Assessment of bat mortality and activity at Buffalo Mountain Windfarm, eastern Tennessee. Thesis, University of Tennessee, Knoxville, Tennessee, USA.

Fiedler, J. K., T. H. Henry, C. P. Nicholson, and R. D. Tankersley. 2007. Results of bat and bird mortality monitoring at the expanded Buffalo Mountain windfarm, 2005. Tennessee Valley Authority, Knoxville, USA

Gannon, W. L., R. E. Sherwin, and S. Haymond. 2003. On the importance of articulating assumptions when conducting acoustic studies of bats. Wildlife Society Bulletin 31: 45–61.

Hayes, J. P. 1997. Temporal variation in activity of bats and the design of echolocation-monitoring studies. Journal of Mammalogy 78: 514–524.

Hayes, J. P. 2000. Assumptions and practical considerations in the design and interpretation of echolocation-monitoring studies. Acta Chiropterologica 2: 225–236.

Horn, J., E. B. Arnett, and T. H. Kunz. 2008. Behavioral responses of bats to operating wind turbines. Journal of Wildlife Management 72: 123–132.

Hurlbert, S. H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54: 187–211.

Jain, A., P. Kerlinger, R. Curry, and L. Slobodnik. 2007. Annual report for the Maple Ridge wind power project post-construction bird and bat fatality study – 2006. Annual report prepared for PPM Energy and Horizon Energy, Curry and Kerlinger LLC, Cape May Point, New Jersey, USA.

Johnson, G. D., W. P. Erickson, M. D. Strickland, M. F. Shepherd, and S. A. Sarappo. 2003. Mortality of bats at a large-scale wind power development at Buffalo Ridge, Minnesota. American Midland Naturalist 150: 332–342.

Kerns, J., and P. Kerlinger. 2004. A study of bird and bat collision fatalities at the Mountaineer Wind Energy Center, Tucker County, West Virginia. Annual Report for 2003. Curry and Kerlinger, L. L. C., McLean, Virginia, USA.

Kerns, J, W. P. Erickson, and E. B. Arnett. 2005. Bat and bird fatality at wind energy facilities in Pennsylvania and West Virginia. Pages 24–95 *in* E. B. Arnett, editor. Relationships between bats and wind turbines in Pennsylvania and West Virginia: an assessment of bat fatality search protocols, patterns of fatality, and behavioral interactions with wind turbines. A final report submitted to the Bats and Wind Energy Cooperative. Bat Conservation International, Austin, Texas, USA.

Kunz, T. H., E. B. Arnett, W. P. Erickson, G. D. Johnson, R. P. Larkin, M. D. Strickland, R. W. Thresher, and M. D. Tuttle. 2007. Ecological impacts of wind energy development on bats: questions, hypotheses, and research needs. Frontiers in Ecology and the Environment: 5: 315–324.

Larkin, R. P. 2006. Migrating bats interacting with wind turbines: what birds can tell us. Bat Research News 47: 23–32.

Manly, B.F.J. 1997. Randomization and Monte Carlo Methods in Biology, 2nd edition. Chapman and Hall. New York, New York, USA.

O'Shea, T. J., M. A. Bogan, and L. E. Ellison. 2003. Monitoring trends in bat populations of the United States and territories: status of the science and recommendations for the future. Wildlife Society Bulletin 31: 16–29.

Pennsylvania Game Commission (PGC). 2007. Pennsylvania Game Commission wind energy voluntary agreement. Pennsylvania Game Commission, Harrisburg, Pennsylvania, USA

Racey, P. A., and A. C. Entwistle. 2003. Conservation ecology of bats. Pages 680–743 *in* T. H. Kunz and M. B. Fenton, editors. Bat Ecology. University of Chicago Press, Chicago, Illinois, USA.

Reynolds, D. S. 2006. Monitoring the potential impact of a wind development site on bats in the northeast. Journal of Wildlife Management: in press.

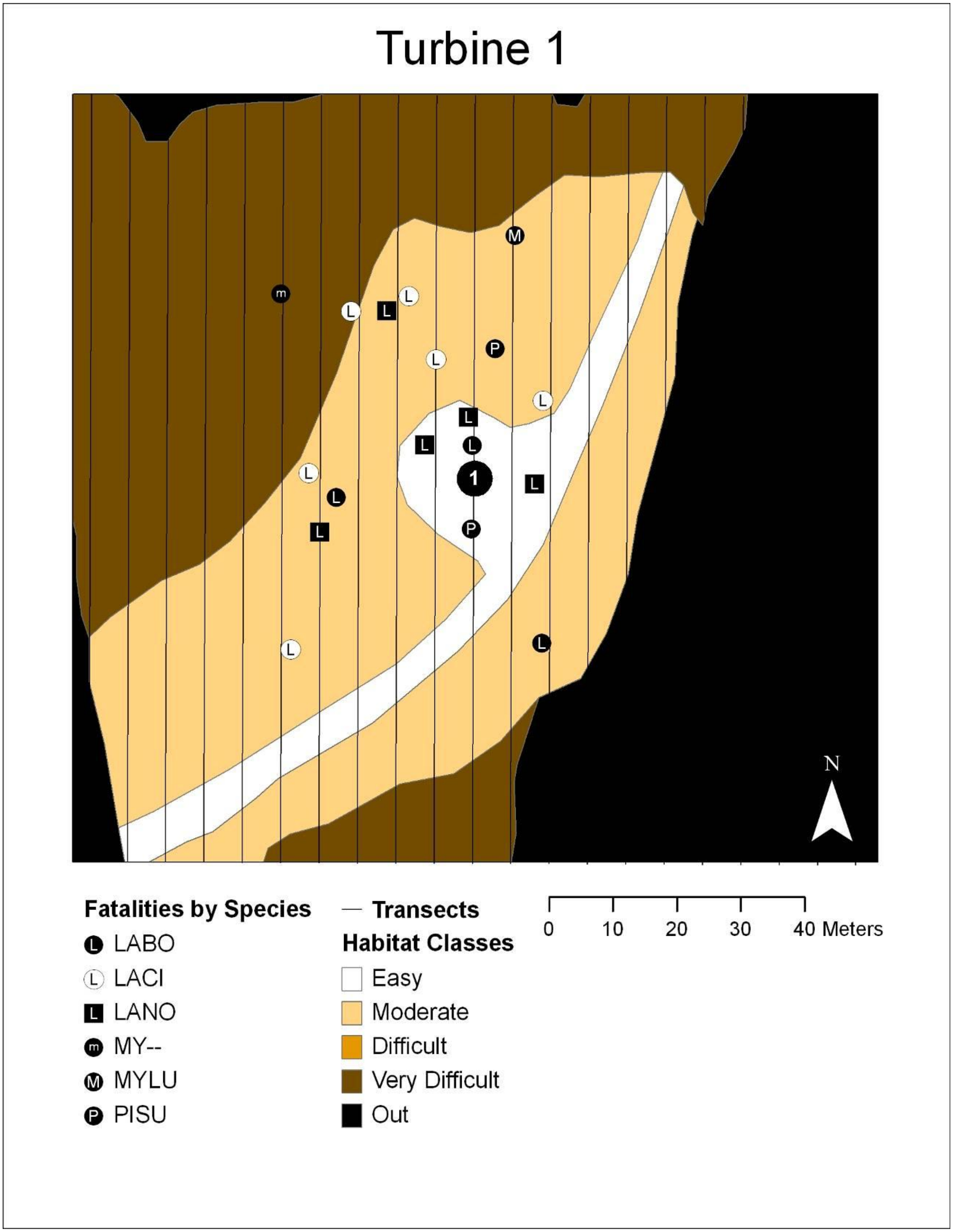
SAS Institute Inc. 2006. SAS/STAT User's Guide, Version 9.0. SAS Institute, Cary, North Carolina, USA.

