Evaluating a Novel Approach to Optimize Operational Minimization to Reduce Bat Fatalities at the Pinnacle Wind Farm, Mineral County, West Virginia, 2015.

Final Report

Michael R. Schirmacher[1], Alex Prichard[2], Todd Mabee[2], and Cris D. Hein[1]

[1]Bat Conservation International, Austin, TX

[2]ABR, Inc.-Environmental Research and Services, Forest Grove, OR

April 2018

REPORT CITATION

Schirmacher, M. S., A. Prichard, T. Mabee, and C. D. Hein. 2018. Evaluating a Novel Approach to Optimize Operational Minimization to Reduce Bat Fatalities at the Pinnacle Wind Farm, Mineral County, West Virginia, 2015. An annual report submitted to NRG Energy and the Bats and Wind Energy Cooperative. Bat Conservation International. Austin, Texas, USA.

ACKNOWLEDGMENTS

This study was conducted under the auspices of the Bats and Wind Energy Cooperative (BWEC). We wish to thank John Anderson (American Wind Energy Association), Christy Johnson-Hughes (U.S. Fish and Wildlife Service), Bob Thresher and Karin Sinclair (National Renewable Energy Laboratory), Kathy Boydston (Association of Fish and Wildlife Agencies), Mylea Bayless (Bat Conservation International), Jocelyn Brown-Saracino (U.S. Department of Energy), and Mona Khalil (U.S. Geological Survey), who provided oversight for the BWEC for this project. We thank Paul Cryan, Taber Allison, Scott Darling, and Karin Sinclair for their thoughtful comments on the draft report.

We thank NRG Energy, in particular Mary Connor, Harth Clem, and James Adkins for their support on this project. We thank the U.S. Fish and Wildlife Service, the West Virginia Division of Natural Resources, the West Virginia Public Service Commission, and members of the Pinnacle Technical Advisory Committee for developing the study proposal. We thank Manuela Huso (U.S. Geological Survey) for her statistical insights for the analysis. We also thank Ryan Conley, Kyla Scherr, Katelyn Southall, and Danielle Spitzer for their dedication in the field, and collecting and managing data throughout the study.

EXECUTIVE SUMMARY

In accordance with the guidance of the West Virginia Public Service Commission (WVPSC) and with recommendations from the Pinnacle Technical Advisory Committee, which included members from the WVPSC, U.S. Fish and Wildlife Service (USFWS), West Virginia Division of Natural Resources (WVDNR), and NRG Energy, we initiated a study in July 2015 to test alternative wind turbine operational strategies to reduce bat fatalities at the Pinnacle Wind, LLC (PWF), Mineral County, West Virginia. Our primary objective was to test the effectiveness of a novel operational minimization strategy to reduce bat fatalities at Pinnacle Wind Farm, LLC (PWF). A secondary objective was to examine potential mechanisms that effect fatality risk to bats.

We randomly selected 15 of the 23 turbines at the PWF for the experiment to evaluate 3 operational minimization strategies. We used a completely randomized block design and treatments were randomly assigned to turbines each night of the experiment, with the night when treatments were applied as the experimental unit. We conducted daily fatality searches between 15 July and 30 September 2015, which represents the expected peak fatality period of bats for this region. The following treatments involved the decision framework to initiate turbine start-up and included:

Treatment A: increased the wind speed requirement to initiate turbine start-up from 3.0 m/s and fully feathered blades until wind speed reached 5.0 m/s based on a 10-minute rolling average as measured at a nearby meteorological (met) tower anemometer at 76 m above ground level (agl). Turbine blades were fully feathered until wind speeds reached 5 m/s. This treatment is currently the standard operating procedure at the PWF from 15 July–30 September,

Treatment B: increased the wind speed requirement to initiate turbine start-up from 3.0 m/s and fully feathered blades until wind speed reached 5.0 m/s based on a 20-minute rolling average measured at the same meteorological tower as Treatment A, and

Treatment C: increased the wind speed requirement to initiate turbine start-up from 3.0 m/s and fully feathered until wind speed reached 5.0 m/s based on a 20-minute rolling average as measured from anemometers on individual turbines at 80 m agl. To reduce the effects of the turbine blades on the wind speed measured downwind on the nacelle mounted anemometer, proprietary calculations were implemented to determine the "free-stream wind speed".

Decisions to shut-down operations, or curtail turbines, were all based on a 10-minute rolling average of wind speed <5.0 m/s as measured at the met tower for Treatments A and B and the individual turbine for Treatment C. Thus, the shutdown/start-up decision framework for Treatment A was symmetrical (10-minute average to shut-down and start-up), whereas Treatments B and C were asymmetrical (10-minute average to shut-down, 20-minute average to start-up), but with wind speed measurements based on the met tower for Treatment A and B and the individual turbine Treatment C.

During standardized searches, we found 57 fresh bat carcasses, representing 5 different species, including 31 eastern red bats (*Lasiurus borealis*), 11 hoary bats (*Lasiurus cinereus*), 10 big brown bats (*Eptesicus fuscus*), 4 silver-haired bats (*Lasionycteris noctivagans*), and 1 tri-colored bat (*Perimyotis subflavus*). No *Myotis* species were found. We found 17 bat fatalities associated with

Treatment A, 12 under Treatment B, and 23 under Treatment C. We removed 5 carcasses prior to analysis because they were associated with nights that experienced treatment implementation error.

We used two methods, Poisson regression and estimated fatality, to evaluate the 3 operational minimization strategies based on fresh bat fatalities. These two methods generally supported each other, although estimated fatality, corrected for detection bias, was the only one that showed a significant difference and only between Treatments B and C. The best Poisson Regression model explaining the number of bat fatalities found under turbines only included turbine differences, but the models with mean hours on and treatment were within 1 Deviance Information Criterion (DIC) unit. In general, Treatment C had higher bat fatalities, significantly higher than Treatment B, and turbines in that treatment were operational for significantly longer periods compared to Treatments A and B. The turbine anemometer had an average 1.03 m/s higher wind speed value compared to the met tower, which likely caused turbines under Treatment C to start-up earlier and shut-down later increasing the operating time. Operating time was not significant and therefore was not solely determined to be the reason for higher bat fatalities based on our Poisson regression models.

As a secondary objective, we examined potential mechanisms that influenced fatality only on nights when turbines were operating regardless of treatment. The best logistic regression mixed model of bat fatalities found per hour the turbine was spinning included number of stops. However, stops/starts and starts were within one AIC unit. This suggested that bats may be at risk during operational transitions (i.e. during turbine start-up or shut-down), specifically the probability of finding a fatality increased significantly with an increasing number of stops. Alternatively, since all treatments were based on a wind speed of 5 m/s it is difficult to separate risk to bats when turbine operations were in transition compared to risk at relatively low wind speeds (e.g. ~ 5 m/s), which might influence changes in turbine operation.

The results of this study suggest that fewer bat fatalities occurred when turbine operations were based on the meteorological tower (Treatment A and B) rather than the individual turbine (Treatment C). This is likely associated with the amount of time turbines were in operation each night, which was longer for Treatment C, although our models suggested other factors may also influence fatality. Furthermore, extending the decision time, from 10 minutes (Treatment A) to 20 minutes (Treatment B), to begin operating turbines when wind speeds exceed the cut-in speed, also may reduce fatalities by reducing the number of transitions (i.e., turbine start-ups and shut-downs). Minimizing the number of start-ups/shut-downs may assist in reducing wear-and-tear on turbines and, at least in this study, may also reduce the power loss related to this reduction strategy. Thus, Treatment B represents a decision framework with fewer fatalities, significantly fewer than Treatment C, and compared to Treatment A had less wear-and-tear on turbines (i.e. start-up and shut-downs) with no additional loss in power, and may be the most cost effective option of the 3 treatments studied in this experiment.

The relationship between turbine transitions and bat fatalities is unclear and additional research is needed at other wind energy facilities to better understand bat/wind turbine interactions during start-ups and shut-downs. Until more data are gathered, implementing strategies that limit operational transition of turbines at low wind speeds, such as extending the average decision time period (e.g., from 10 to 20 minutes) to inform turbine operation, may further reduce bat fatalities at the same cut-in speed. Moreover, limiting the number of times turbines start-up and shut-down may reduce turbine wear-and-tear and power loss, which provide benefits for wind facility operators. Future research across a variety of facilities, turbine types and species should consider comparing differences between a longer decision framework and higher cut-in speeds or combine different decision frameworks with additional weather variables to assess the most cost-effective strategy to reduce bat fatalities at wind turbines.

INTRODUCTION

The U.S. is a world leader in wind energy generation, recently surpassing 74,000 Megawatts (MW) in late 2015 (AWEA 2015a). Currently, West Virginia ranks 22nd in the U.S. for installed capacity at 583 MW (AWEA 2015b). Wind-generated electricity is renewable, generates few emissions of greenhouse gases and other pollutants, displaces energy generated from carbon-based fuels, and consumes no water (National Research Council 2007, Ledec et al. 2011, Union of Concerned Scientists 2011), and it can result in direct and indirect impacts to bats and other wildlife (Arnett and Baerwald 2013). Specifically, there are concerns regarding potential cumulative negative impacts of wind energy development on bat populations, particularly when many species of bats are known or suspected to be in decline from natural (e.g., white-nose syndrome [WNS]) and other human-induced stressors (Pierson 1998, Racey and Entwistle 2003, Winhold et al. 2008, Jones et al. 2009, Frick et al. 2010). Because bats provide numerous ecosystem services (e.g., insect suppression), adverse impacts of wind development on local bat populations could disrupt the ecological health and stability of a region (Kunz et al. 2011).

The period of highest risk for bat fatalities at wind energy facilities tends to occur during relatively low-wind conditions during late summer through early fall, when bats are mating and migrating (Arnett et al. 2008, Rydell et al. 2010), although this is likely dependent on latitude. Previous studies indicate that bats suppress their activity during certain weather conditions (e.g., periods of rain, low temperatures, and strong winds (Erickson and West 2002, Reynolds 2006, Horn et al. 2008, Weller and Baldwin 2012) and appear to be less vulnerable to turbines under these conditions. Thus, altering turbine operations when bats are most at risk was proposed as a possible means of reducing impacts to bats by Kunz et al. (2007) and Arnett et al. (2008). Raising turbine cut-in speeds (i.e., the wind speed at which the generator is connected to the grid and producing electricity) from the manufactured speed (usually 3.0–4.0 m/s for modern turbines) by 2.0–3.0 m/s during periods of high risk for bats has been shown to significantly reduce bat fatalities compared to fully operating turbines (Arnett et al. 2013).

Results from studies in Canada (Baerwald et al. 2009), Pennsylvania (Arnett et al. 2011), West Virginia (Young et al. 2011, 2012), and Indiana (Good et al. 2011, 2012) indicate that raising the turbine cut-in speed and feathering turbine blades, i.e., adjusting the angle of the rotor blade parallel to the wind, or turning the whole unit out of the wind to slow or stop blade rotation resulted in significant reductions (approximately 45–93%) in bat fatalities. However, altering turbine operations, even on a limited-term basis may pose operational and financial difficulties for wind energy facilities. Further research that evaluates the efficacy of operational minimization to reduce bat fatalities and its inherent economic and operational implications is warranted.

OBJECTIVES

In accordance with the guidance of the West Virginia Public Service Commission (WVPSC) and with recommendations from the Technical Advisory Committee, which included members from the WVPSC, U.S. Fish and Wildlife Service (USFWS), West Virginia Division of Natural Resources (WVDNR), and NRG, formerly Edison Mission Energy, we initiated a study in July 2015 to test the effectiveness of a novel operational minimization strategy to reduce bat fatalities at Pinnacle Wind Farm, LLC (PWF). Specifically, we used wind speed data collected from the meteorological tower versus individual wind turbines to inform curtailment decisions. We also used 2 decision times (10-minute versus 20-minute wind speed average) to inform start-up. A secondary objective was to examine potential mechanisms that effect fatality risk to bats.

STUDY AREA

The PWF is located near the town of Keyser in Mineral County, West Virginia. The PWF is situated along a 3.5-mile stretch of privately owned land, along a wooded ridge-top on Green Mountain. The PWF lies within the Appalachian mixed mesophytic forests ecoregion composed of moist broadleaf forests that cover the plateaus and rolling hills west of the Appalachian Mountains (Brown and Brown 1972, Strausbaugh and Core 1978). The elevation of the project area varies from 766 to 869 m above mean sea level. The PFW consists of 23 Mitsubishi 2.4-MW turbines, with 95 m rotor diameter and 80 m hub height for a total height of approximately 128 m (from base of tower to highest point of the blade), and a manufacturer's cut-in speed of 3 m/s (Fig. 1). Turbines at the PWF are fully "feathered" below the manufacturer's cut-in speed. In this position, there is no aerodynamic lift from the blades and thus no rotor rotation. When wind speeds reach 3.0 m/s the blades are normally pitched to generate lift and the rotor begins rotating. However, as standard operation procedure at the PFW, all turbines are feathered up to 5.0 m/s based on a 10-minute rolling average of values measured at a meteorological tower from 15 July–30 September.

METHODS

Turbine Operations. We randomly selected 15 of the 23 turbines at the PWF for the experiment. The experiment used a completely randomized block design to evaluate 3 operational treatments. Each night treatments were re-randomized and implemented among these turbines from sunset to sunrise. The following treatments involved the decision framework for start-up operations and included:

Treatment A: increased the wind speed requirement to initiate turbine start-up from 3.0 m/s and fully feathered blades until wind speed reached 5.0 m/s based on a 10-minute rolling average as measured at a nearby meteorological (met) tower anemometer at 76 m above ground level (agl). Turbine blades were fully feathered until wind speeds reached 5 m/s. This treatment is currently the standard operating procedure at the PWF from 15 July–30 September,

Treatment B: increased the wind speed requirement to initiate turbine start-up from 3.0 m/s and fully feathered blades until wind speed reached 5.0 m/s based on a 20-minute rolling average measured at the same meteorological tower as Treatment A, and

Treatment C: increased the wind speed requirement to initiate turbine start-up from 3.0 m/s and fully feathered until wind speed reached 5.0 m/s based on a 20-minute rolling average as measured from nacelle anemometers on each individual turbines at 80 m agl. To reduce the effects of the turbine blades on the wind speed measured downwind on the nacelle mounted anemometer, proprietary calculations were implemented to determine the "free-stream wind speed".

Decisions to shut-down operations, or curtail turbines, were all based on a 10-minute rolling average of wind speed <5.0 m/s as measured at the met tower for Treatments A and B and the individual turbine for Treatment C. Thus, the shutdown/start-up decision framework for Treatment

A was symmetrical (10-minute average to shut-down and start-up), whereas Treatments B and C were asymmetrical (10-minute average to shut-down, 20-minute average to start-up), but with wind speed measurements based on the met tower for Treatment A and B and the individual turbine Treatment C.

We designed the treatment schedule such that treatments were randomly assigned each night and each turbine received each treatment an equal number of nights. Every 15 nights each turbine received each of the 3 treatments on 5 nights. The 75-day experiment allowed for 5 replicates, one every 15 days (herein referred to as periods 1–5). The decision framework for turbines was based on 10- or 20-minute average wind speed data collected at the permanent meteorological tower or individual turbines. Thus, turbines could still operate below 5.0 m/s until the conditions for the decision framework were met. Furthermore, turbines were able to switch between feathering and operating normally several times per night depending on variations in wind speed.

Delineation of Carcass Search Plots and Habitat Mapping. We initiated an operational minimization study following protocols outlined in the Technical Advisory Committee proposal. We conducted daily searches at all 15 turbines (Turbines 1, 2, 4, 5, 7, 9, 11, 13, 14, 15, 16, 19, 21, 22, and 23) from 15 July–30 September 2015 (treatments were in effect between 14 July and 29 September 2015). We attempted to delineate a rectangular plot 125 m east-west by 120 m north-south (15,120 m^2 total area) centered on each turbine sampled; this area represents the maximum possible search area for this study (see Fig. 2 for an example). We set transects 5 m apart within each plot and observers searched 2.5 m on each side of the transect line. We considered contiguous forest cover and areas unsafe to search as unsearchable habitat (e.g. steep terrain) and eliminated them from our search plots. Because the area cleared of forest varied by search plot, actual searchable area differed among turbines. We used a Trimble GeoXT (Trimble Navigation Limited, Sunnyvale, CA) global positioning system (GPS) to map the actual area searched and the visibility classes within each plot at each turbine (Appendix 1). The density weighted proportion (DWP) searched was used to standardize results and adjust fatality estimates (see below).

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; modified from Pennsylvania Game Commission [PGC] 2007).

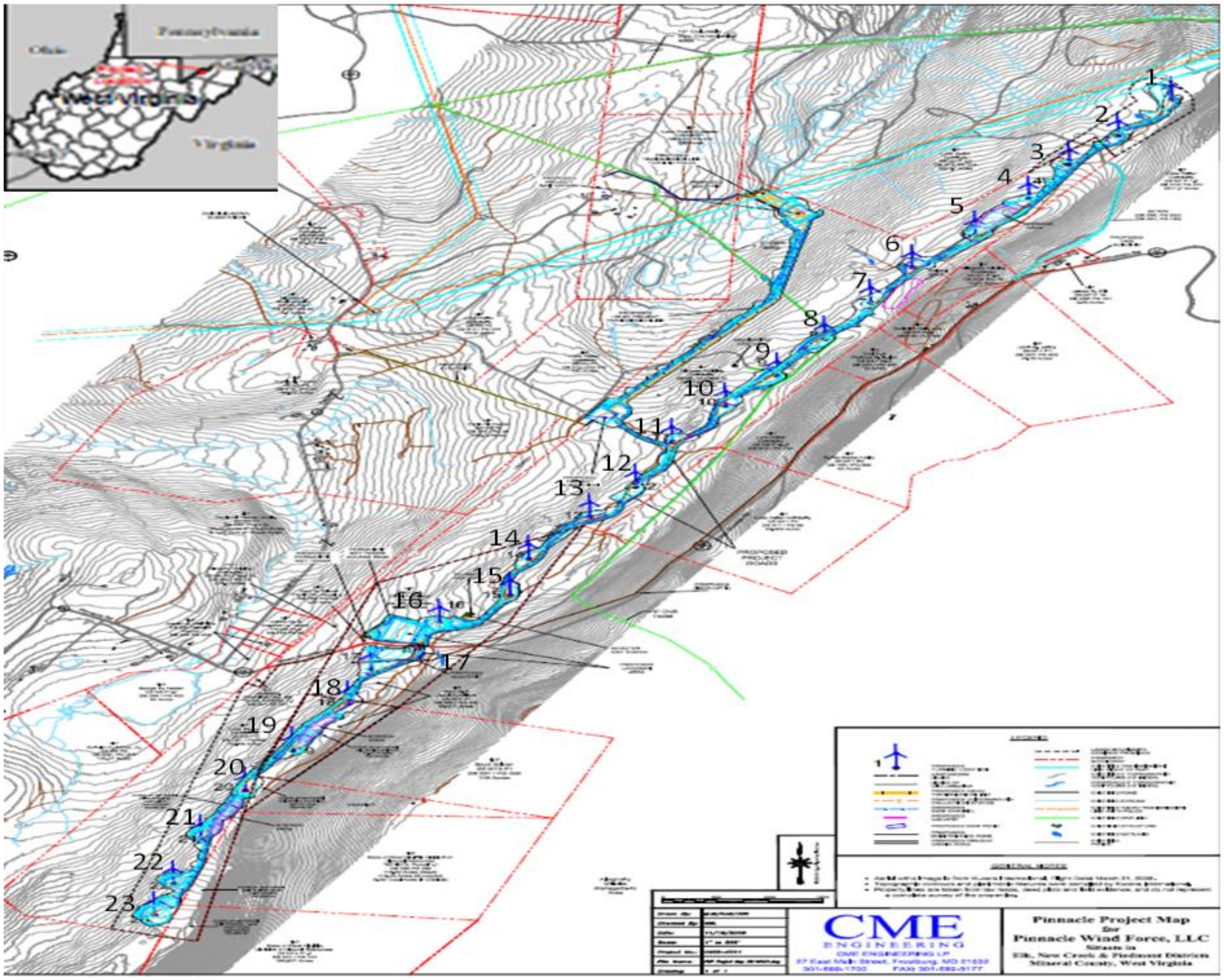


Figure 1. Location of all 23 turbines at the Pinnacle Wind Farm near Keyser, Mineral County, West Virginia. Meteorological tower was located 220 m southwest of Turbine 16. We conducted daily searches at 15 turbines (Turbines 1, 2, 4, 5, 7, 9, 11, 13, 14, 15, 16, 19, 21, 22, and 23) from 15 July–30 September 2015.