Sherwin, R. E., W. L. Gannon, and S. Haymond. 2000. The efficacy of acoustic techniques to infer differential use of habitat by bats. Acta Chiropterlogica 2: 145–153.

Strausbaugh, P.D., and E. L. Core. 1978. Flora of West Virginia. Second edition. Seneca Books, Grantsville, West Virginia, USA.

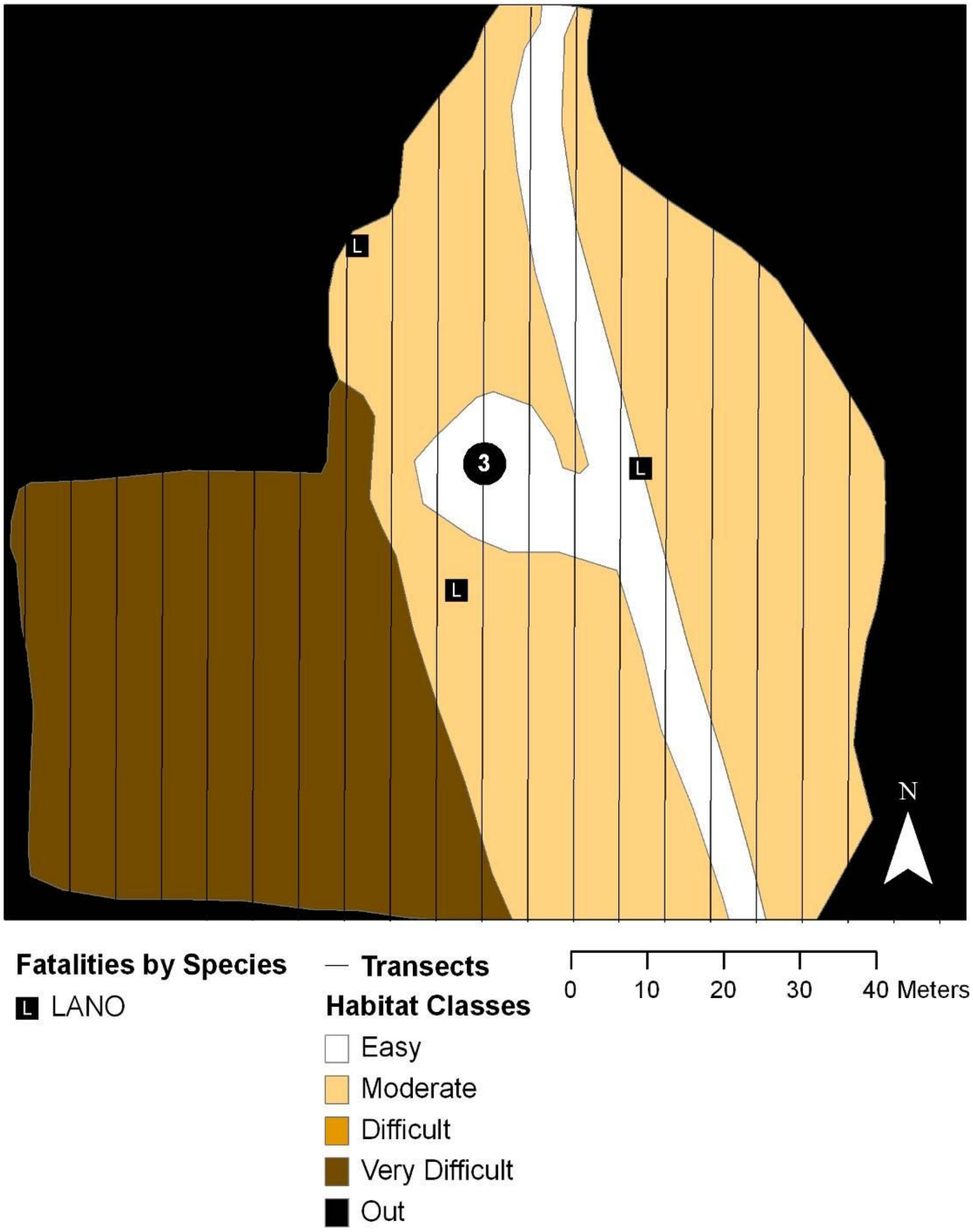
Winhold, L., and A. Kurta. 2006. Are red bats (*Lasiurus borealis*) declining in southern Michigan? Bat Research News 46: 229.

APPENDIX 1
(TURBINE MAPS)

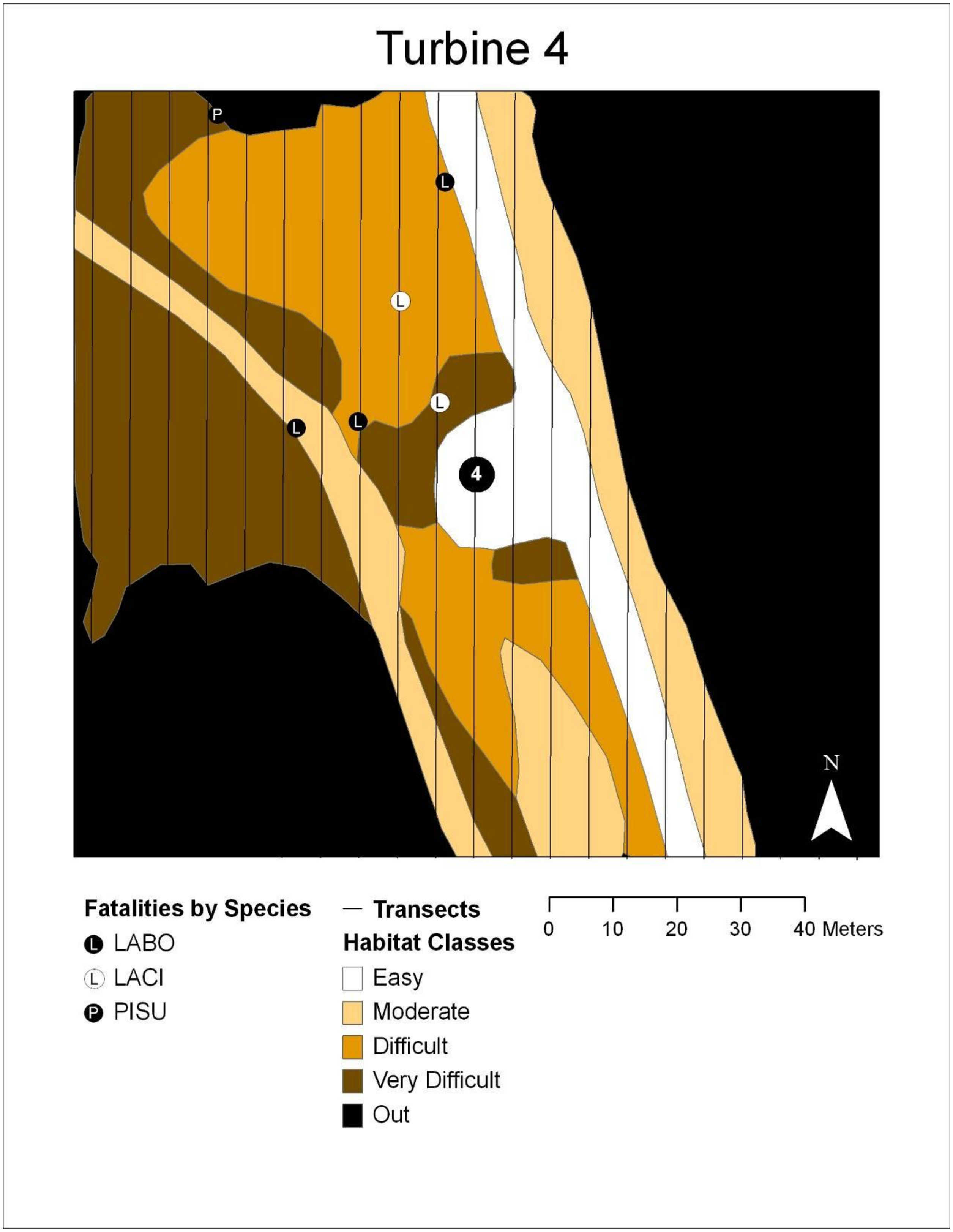

Turbine 1

1
L
M
m
P
N
Fatalities by Species
LABO
LACI
LANO
MY--
MYLU
PISU
Transects
Habitat Classes
Easy
Moderate
Difficult
Very Difficult
Out
0
10
20
30
40 Meters