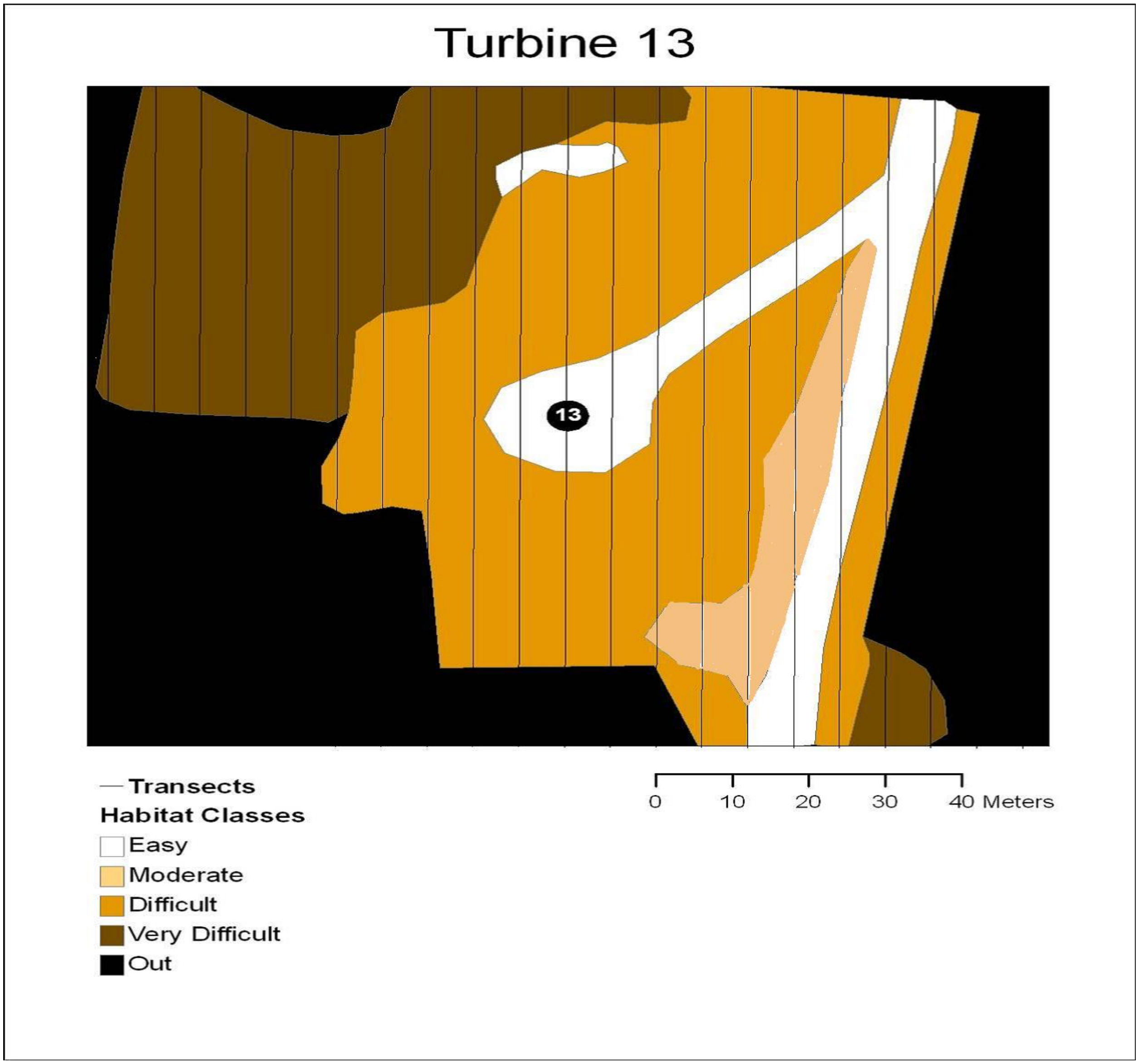


Figure 2. Example carcass search plot at a wind turbine depicting the maximum plot size of 125 m east-west and 120 m north-south, 5 m wide transect lines (searched 2.5 m on each side), unsearchable area (black), and area encompassed by easy (white), moderate (light tan), difficult (dark tan), and very difficult (brown) visibility habitat.

Table 1. Habitat visibility classification scheme (following PGC 2007).

% 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)

Fatality Searches. We conducted a "clean-out" search of each plot on 14 July to remove any fatalities that may have occurred prior to 15 July. Each day, we systematically selected the order of turbine searches to ensure turbines were searched at different times across the study. In most cases field technicians did not search the same turbines on consecutive days, and the direction in which transects were walked changed daily. Searches commenced within 15 minutes of sunrise. We recorded date, start time, end time, turbine number, weather, and observer for each search. When a bat or bird carcass was found, the searcher placed a small rock pile one meter from the carcass, noted the time, contacted the crew leader, and continued the search. In most cases the crew leader, but on rare events the searcher, 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., fresh [i.e., died the previous night], 2–3 days) based on condition of the carcass (e.g., eyes, smell, insects, and insect load, etc.). We visually examined the wings of each bat carcasses for obvious signs of WNS using the Reichard scoring index (Reichard and Kunz 2009). We used rubber gloves to handle all carcasses to reduce possible human scent bias for carcasses later used in scavenger removal trials. We placed each carcass in a labeled plastic bag and stored them in a secured and dedicated freezer at the Operations and Maintenance office building. We obtained a USFWS Special Purpose Utility Permit for Migratory Bird Mortality Monitoring (MB74673A-0) and a Scientific Collecting Permit (No. 2015.257) from the WVDNR to handle bird and bat carcasses.

We used similar methods to monitor fatality at 10 turbines between (2 June–14 July 2015) and (1–15 October 2015) at the PWF (see Appendix 2).

Field Bias Trials. We quantified carcass persistence and searcher efficiency at all 15 sample turbines to adjust the estimate of total bat and bird fatalities. We conducted bias trials throughout the entire study period and at all sampled turbines, and searchers were never aware which turbines were used or the number of carcasses placed beneath those turbines during trials. Due to high removal rate on the site, most carcasses were placed the day of a search to maximize the chance carcasses would be present during a scheduled search, therefore in most cases we used frozen carcasses but when possible we used fresh (i.e. last night unfrozen carcasses). We used a list of random turbine numbers, and random azimuths and distances (m) from turbines for placement of each carcass used in bias trials. We also used carcasses of fatalities if found by non-search personnel, who left the carcass in place, until found during a scheduled search. Incidental carcasses were those found on non-searched turbines, found outside the plot of searched turbines, or those observed by non-search personnel that were not found later during a standardized search.

Data recorded for each trial carcass prior to placement included date and time of placement, species, turbine number, distance and azimuth from turbine, and visibility class surrounding the carcass. We attempted to distribute trial carcasses equally among the different visibility classes throughout the study period. We attempted to avoid "over-seeding" by limiting the number of carcasses on any one turbine during the same period of time. Each trial carcass was left in place and checked by the crew leader, who was not involved with daily searches. Thus, trial carcasses were available to be found by searchers on consecutive searches during daily searches unless removed by a scavenger. We recorded the day and time that each carcass was found by a searcher, and the time when the carcass was marked with a rock pile and left for the scavenger removal trial. If, however, a carcass was removed by a scavenger before detection by a searcher (i.e., carcass not present before search was conducted) it was removed from the searcher efficiency trial and used only in the carcass persistence data set. Carcasses were left in place until removed or at the end of the twenty-day trial. Carcass condition was recorded daily up to 20 days, as present and observable (1) or missing or no longer observable (0).

Density of carcasses and proportion of area surveyed. The actual area surveyed within a plot varied among turbines and from the delineated theoretical maximum search plot (i.e. 125m by 120m). Density of carcasses is known to diminish with increasing distance from the turbine because carcasses are more likely to fall nearer the turbine and increasing area further from the turbine causes carcasses to be more spread out over a greater area and distance (Huso and Dalthorp 2014). A simple adjustment to fatalities based on area surveyed would likely lead to over-estimates, because unsearched areas tend to be farthest from turbines. The size and configuration of the area searched can greatly affect the proportion of actual fatalities represented in the searched area. To accurately estimate the fraction of carcasses landing in the sampled areas, we used the observed distribution of bat carcasses relative to distance from the turbines to estimate the distance-weighted proportion searched (DWP) a measure of the probability that a carcass will be in the searchable area around a turbine. We calculated the total area in each visibility category (Easy, Moderate, Difficult [Very Difficult was included as Difficult], or Not Searchable) within each 2m band from the base of each turbine (Arnett et al. 2009). We also calculated the number of bat fatalities that were found in each 2 m distance band and visibility category combination. We then used Poisson Regression to model the number of bats that were found by distance from turbine and visibility category (excluding Not Searchable). Distance was treated as a continuous independent variable and visibility category was treated as a categorical independent variable. We compared models with distance as a linear and quadratic term with AIC_c model (Burnham and Anderson 2002). We used the natural logarithm of the area in each visibility category (Easy, Moderate, or Difficult) as an offset term to account for differing search areas.