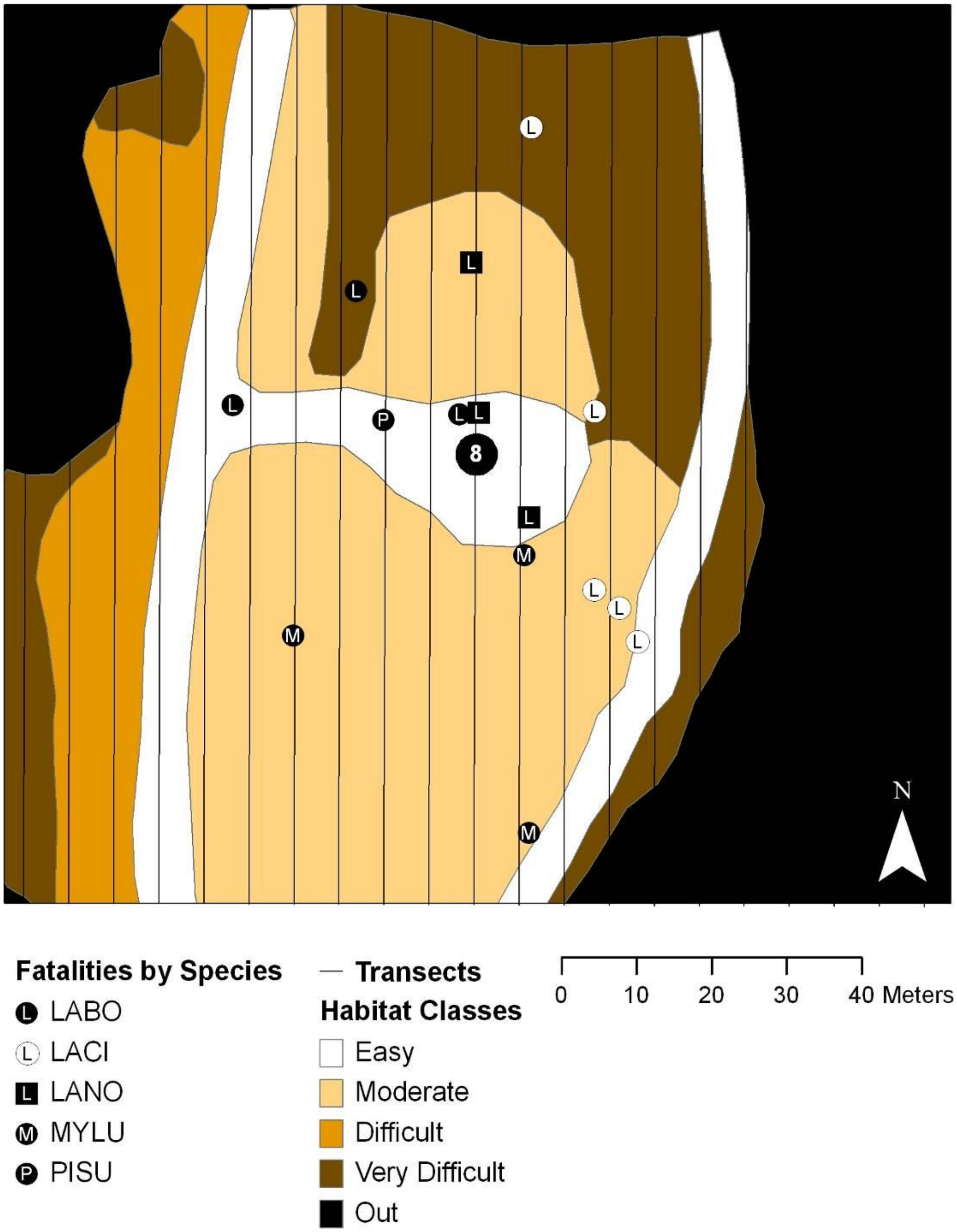
Turbine 3



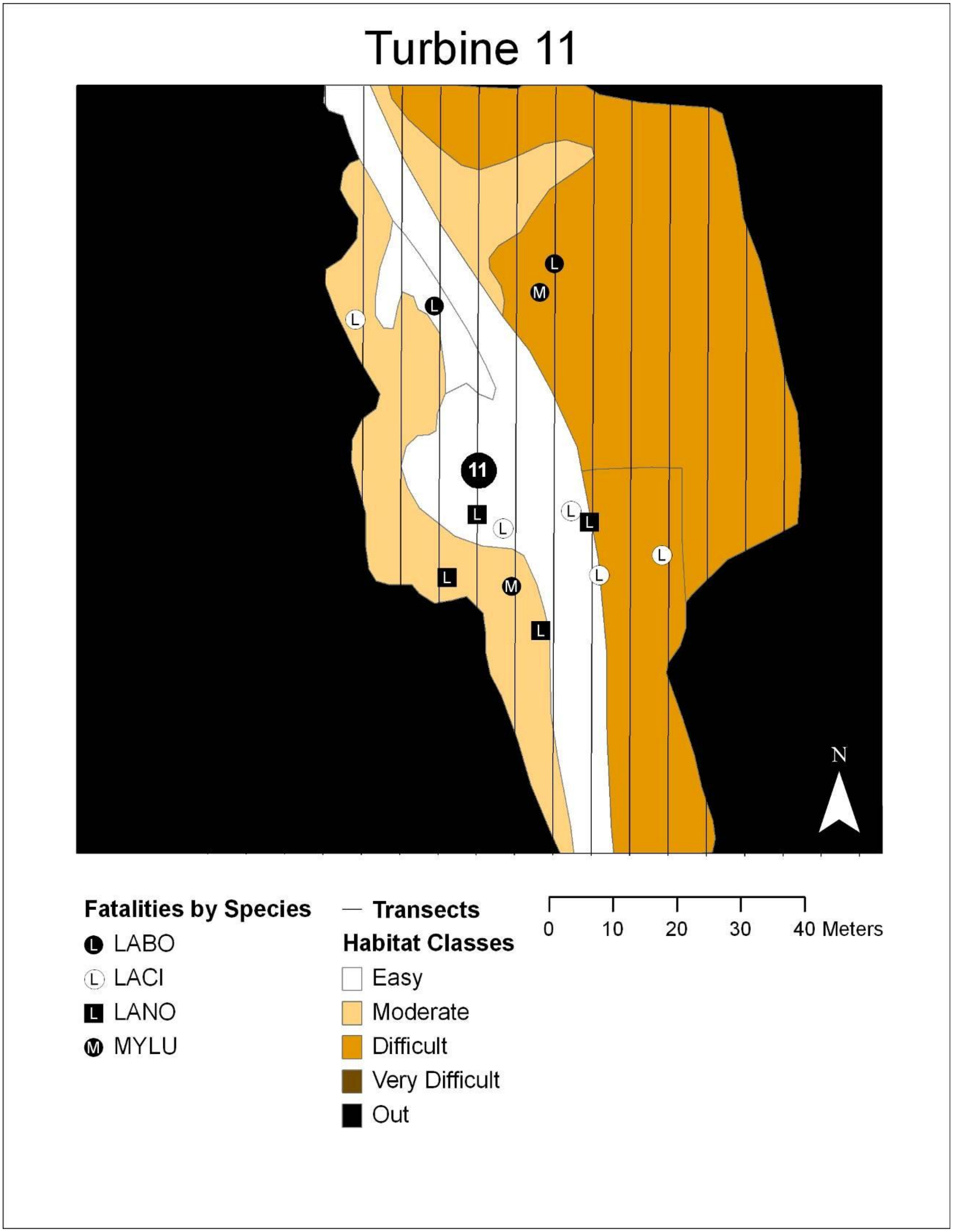
L
3
L
L
N
Fatalities by Species
L LANO
Transects
Habitat Classes
Easy
Moderate
Difficult
Very Difficult
Out
0
10
20
30
40 Meters

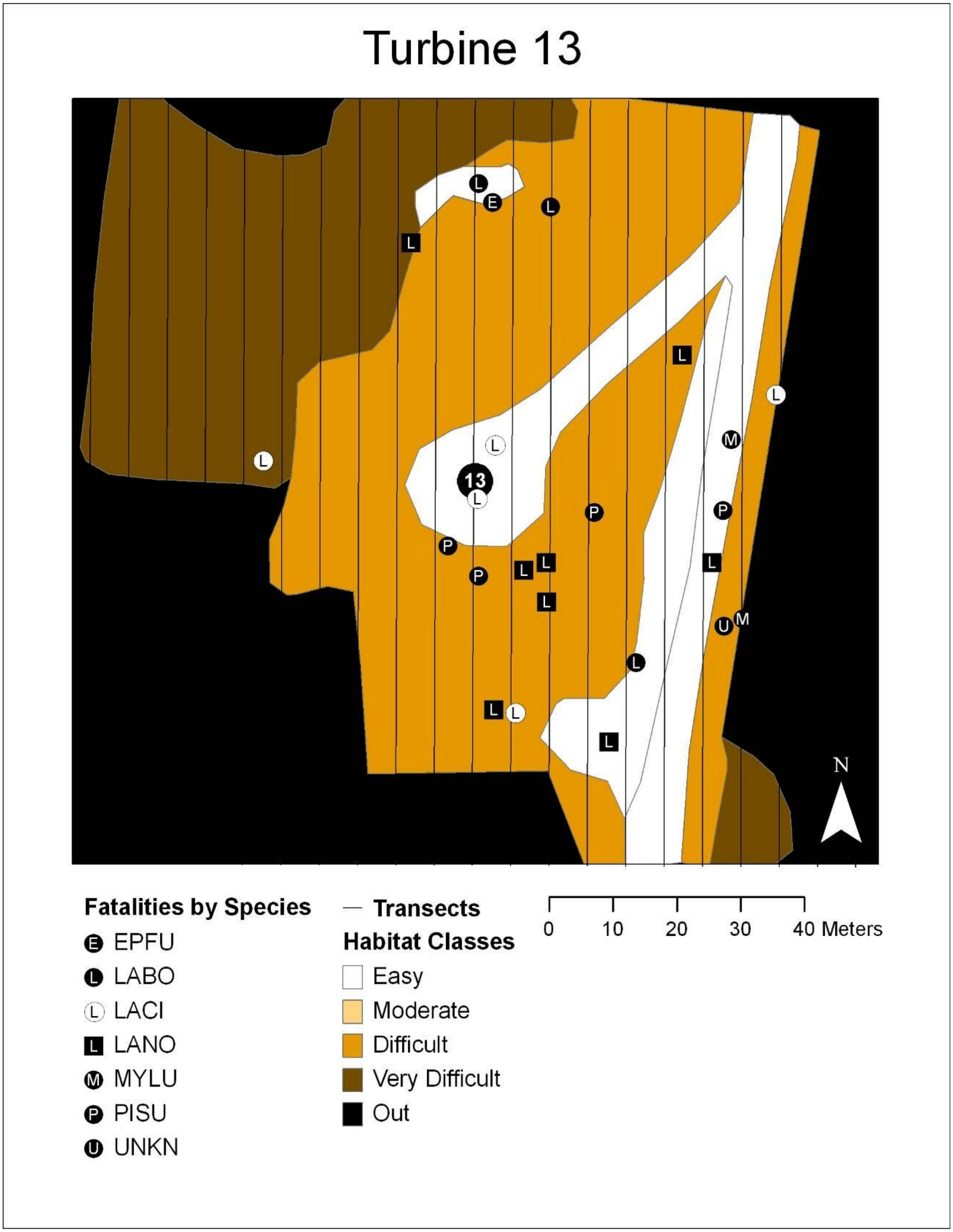

Turbine 4
P
L
L
L
L
L
4
N
Fatalities by Species
LABO
LACI
PISU
Transects
Habitat Classes
Easy
Moderate
Difficult
Very Difficult
Out
0
10
20
30
40 Meters