With this data set, the carcass densities were highest in the Moderate visibility category (possibly because of high scavenger removal in the easy category). The best model was used to predict the number of fatalities that would have been found in the entire search area if the entire area was in the Moderate visibility category (e.g. number of carcasses found if the probability of detecting carcasses was high over the entire area). The number of fatalities predicted to fall in the searchable area divided by the total number predicted to fall in the entire plot was used as our estimates of the bat DWPs for each turbine in subsequent analyses.

Carcass Persistence. Estimates of the probability that a carcass was not removed in the interval between searches were used to adjust carcass counts for removal bias. Removal was defined as a carcass not present within the searchable plot (e.g., removed by scavenging, wind or water) or within the 20-day trial period. The length of time a carcass remains on the study area before it is removed was modeled as an exponential, Weibull, loglogistic or lognormal distributed random variable. We fit carcass persistence time data to each of these failure time models with and without visibility class as a covariate and used AIC_c model selection to determine the best model (Burnham and Anderson 2002). There were adequate sample sizes to compare 3 levels of carcass visibility (easy, moderate, and difficult) for bats. Therefore, we compared 8 models for carcass persistence (intercept only and visibility for 4 distributions [Weibull, exponential, loglogistic, and lognormal]). We used 5000 bootstrap simulations to calculate confidence intervals.

Searcher Efficiency. 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). Since there are limitations in determining the time of death accurately and for every carcass, it is assumed that "observability" of a carcass is constant over the period of the search interval, although it likely is not (Warren Hicks et al. 2012). In this study, searches were conducted daily and carcass persistence times were short, providing limited opportunity for a searcher to detect a carcass that was missed on a previous search. After accounting for carcasses removed before a searcher had the chance of observing them, data from bat searcher efficiency trials were fit separately to a logistic regression model using the Fatality Estimator software developed by Huso et al. (2012). We modeled searcher efficiency for bats that included visibility class as a covariate and assessed model fit using AIC_c (Burnham and Anderson 2002). There were adequate sample sizes to compare 3 levels of carcass visibility (easy, moderate, and difficult) for bats. Hence, for bats we compared 2 models for searcher efficiency (intercept only, visibility). We used 5000 bootstrap simulations to calculate confidence intervals.

Turbine operation and weather. Turbine operation and weather data were provided by NRG Energy. Time curtailed (hours), expected power loss (MWh) during curtailment, and turbine fault information were available for each turbine and were recorded in real time. Wind speed (m/s) and turbine rotations per minute (RPM) were available in 10-minute averages at approximately 80 m hub height agl for each individual turbine. Wind speed and temperature (°C) were available in 10-minute averages from the only meteorological tower on site, located 220 meters southwest of Turbine 16, at 76 m above ground level (agl) and 78 m agl, respectively. Using Pearson Correlation, we compared the wind speed measurements recorded at the met tower to each of the 15 turbines surveyed, which ranged in correlation from $r = 0.98$ at Turbine 16 to $r = 0.89$ at Turbine 9, although with the exception of Turbine 9 the correlation seemed to be a function of distance from the met tower. Given that Turbine 16 was nearer to the met tower and had the highest correlation of all turbines, we used it to examine differences in wind speed measurements between turbine and met tower anemometer as the "best-case scenario". Proper implementation of treatments were assessed for Treatment A and B by examining wind speed at the meteorological tower versus RPM of the turbine, whereas Treatment C was assessed by examining wind speed and RPM from individual turbines. Turbine start-up was determined by manually counting the number of times per night the turbines' RPM were at or below 2 and increased to greater than 2 in two consecutive 10-minute periods, whereas the reverses (i.e., RPMs above 2 and decreased below 2 in two consecutive 10-minute periods) was counted for turbine shut-down. One of the differences between shut-down and start-up metrics was that counts of turbine shut-down were likely to be higher than start-up due to the initial implementation of the treatments at sunset. Temperature change was calculated by subtracting the maximum from the minimum temperature in a night (i.e., civil sunset to civil sunrise). To determine turbine downtime not associated with curtailment (i.e. turbines feathered below turbine cut-in speed of 3 m/s), we took the difference of total time curtailed per night and 10-minute time blocks when RPM was less than 1.

Statistical Methods. We used two methods to test for a treatment effect. Our first method used Fatality Estimator software (Huso et al. 2012) to estimate the total number of bat fatalities occurring for each treatment during the study period after adjusting for the various sources of potential biases associated with fatality studies (i.e., searcher efficiency, carcass persistence, and unsearchable area). This method accounts for these biases but does not currently allow continuous covariates to be included in the model (Huso et al. 2012). For this method, only fresh carcasses were included in the analysis. Carcasses that were missed during the first search after the fatality occurred were accounted for in the estimate with the searcher efficiency adjustment and, therefore, were not added in again. The Huso fatality method assumes that we correctly accounted for detection bias and that we could accurately determine the night a fatality occurred and therefore the associated treatment.

The second method used Bayesian Poisson Regression to model the number of observed fatalities by treatment. Because turbines were randomly assigned to treatment, the expected number of fatalities per night for each turbine should be equal among treatments if there was no treatment effect. We could therefore test for significant differences in bat carcasses found among treatments without accounting for potential biases (e.g., carcass persistence, searcher efficiency, and unsearched area). The Bayesian Poisson Regression method assumes that detection bias would affect all treatments equally across a night, therefore there was no correction for detection bias. Similar to the Huso fatality method, we assumed we could accurately determine the night a fatality occurred and therefore the associated treatment.

For each turbine-treatment combination we calculated the number of fresh bat fatalities. We modeled the number of fatalities using the independent variables Turbine, Treatment B, and Treatment C (i.e., Treatment A was considered the control treatment because this impact reduction strategy is already being implemented during this period of time). Since our experimental unit was the turbine, it was treated as a random variable with a normal distribution. We used the natural logarithm of nights as an offset term to account for differences among treatments (i.e., treatment implementation error). All Bayesian priors were non-informative, so the resulting posterior distributions were not strongly influenced by our choice of priors. The Bayesian priors for treatment were normal distributions with mean zero and $\sigma^2 = 10{,}000$. The variance of the normal distribution of turbine means had a Bayesian prior of an exponential distribution with $\lambda=0.0001$. We ran 100,000 simulations, with a burn-in of 10,000, with 3 chains, and with a thinning level of 10. The resulting fatality estimates from this analysis are adjusted for individual turbine differences, but they estimate just the number of carcasses expected to be found and do not try to estimate the number of carcasses that were removed by scavengers before searches were conducted or carcasses that were not located by searchers during the first search (i.e. did not include searcher efficiency or carcass persistence).

We also used the same methods to compare a number of Bayesian Poisson Regression models with different independent variables to explain the number of bat fatalities found. Independent variables considered were Treatment (A, B, or C), mean hours turbines were spinning per night (hours on), and mean number of starts, stops, and starts plus stops per night. The turbine variable was included in all models. We did not include hours curtailed because it was highly correlated with hours on ($r = 0.988$). We tested all combinations of variables, including a turbine only model, except that the three start-stop variables were all strongly correlated (Table 2; $r > 0.97$), therefore they were not included in the same models. This resulted in 16 models that were compared based on the lowest Deviance Information Criterion score (DIC; Spiegelhalter et al. 2002).

As a secondary objective, we examined which factors influenced bat fatalities while turbines were spinning, using data examined on a nightly basis. We fit a logistic regression mixed model using the package glmmML for R (Broström and Broström 2009) to determine the probability of finding a fatality (yes or no) under a turbine during each search of each turbine. We tested four variables: 1) the number of stops; 2) the number of starts; 3) the number of stops and starts combined; and 4) the temperature change during the night. The 3 variables related to turbine operational changes were used to examine potential risk to bats when turbine operation was in transition (i.e. shut-down and start-up). The fourth variable, temperature change, was used to examine if risk differed when weather conditions changed during a night, such as during a cold front (i.e. large temperature change in a night). In contrast to Poisson regression, all models included turbine and time period (one of five 15-day periods) as fixed factors and night as a random variable (modeled with a random intercept model), which allowed us to account for intra-night differences. The number of hours the turbine was operational per night was included as an offset term (log of hours) to account for different time of operation, hence we were testing for factors that increased the fatality rate per hour the turbine was actually spinning. We used all turbine-nights when turbines were spinning for some portion of the night and searches were conducted the following day. However, data from Turbine 5 and data after 26 September (after period 5) were not included in the analysis because no bat fatalities were found at Turbine 5 and fatality surveys conducted 26–30 September were outside of the 75 day experiment.

Because the three operational transitions variables (i.e. start, stop, and start plus stop) were all highly correlated (Table 3; $r > 0.94$), we only included one of the three variables in each model. We tested models with each of the three start and stop variables individually and with temperature change and a null model with none of those three variables for a total of seven models. These seven models were compared with AIC (Burnham and Anderson 2002) to determine the best model of probability of finding a bat fatality when turbines were operating for some portion of the night.

Table 2. Pearson correlation for independent variables used in the Bayesian Poisson regression model for 15 turbines at the Pinnacle Wind Farm, Mineral County, West Virginia, 15 July–30 September 2015.

	Number of Starts	Number of Stops	Number of Stops and Starts
Number of Starts	—	—	—
Number of Stops	0.974	—	—
Number of Stops and Starts	0.993	0.994	—
Hours On	-0.542	-0.612	-0.583

Table 3. Pearson correlation for independent variables used in the mixed model logistic regression model for 15 turbines at the Pinnacle Wind Farm, Mineral County, West Virginia, 15 July–30 September 2015.