Turbine 8

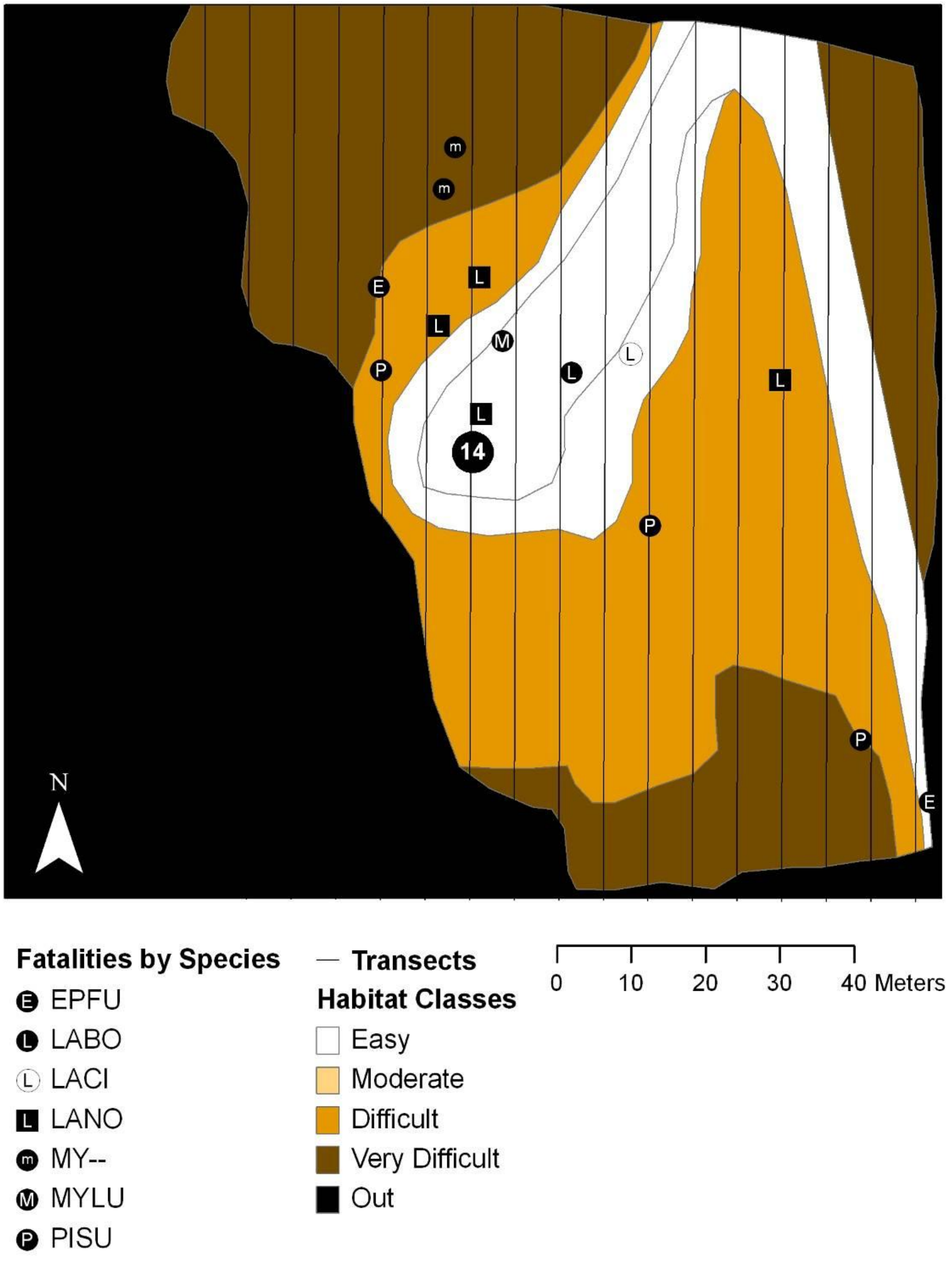


8
L
P
M
N
Fatalities by Species
LABO
LACI
LANO
MYLU
PISU
Transects
Habitat Classes
Easy
Moderate
Difficult
Very Difficult
Out
0
10
20
30
40 Meters

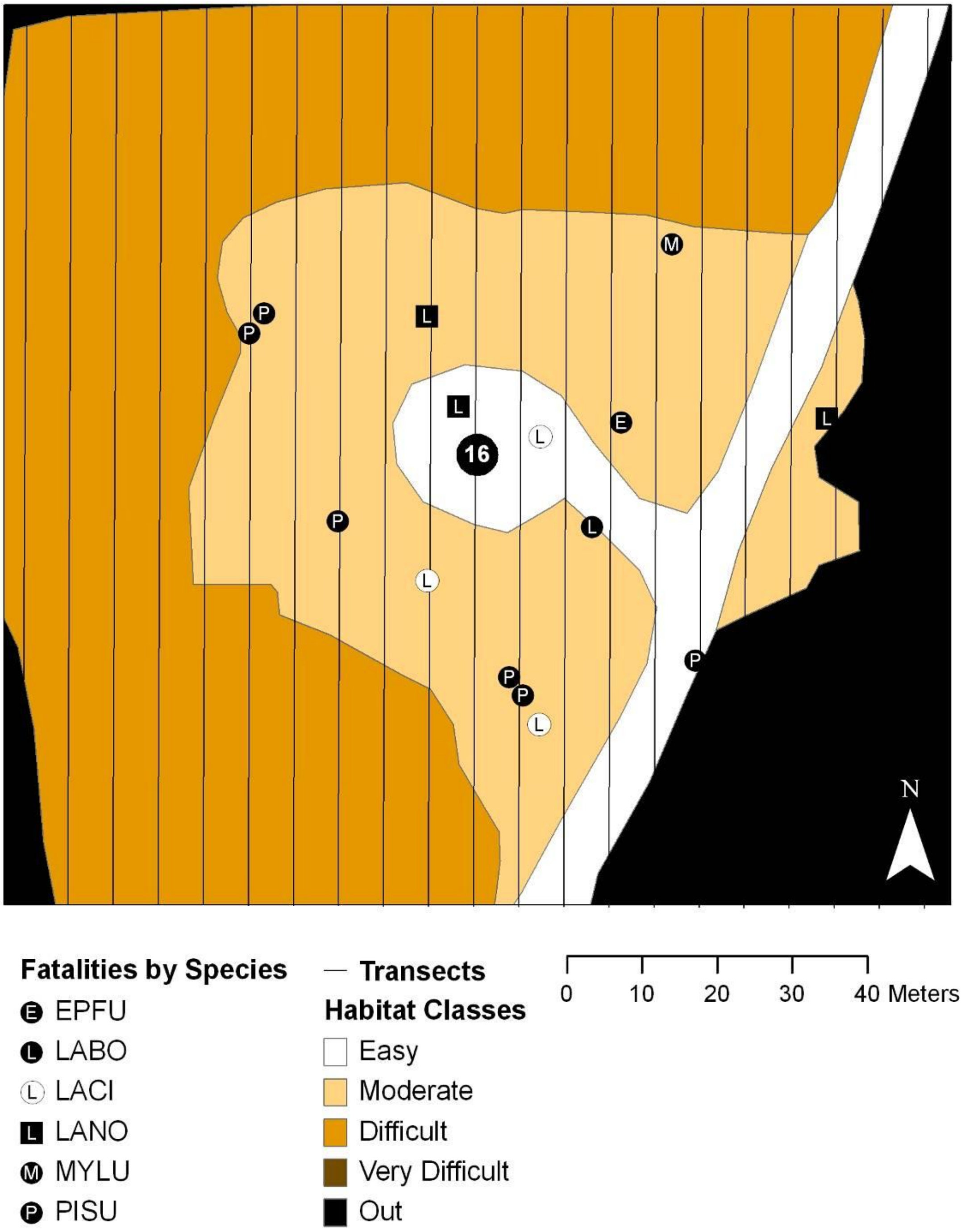

Turbine 11
11
L
M
N
Fatalities by Species
LABO
LACI
LANO
MYLU
Transects
Habitat Classes
Easy
Moderate
Difficult
Very Difficult
Out
0
10
20
30
40 Meters


Turbine 13
13
N
Fatalities by Species
E EPFU
L LABO
L LACI
L LANO
M MYLU
P PISU
U UNKN
Transects
Habitat Classes
Easy
Moderate
Difficult
Very Difficult
Out
0
10
20
30
40 Meters

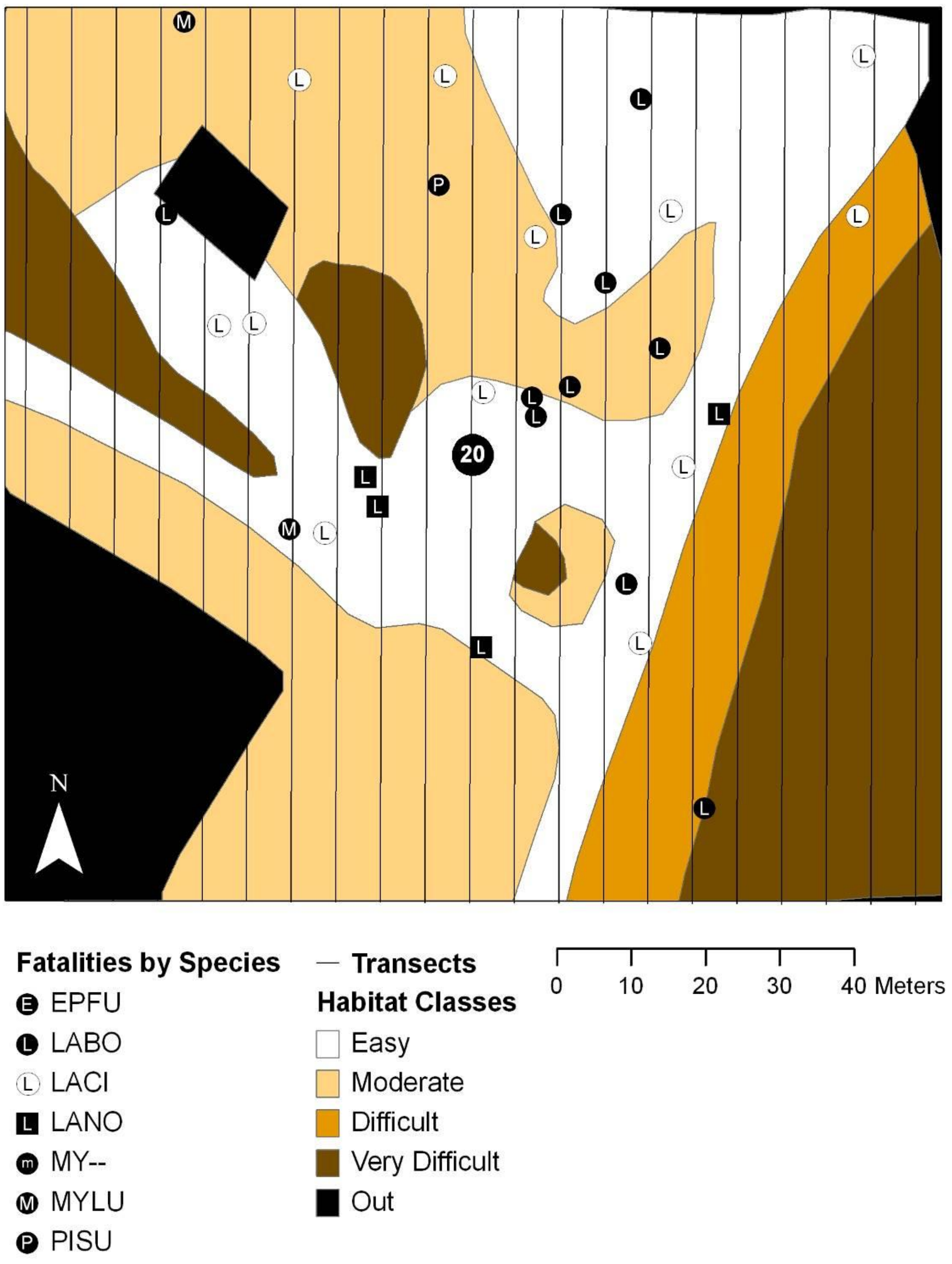
Turbine 14


m
m
E
L
L
M
L
L
P
L
L
14
P
P
E
N
Fatalities by Species
E EPFU
L LABO
L LACI
L LANO
m MY--
M MYLU
P PISU
— Transects
Habitat Classes
Easy
Moderate
Difficult
Very Difficult
Out
0
10
20
30
40 Meters