	Number of Starts	Number of Stops	Number of Stops and Starts
Number of Starts	—	—	—
Number of Stops	0.946	—	—
Number of Stops and Starts	0.986	0.997	—
Temperature Change	-0.067	-0.165	-0.119

RESULTS

Carcass Detectability. Across all turbines combined, only 19.9% of the survey plots were in searchable habitat (Table 4), but because much of the unsearchable portion of the plots was far from turbines where fewer fatalities are typically found, the DWPs were higher than the naïve estimates of searchable area. The best model for bat fatalities included distance from the turbine as a quadratic function ($y = -5.917 + 0.0463 * \text{distance} – 0.00010 * \text{distance}^2$). The mean turbine-specific DWP was 0.470 (minimum = 0.367, maximum = 0.575; Table 4). The model suggests that the highest number of bats would fall in the 36–38 m distance category, but because the area under the turbine increases with distance, the highest density of carcasses would be found in the 22–24 m distance category (Fig. 3).

The most parsimonious models for searcher efficiency included the visibility variable (3 classes; Table 5). The most parsimonious models for carcass persistence used the lognormal distribution and the visibility variable, although the loglogistic distribution was almost as good (Table 6). Searcher efficiency was highest for the easy visibility carcasses and lowest for the difficult visibility class (Table 7). Bat carcasses persisted longest in the difficult visibility class, second longest in the moderate visibility class, and were removed most quickly in the easy visibility areas (Table 7).

Table 4. Distance-weighted proportions of area searched for bats at each turbine for 15 turbines at the Pinnacle Wind Farm, Mineral County, West Virginia, 15 July–30 September 2015.

Turbine	Proportion searched	Distance-weighted proportion searched
1	0.255	0.555
2	0.198	0.432
4	0.214	0.447
5	0.228	0.525
7	0.233	0.545
9	0.187	0.374
11	0.195	0.496
13	0.155	0.367
14	0.169	0.423
15	0.170	0.438
16	0.178	0.446
19	0.205	0.496
21	0.154	0.420
22	0.214	0.503
23	0.227	0.575
Overall	0.199	0.470

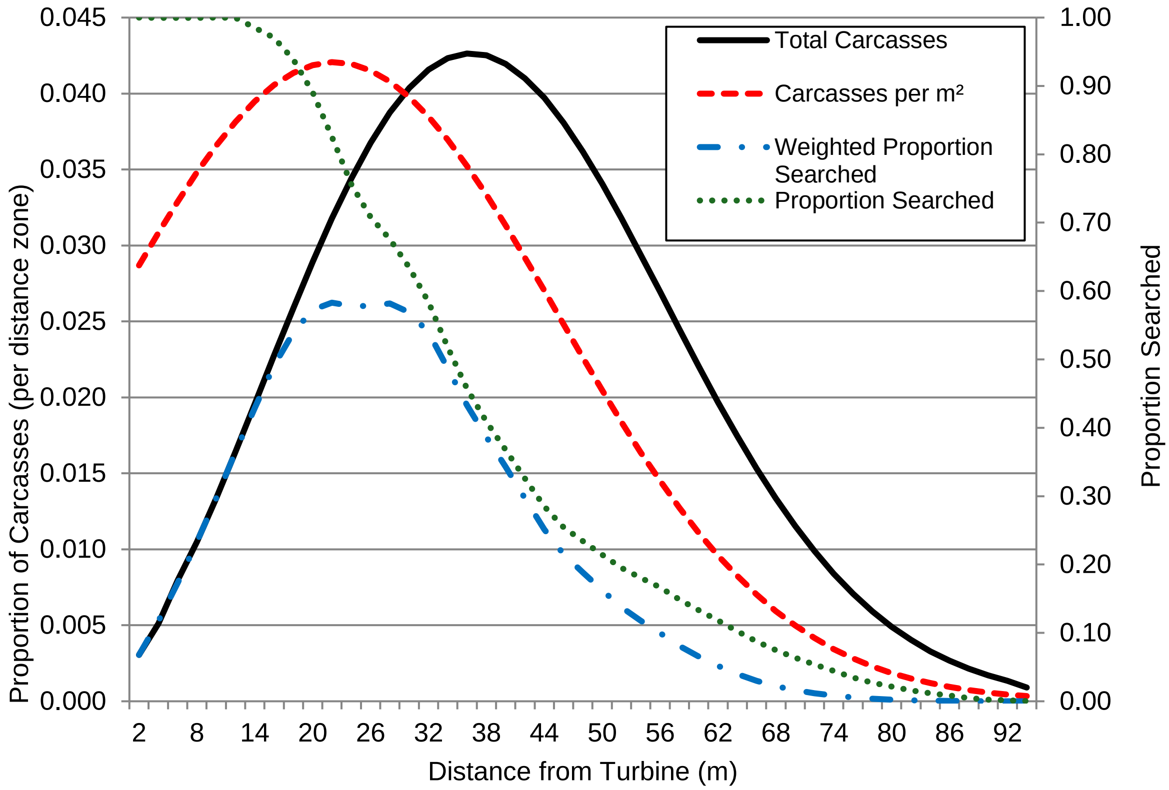


Figure 3. The estimated proportion of bat carcasses, carcass density, proportion of the area searched, and proportion of carcasses by distance from the turbines for 15 turbines at the Pinnacle Wind Farm, Mineral County, West Virginia, 15 July–30 September 2015.

Table 5. Model selection results (AIC_c) for different models of searcher efficiency for 15 turbines at the Pinnacle Wind Farm, Mineral County, West Virginia, 15 July–30 September 2015. Models run using Fatality Estimator software (Huso et al. 2012). Numbers in bold were the best model in the candidate model set.

Variables	AICc[a]	ΔAIC[b]	ω_i[c]
None	130.96	14.31	0.00
Visibility	**116.65**	**0**	**1.00**

[a]Akaike's Information Criterion.
[b]Difference in value between the AIC of the current model and that of the best approximating model.
[c]w_i (Akaike Weight) = Probability that the current model (i) is the best approximating model in the candidate set.

Table 6. Model selection results (AICc) for different models and statistical distributions for estimating carcass persistence for 15 turbines at the Pinnacle Wind Farm, Mineral County, West Virginia, 15 July–30 September 2015. Models run using Fatality Estimator software (Huso et al. 2012). Number in bold indicates the best model in the candidate model set.

	Distribution			
Variables	Weibull	Exponential	Loglogistic	LogNormal
None	412.46	418.44	407.59	410.54
Visibility	405.43	407.29	397.82	**397.35**

Table 7. Estimates (mean and 95% confidence intervals) of searcher efficiency and carcass persistence (r for an interval of 1 day) for bat carcasses with easy, moderate, and difficult visibility classes for 15 turbines at the Pinnacle Wind Farm, Mineral County, West Virginia, 15 July–30 September 2015. Estimates calculated using methods of Huso et al. (2012).

	Easy	Moderate	Difficult
Searcher efficiency	0.80 (0.60–0.95)	0.51 (0.38–0.64)	0.15 (0–0.30)
Carcass persistence	0.60 (0.40–0.77)	0.89 (0.84–0.93)	0.91 (0.84–0.95)

Bat Fatality. We were unable to search turbines on 8 out of 1,125 turbine-days during the 15 July–30 September study period due to safety concerns (e.g. lightning). We found a total of 68 bats, of which 8, 34, and 26 were found in July, August, and September, respectively. We found fresh carcasses (i.e., identified as having died the previous night) from 5 different species, including 31 eastern red bats (*Lasiurus borealis*), 11 hoary bats (*Lasiurus cinereus*), 10 big brown bats (*Eptesicus fuscus*), 4 silver-haired bats (*Lasionycteris noctivagans*), and 1 tri-colored bat (*Perimyotis subflavus*). No species of the genus *Myotis* (e.g., little brown bat [*M. lucifugus*], Indiana bat [*M. sodalis*], northern long-eared bat [*M. septentrionalis*], eastern small-footed bat [*M. lebii*]) were found. Migratory tree-roosting bats (i.e., eastern red bats, hoary bats, and silver-haired bats) comprised 82.4% (n = 56) of fatalities. Silver-haired bats are a state imperiled (S2) species (i.e., imperiled in the state because of rarity or because of some factors(s) making it very vulnerable to extirpation from the state) in West Virginia. Big brown bats and tri-colored bats are two species impacted by WNS. We found no evidence of WNS on any bat found during the study, although clinical signs of disease (e.g., wing damage) are not expected during the time of year that this study took place (Fuller et al. 2011).

Operation Minimization. Treatments A and B had similar hours on, hours curtailed, and curtailment power loss (MWh), whereas Treatment C had more hours on, fewer hours curtailed, and lower curtailment power loss (MWh) compared to Treatments A and B (Table 8). The mean hours off with wind below 3 m/s was lower for Treatment A than Treatments B and C, likely related to 10-minute versus 20-minute rolling average framework for treatment A versus treatments B and C, respectively. The number of starts, number of stops, and number of starts and stops combined per night were all highest in Treatment A, and lowest in Treatment C. The mean change in degrees Celsius during a night did not vary among treatments.

Given that Turbine 16 was nearer to the met tower and had the highest correlation, we used it to examine differences in wind speed measurements between turbine and met tower anemometer across 6 nights in July when this turbine was implementing Treatment C. We found that turbine wind speed was on average 1.03 m/s greater than the met tower, although this difference should be considered the “best-case scenario”. Ninety-seven percent of the time the turbine wind speed was greater than the met tower. Only 3% of the time was the turbine wind speed less than the met tower wind speed when the turbine was operating, the remaining 4% was when the turbine was idle. These differences likely explain why turbines under treatment C operated more, were curtailed less, and had less operational transitions (e.g. start-up and shut-down) and power loss on average per night (Table 8). For example, higher wind speed measurements on the turbines (i.e. Treatment C) would likely cause turbines to start-up earlier and shut-down later than treatments based on the met tower (i.e. Treatment A and B), regardless of the time period criteria (i.e. 10 or 20 minute) to initiate turbine start-up.