Turbine 16

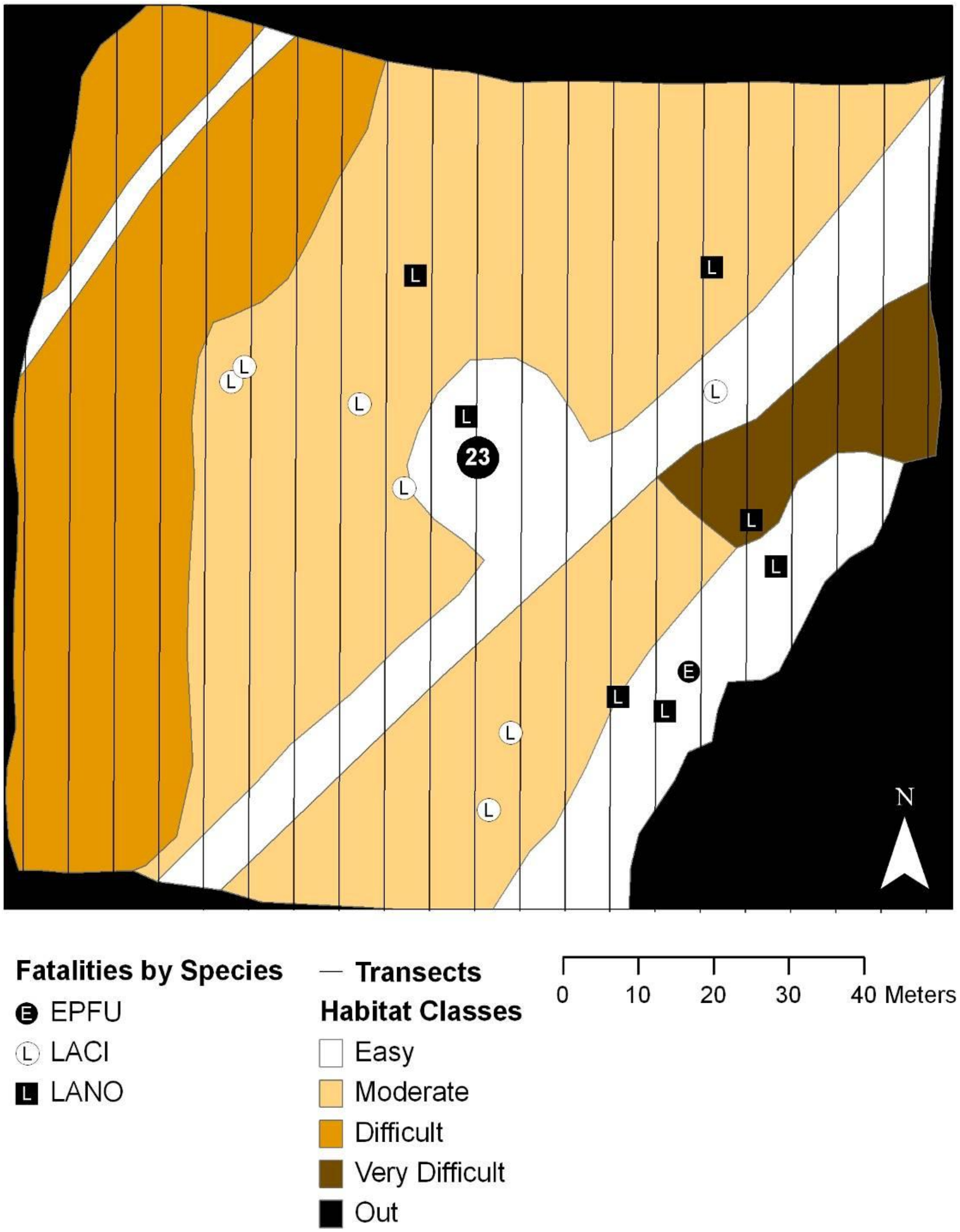

16
N
Fatalities by Species
E EPFU
L LABO
L LACI
L LANO
M MYLU
P PISU
Transects
Habitat Classes
Easy
Moderate
Difficult
Very Difficult
Out
0
10
20
30
40 Meters

Turbine 20



M
L
L
L
L
P
L
L
L
L
L
L
L
L
L
L
L
L
L
L
20
L
L
L
M
L
L
L
L
L
N
Fatalities by Species
E EPFU
L LABO
L LACI
L LANO
m MY--
M MYLU
P PISU
Transects
Habitat Classes
Easy
Moderate
Difficult
Very Difficult
Out
0
10
20
30
40 Meters

Turbine 23


23
L
E
N
Fatalities by Species
E EPFU
L LACI
L LANO
— Transects
Habitat Classes
Easy
Moderate
Difficult
Very Difficult
Out
0
10
20
30
40 Meters

APPENDIX 2
(INCIDENTAL CARCASSES)

Appendix 3-1. Number and species of birds found outside of scheduled searches or at turbines not searched (incidental fatalities) at the Casselman Wind Project, 19 April through 15 November 2008.

Species	**Total No.**
Ruby-throated hummingbird	1
Ruffed grouse	1
Unknown bird	3
Total	**5**

Appendix 3-2. Total number of bats found outside of scheduled searches or at turbines not searched (incidental fatalities) by each species, sex and age class at the Casselman Wind Project, Somerset County, Pennsylvania, 19 April through 15 November 2008.

	Adult			**Juvenile**			
Species	**M**	**F**	**UNK**	**M**	**F**	**UNK**	**TOTAL**
Hoary bat	5	0	2	2	1	0	10
Red bat	3	0	1	0	0	0	4
Little brown bat	1	0	0	1	0	0	2
Silver-haired bat	0	1	1	0	0	0	2
Total	**9**	**1**	**4**	**3**	**1**	**0**	**18**