Due to mechanical difficulties and implementation error, some turbines did not operate during some nights and some turbines operated in treatments other than those assigned. Four additional nights of the experiment were conducted, but because the treatments were not all conducted equally, these last 4 nights were dropped from the analyses. Of a possible 375 turbine-nights per treatment, the final analysis included a total of 332 turbine-nights in Treatment A, 334 turbine-nights in Treatment B, and 351 turbine-nights in Treatment C.

Due to the experimental design only fresh bat fatalities were used in the analysis. Of these 57 fresh bat carcasses found, 17 were under turbines with raised cut-in speed of 5 m/s based on 10-minute average from the meteorological tower (Treatment A), 12 under turbines with raised cut-in speed of 5 m/s based on 20-minute average from the meteorological tower (Treatment B), 23 under turbines with raised cut-in speed of 5 m/s based on 20-minute average from individual turbines (Treatment C; Table 9), and 5 were removed due to treatment implementation error. Of those, 3 fatalities were assigned to treatment A and two fatalities to treatment B.

We used estimated fatality rate corrected for detection bias (Huso et al. 2012) as one of two methods to test for a treatment effect. The estimated fatality rate for Treatment A was 17.18 bats/turbine/study period (95% CI: 8.10–29.60), 13.05 bats/turbine/study period (95% CI: 6.08–24.00) for Treatment B, and 30.75 bats/turbine/study period (95% CI: 15.38–70.95) for Treatment C (Table 10). Estimated fatality rate varied by turbine and treatment group (Table 11). Using bootstrapped results from the Huso et al. (2012) estimator, there was not a significant difference between Treatment A and B ($P = 0.530$) or between Treatment A and C ($P = 0.182$), but there was a significant difference between Treatment B and C ($P = 0.031$).

Our second method to test for a treatment effect, Bayesian Poisson Regression, gave results that were generally similar to the Huso et al. (2012) analysis. The estimated mean number of carcasses, with assumed detection bias equally distributed among Treatments, expected to be found was 1.151 per turbine over a 25 day treatment period (95% CI: 0.572–1.920) for Treatment A, 0.808 per turbine (95% CI: 0.368–1.429) for Treatment B, and 1.466 per turbine (95% CI: 0.783–2.336) for Treatment C (Table 12). These estimates are lower than the fatality estimates from the Huso et al. (2012) method because this estimates only the number of bat fatalities that are found and does not corrected for potential sources of bias (scavenger removal, searcher efficiency, or unsearched area). We used a 25 day period because all treatments were assigned to all turbines every 25 days. The 95% credible intervals of the percent change for the estimated mean number of carcasses to be found all contained zero indicating no significant differences existed among treatments.

The best Poisson Regression model explaining the number of bat fatalities found under turbines only included turbine differences (Table 13), but the models with mean hours on and treatment were within 1 DIC unit. The second-best model with hours on, estimated that total fatalities found per turbine increased as the mean hours turbines were spinning per night increased, but the 95% credible interval included zero (β =0.224; -0.111–0.577) indicating it was not statistically significant.

We examined potential mechanisms that influenced fatality only on nights when turbines were operating and regardless of treatment. The best logistic regression mixed model of bat fatalities found per hour the turbine was spinning included number of stops, although stops/starts and starts were within one AIC unit (Table 14)), the available data suggests that the number of stops is the best predictor variable among these three highly correlated variables. Models with the number of stops and temperature change and the number of stops/starts and temperature change were also within 2 AIC units of the best model, but because these models only differed by one parameter from the best model and the 95% CIs of temperature change did include zero, temperature change was determined to be an uninformative parameter (Arnold 2010). The probability of finding a fatality increased significantly with an increasing number of stops (Table 15 and Fig. 4; β =0.156, 95% CI: 0.001–0.311). The probability of finding a fatality was higher during the third period (i.e. 13 August to 27 August) than the first period (β =1.435; 95% CI: 0.284–2.586).

Table 8. Comparison of mean nightly value of turbine metrics among treatments for 15 turbines at the Pinnacle Wind Farm, Mineral County, West Virginia, 15 July–30 September 2015. Values with different letters for the same metric are significantly different ($p < 0.05$).

Metric	Treatment A	Treatment B	Treatment C
Hours On	5.77^{a}	5.88^{a}	7.05^{b}
Hours Off (below 3 m/s)	0.12^{a}	0.28^{b}	0.27^{b}
Hours Curtailed	4.71^{a}	4.43^{a}	3.27^{b}
Curtailment Power Loss (MWh)	0.63^{a}	0.60^{a}	0.21^{b}
Number of Starts	1.75^{a}	1.25^{b}	0.88^{c}
Number of Stops	2.08^{a}	1.60^{b}	1.03^{c}
Number of Starts and Stops	3.83^{a}	2.85^{b}	1.90^{c}
Temperature Change (°C)	3.95^{a}	3.93^{a}	3.93^{a}

Table 9. Observed number of fresh bat fatalities by turbine and treatment for 75 nights when treatments were in effect (July 14–September 29, 2015) for 15 turbines at the Pinnacle Wind Farm, Mineral County, West Virginia, 15 July–30 September 2015.

Turbine Number	A	B	C
1	0	0	5
2	2	1	4
4	4	1	0
5	0	0	0
7	2	0	0
9	0	2	1
11	2	4	2
13	0	1	3
14	1	0	1
15	0	1	0
16	1	1	2
19	2	0	0
21	0	0	1
22	0	0	3
23	3	1	1
Total	17	12	23
Per Turbine	1.13	0.80	1.53

Table 10. Huso estimates (mean and 95% confidence intervals) of fatalities per turbine per night and per study period for 15 turbines at the Pinnacle Wind Farm, Mineral County, West Virginia, 15 July–30 September 2015. Estimates calculated using methods of Huso et al. (2012) and includes corrections for detection bias.

	Bats/Turbine/Night	Bats/Turbine/Study Period
Treatment	Estimate	Estimate
A	0.229 (0.108–0.395)	17.18 (8.10–29.63)
B	0.174 (0.081–0.320)	13.05 (6.08–24.00)
C	0.410 (0.205–0.946)	30.75 (15.38–70.95)
Total[1]	0.266 (0.180–0.450)	19.95 (13.50–33.75)

[1]Includes 5 fatalities that did not occur when a treatment was in effect.

Table 11. Estimates (mean fatality and 95% confidence intervals) of bat fatality per night by individual turbines for 15 turbines at the Pinnacle Wind Farm, Mineral County, West Virginia, 15 July–30 September 2015. Estimates calculated using methods of Huso et al. (2012) and includes corrections for detection bias.

Turbine	Treatment A	Treatment B	Treatment C
1	0	0	0.86 (0.22–2.93)
2	0.44 (0.09–1.54)	0.24 (0.05–0.83)	0.87 (0.17–2.90)
4	0.84 (0.17–2.86)	0.23 (0.05–083)	0
5	0	0	0
7	0.39 (0.1–1.34)	0	0
9	0	0.47 (0.08–1.68)	0.25 (0.05–0.91)
11	0.38 (0.09–1.30)	0.76 (0.18–2.72)	0.36 (0.08–1.24)
13	0	0.25 (0.04–0.87)	1.32 (0.13–6.06)
14	0.22 (0.04–0.74)	0	0.20 (0.04–0.70)
15	0	0.21 (0.04–0.72)	0
16	0.22 (0.04–0.72)	0.22 (0.04–0.72)	0.84 (0.08–4.40)
19	0.36 (0.08–1.23)	0	0
21	0	0	0.21 (0.04–0.74)
22	0	0	1.05 (0.14–4.81)
23	0.52 (0.14–1.76)	0.16 (0.04–0.55)	0.15 (0.04–0.53)

Table 12. Estimates (mean and 95% confidence intervals) of expected fatalities found (mean and 95% credible intervals) observed per turbine by treatment and estimated difference between treatments for a 25-day period from the Bayesian Poisson Regression analysis for 15 turbines at the Pinnacle Wind Farm, Mineral County, West Virginia, 15 July–30 September 2015. This method does not include correction for detection bias because it assumes it is distributed equally among treatments across a night.

	Treatment	Mean
Fatalities Found	A	1.151 (0.572–1.920)
	B	0.808 (0.368–1.429)
	C	1.466 (0.783–2.336)
Percent Change	A to B	-29.8 (-68.0–24.2)
	A to C	27.4 (-32.0–103.0)
	B to C	81.4 (-3.1–189.1)

Table 13. Model selection results Bayesian Poisson regression of bat fatalities compared using Deviance Information Criterion (DIC) and the change in DIC (ΔDIC) for 15 turbines at the Pinnacle Wind Farm, Mineral County, West Virginia, 15 July–30 September 2015. All models contained turbine as a factor. DIC can be interpreted similar to AIC values.

Model	DIC[a]	ΔDIC[b]	ω_i[c]
Null Model	137.7	0	0.16
Hours On	138.0	0.3	0.13
Treatments	138.7	1.0	0.10
Number Starts/Stops	139	1.3	0.08
Number Stops	139.1	1.4	0.08
Number Starts	139.1	1.4	0.08
Hours On, Number Stops	139.9	2.2	0.05
Hours On, Number Starts	140.0	2.3	0.05
Hours On, Number Starts/Stops	140.1	2.4	0.05
Treatment, Hours On	140.3	2.6	0.04
Treatment, Number Starts/Stops	140.5	2.8	0.04
Treatment, Number Starts	140.5	2.8	0.04
Treatment, Number Stops	140.6	2.9	0.04
Treatment, Hours On, Number Stops	142.1	2.9	0.04
Treatment, Hours On, Number Starts/Stops	142.1	4.4	0.02
Treatment, Hours On, Number Starts	142.2	4.5	0.02

[a] Deviance Information Criterion.

[b] Difference in value between the DIC of the current model and that of the best approximating model.

[c] w_i (DIC Weight) = Probability that the current model (i) is the best approximating model in the candidate set.

Table 14. Final model selection results for logistic regression mixed models of bat fatalities compared using Akaike's Information Criterion (AIC) and the change in AIC (ΔAIC) for 15 turbines at the Pinnacle Wind Farm, Mineral County, West Virginia, 15 July–30 September 2015. All models contain turbines and time periods as fixed factors and night as a random variable.

Model	AIC[a]	ΔAIC[b]	ω_i[c]
Number of Stops	392.2	0	0.23
Number of Starts/Stops	392.5	0.3	0.19
Number of Starts	393.0	0.8	0.15
Null Model	393.7	1.5	0.11
Number of Stops, Temperature Change	393.7	1.5	0.11
Number of Starts/Stops, Temperature Change	394.0	1.8	0.09
Number of Starts, Temperature Change	394.7	2.5	0.06
Temperature Change	394.8	2.6	0.06

[a]Akaike's Information Criterion.

[b]Difference in value between the AIC of the current model and that of the best approximating model.

[c]w_i (Akaike Weight) = Probability that the current model (i) is the best approximating model in the candidate set.

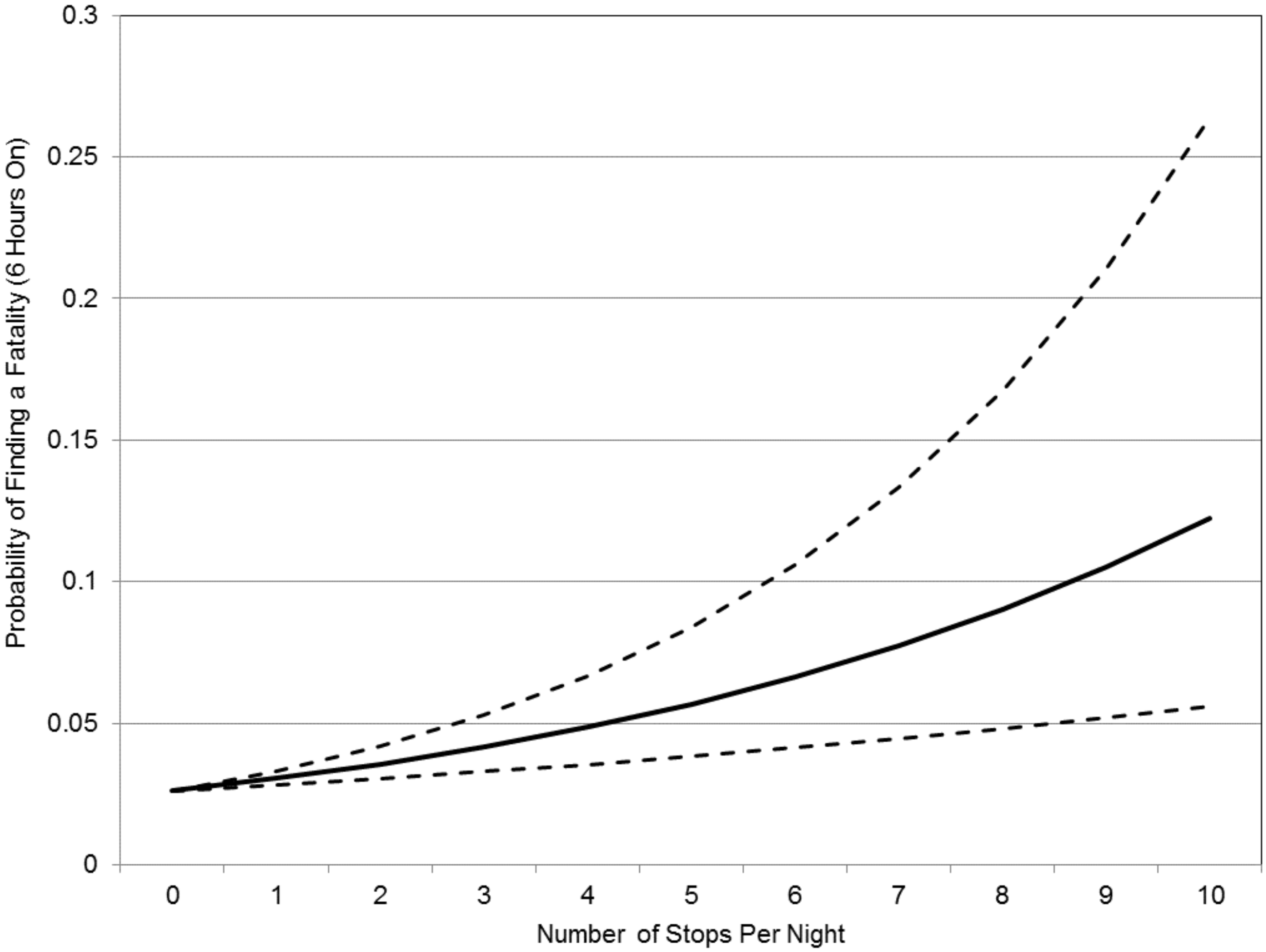


Figure 4. Probability and 95% confidence intervals of finding a bat fatality in relation to the number of times a turbine shutdown in a night, given that turbines were operating for at least 6 hours for 15 turbines at the Pinnacle Wind Farm, Mineral County, West Virginia, 15 July–30 September 2015. Based on the final model selection results for mixed model logistic regression of bat fatalities compared using Akaike's Information Criterion (AIC) and the change in AIC (ΔAIC). All models contain turbines and time periods as fixed factors and night as a random variable.

Table 15. Coefficients and 95% confidence intervals (CI) of the best mixed model logistic regression of bat fatalities for 15 turbines at the Pinnacle Wind Farm, Mineral County, West Virginia, 15 July–30 September 2015. Significant variables are bold.

Variable	β	SE	95% Lower CI	95% Upper CI
Intercept	-5.476	0.708	-6.864	-4.088
Number of Stops	**0.156**	**0.079**	**0.001**	**0.311**
Period 1[a]	–			
Period 2	0.175	0.716	-1.228	1.578
Period 3	**1.435**	**0.587**	**0.284**	**2.586**
Period 4	1.180	0.607	-0.010	2.370
Period 5	0.212	0.652	-1.066	1.490

[a]15-day period of time when each turbine received each treatment on 5 nights.

DISCUSSION

This study represents the third and final year of testing experimental operational minimization treatments at the PWF, and is the first to compare different operational decision frameworks. Our goal was to test the minimization strategy currently being implemented against a novel operational minimization strategy to reduce bat fatalities by not raising cut-in speed, but by adjusting the decision framework upon which turbine start-up is initiated (i.e. meteorological tower vs. wind turbines, and 10-minute versus 20-minute wind speed averages to initiate turbine start-up). Our two methods to test for a treatment effect generally supported each other, although estimated fatality, corrected for detection bias, was the only one that showed a significant difference and only between Treatments B and C. The best Poisson Regression model explaining the number of bat fatalities found under turbines only included turbine differences, but the models with mean hours on and treatment were within 1 DIC unit. In general, Treatment C had higher bat fatalities, significantly higher than Treatment B, and turbines in that treatment were operational for significantly longer periods compared to Treatments A and B. The turbine anemometer had an average 1.03 m/s higher wind speed value compared to the met tower, which likely caused turbines under Treatment C to start-up earlier and shut-down later increasing the operating time. Operating time was not solely determined to be the reason for significantly higher fatalities based on our Poisson regression models. A secondary analysis examined whether bat fatalities were associated with operational transitions (i.e. during turbine start-up or shut-down). Cryan et al. (2014) observed higher bat activity near turbines when blades were stationary or barely moving. Thus, bats may already be in risk when turbines begin ramping up and spinning at high RPMs. Alternatively, since all treatments were based on a wind speed of 5 m/s it is difficult to separate risk to bats when turbine operations were in transition compared to risk at relatively low wind speeds (e.g. ~ 5 m/s), which might influence changes in turbine operation. Other methods, such as videography, are likely needed to determine if operational transition is a period of risk to bats, since RPM and wind speed data are typically only available at a course scale (e.g. 10 minute averages), actual time of death is unknown, and operational transition is dependent on wind speed. Although fatalities were not significantly different between Treatments A and B, we observed lower fatalities for Treatment B, which also experienced significantly fewer transitions per night. Moreover, there was no significant difference in power loss or the amount of time turbines were curtailed between Treatments A and B. Thus, Treatment B represents a decision framework with lower estimated bat fatality, less wear-and-tear on turbines with no additional power loss, and may be the most cost-effective option of the 3 treatments studied in this experiment.

The PWF is unique in that it has 3 years of studies investigating different impact reduction strategies, while maintaining some consistency among years, specifically the 5.0 m/s treatment (Treatment A in 2015). We examined how the results from 2015 compared to previous studies conducted at the PWF. In 2012, our study tested normal operations (3.0 m/s) versus cut-in speed adjustments of 5.0 m/s for the first 4 hours of the night and 5.0 m/s for the entire night (Hein et al. 2013). When we removed one night (30 July) in which 7 bats were killed when the treatment was not implemented properly (i.e, the 5.0 m/s treatment assigned to Turbine 1 was actually fully operational), we found a significant difference between the 5.0 m/s all night treatment and the control group, but not a significant difference between control and the 5.0 m/s half-night treatment. We observed a 46.6% (95% CI: 12.0–77.6%) reduction in fatalities from the 5.0 m/s all-night treatment relative to the control group. In 2013, we tested normal operations versus cut-in speed adjustments of 5.0 m/s and 6.5 m/s, both for the entire night (Hein et al. 2014). We observed significant reductions in bat fatalities of 54.4% (95% CI: 17.7–74.7) and 76.1% (95% CI: 49.1–88.8) at cut-in speed adjustments of 5.0 m/s and 6.5 m/s, respectively compared to the control group. However, we found no statistical difference between the two higher cut-in speeds, which is similar to the findings of Arnett et al. (2011).

The PWF is currently operating under Treatment A conditions during the period of our study, thus we considered that treatment as the control group. In comparing the fatality rate for higher cut-in speed treatments, we observed a higher fatality rate in 2012 and 2013 than in 2015 (Appendix 3). In 2012, the fatality rate for 5.0 m/s (half night) and 5.0 m/s (all-night) was estimated to be 72.7 (95% CI: 49.6–104.4) and 39.8 (95% CI: 25.9–59.7) bats/turbine/study period, respectively. In 2013, the fatality rate for 5.0 m/s and 6.5 m/s treatments was estimated to be 38.4 (95% CI: 18.4–68.9) and 23.0 (95% CI: 11.3–45.9) bats/turbine/study period, respectively. In 2015, the number of bat fatalities/turbine/study period for Treatment A (17.19; 95% CI: 8.10–29.63), which was operationally equivalent to the 5.0 m/s treatment in 2013, and Treatment B (13.05; 95% CI: 6.08–24.00), were both lower than the 6.5 m/s treatment in 2013. It is difficult to compare results among years and it is common to see lower estimated bat fatality in subsequent years of study (PGC 2012). There are a number of factors that might contribute to these differences, including inter-annual variation in bat activity, changes in weather conditions, insect abundance and availability, or decreases in bat population (Erickson and West 2002, Reynolds 2006, Horn et al. 2008, Weller and Baldwin 2012). Estimated bat fatality across the 3 years showed similar results for 5.0 m/s all night treatment, in 2012 and 2013, as we found at Treatment C in 2015 (Appendix 3). Overall, our results demonstrate the importance of replicating studies over multiple years to better understand the effectiveness of proposed strategies before making management decisions. More research is needed in the wind industry, but extending wind speed measurements over longer periods of times before initiating turbine start-up might be a cost-effective strategy, and potential alternative to raising the cut-in speed.

Operational minimization studies consistently show substantial reductions in bat fatalities when turbines are feathered during low wind speed conditions (Arnett et al. 2013). However, numerous factors influence the logistics and financial costs of changing the cut-in speed of wind turbines to reduce bat fatalities, including the type and size of wind turbine, software system available to program turbine operations, market or contract prices of power, power purchase agreements and associated fines for violating delivery of power, and variation in temporal consistency, speed, and duration of wind across different sites. In this study, Treatments A and B were statistically similar and showed a 0.63 MWh and 0.60 MWh loss of power production. The slightly higher power loss for Treatment A could be contributed to the significantly more operational changes (i.e. turbine start-up and shut-down), even though hours curtailed was slightly higher than Treatment B. Regardless, this loss of power was statistically higher than that of Treatment C, which had a 0.21 MWh loss of power. Baerwald et al. (2009) reported a 42.3% reduction in the amount of time turbines would have produced electricity. However, because of the technological limitations of the V80 turbines at that facility, cut-in speeds were altered 24 hours/day during the entire study. Arnett et al. (2011) reported the loss in power production resulting from the experimental treatments was low relative to annual energy production (i.e., 0.3–1%). Power loss for the 5.0 m/s treatment was 1/3 that of the 6.5 m/s treatment, reflecting the cubic effect of wind speed and power produced (Albadi and El-Saadany 2009, Arnett et al. 2011). Despite a number of publicly available operational minimization studies, few have reported the financial cost (Arnett et al. 2013). Providing the associated economic data will allow future minimization strategies and technologies to be developed in a cost competitive way. Therefore, it is important to continue to estimate the financial costs of impact reduction strategies across various species ranges, habitat conditions and wind regimes, and find ways to minimize the economic impact while achieving the desired level of conservation value.

Many factors influenced our ability to test and interpret this novel operational minimization strategies at PWF. As mentioned above, the PWF had already agreed to operate at Treatment A which prevented our study from including a "true" control (i.e. normal operating turbine with a cut-in speed of 3 m/s). This affected our ability to determine significant reductions in bat fatality for all treatments versus a normally operating turbine but likely would not have influenced our ability to differentiate between the three treatments. Treatment A and B were not significantly different in hours on, hours curtailed, or power loss but did show a significant difference in the operational changes (i.e. turbine start-up, shut-down) in a night. The similarities between treatments is likely related to comparing wind speed measurements over a relatively short period of time (i.e. difference of 10 minutes). Future studies should consider trying to compare treatments with broader difference in time periods before initiating turbine start-up (e.g. difference of 20 or 30 minutes rather than 10 minutes). This would likely increase the differences between treatments to help determine a treatment effect. Alternatively increasing the number of turbines, duration, or using a different metric of risk (e.g. bat passes recorded by video) could help to differentiate between treatments with only modest operational differences. In addition, determining the factors that influence wind speed measurements on the nacelle versus a met tower could help to determine which might be a more cost-effective strategy. From a research perspective, controlling for differences between turbines in the same treatment is likely advantageous. Moreover, we were originally interested in testing strategies that influenced turbine start-up but found that turbine shut-down was implemented differently between Treatments A and B (i.e. met tower anemometer) compared to Treatment C (i.e. turbine anemometer). Future studies should try to limit differences in turbine operation that might limit the interpretation of the results, such as having turbine shut-down based on the same wind speed measurement. Interestingly, our top model examining factors that influenced fatality at operating turbines included turbine shut-down. A number of factors might influence this relationship, such as slight changes in wind speeds around the 5 m/s treatment cut-in speed threshold. The relationship of higher bat fatalities at lower wind speeds has been well documented and is currently the basis for many operational minimization strategies (Arnett et al. 2013). But future consideration should be given to the possibility that any operational transition might influence risk to bats. If we can determine mechanisms that directly or indirectly influence fatality, then we might be able to develop other strategies that might be more cost-effective.

Presently, our understanding of the sustainability of wind energy impacts on bats is limited by the lack of knowledge of population size, structure and dynamics (O'Shea et al. 2003). Until we have a better understanding of bat populations, our ability to determine whether the observed reduction in bat fatalities, from operational minimization strategies, is adequate to reduce the adverse effects of wind energy development remains limited. Gathering population data that are sufficient to address this issue is a priority, but such data are not expected to be available in the near future, particularly for migratory tree-roosting bats that constitute the highest proportion of bat fatalities. Because bats have low reproductive potential (i.e., reproducing once per year and typically only having 1–2 pups) and require high adult survivorship to avoid population declines, we assume that they are not able to recover quickly from large-scale impacts (Findley 1993, Barclay and Harder 2003). Yet, our current understanding of operational minimization indicates that bat fatalities at wind turbines can be decreased when turbines are feathered under the manufacturer's cut-in speed, which was recently adopted by the American Wind Energy Association and enhanced and further reduced when the manufacturer's cut-in speed is raised by 1.5–3.0 m/s. Given the magnitude and extent of bat fatalities throughout North America, we believe that impact reduction strategies, such as operational minimization, should be considered at operating wind energy facilities to reduce the direct impact to bats, even in the absence of population data.

We caution that these data are site-specific and represent 1 year of study investigating a novel strategy to reduce bat fatalities and limit wear and tear on wind turbines. The relationship between turbine transitions and bat fatalities is unclear and further research at additional wind energy facilities is warranted to fully understand bat/wind turbine interactions during start-ups and shut-downs. Until more data are gathered, implementing strategies that limit operational transition of turbines at low wind speeds, such as having an asymmetrical shut-down/start-up decision framework (i.e., maintaining a shorter average time period [e.g., 10 minutes] to shut-down turbine operations and extending the average time period [from 10 to 20 minutes] to inform turbine start-up) may further reduce bat fatalities at the same cut-in speed. Future research might compare differences between a longer decision framework and higher cut-in speeds to assess the cost effectiveness and conservation value, particularly at other sites, regions, and turbine types. Our data regarding changes to the decision framework in combination with research from other studies investigating operational changes that incorporate temperature (Martin et al. 2014) or other weather variables may provide a more cost-effective approach to minimizing bat fatalities at wind turbines. Given the results from our 3 years of study at this site, we recommend the PWF implement Treatment B from 1 July to 30 September.

LITERATURE CITED

Albadi, M. H., and E. F. El-Saadany. 2009. Wind turbines capacity factor modeling-a novel approach. IEEE Transactions on Power Systems 24:1637–1638.

American Wind Energy Association (AWEA). 2015a. AWEA U.S. Wind industry fourth quarter 2015 market report. http://awea.files.cms-plus.com/FileDownloads/pdfs/4Q2015%20AWEA%20Market%20Report%20Public%20Version.pdf.

American Wind Energy Association (AWEA). 2015b. Wind energy facts: West Virginia. http://www.awea.org/resources/statefactsheets.aspx?itemnumber=890.

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.

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.

Arnett E. B., M. M. P. Huso, M. R. Schirmacher, and J. P. Hayes. 2011. Altering turbine speed reduces bat mortality at wind-energy facilities. Frontiers in Ecology and the Environment 9:209–214.

Arnett, E. B., G. D. Johnson, W. P. Erickson, and C. D. Hein. 2013. A synthesis of operational mitigation studies to reduce bat fatalities at wind energy facilities in North America. A report submitted to the National Renewable Energy Laboratory. Bat Conservation International. Austin, TX.

Arnett, E. B., and E. F. Baerwald. 2013. Impacts of wind energy development on bats: implications for conservation. Pages 435–456 *in* Bat evolution, ecology and conservation. R. A. Adams and S. C. Pedersen (eds). Springer, New York, USA.

Arnold, T.W. 2010. Uninformative parameters and model selection using Akaike's Information Criterion. Journal of Wildlife Management 74(6): 1175–1178.

Barclay, R. M. R. and L. D. Harder. 2003. Life histories of bats: life in the slow lane. *In* T.H. Kunz and M.B. Fenton (eds), Bat ecology. University of Chicago Press; Chicago, IL.

Baerwald, E. F., J. Edworthy, M. Holder, and R. M. R. Barclay. 2009. A large-scale mitigation experiment to reduce bat fatalities at wind energy facilities. Journal of Wildlife Management 73:1077–1081.

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

Brostrom, G., and M. G. Brostrom. 2009. Packag ‘glmmML’. Available at http://crian.r-project.org/web/packages/glmmML/index.html.

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

Cryan, P. M., P. M. Gorresen, C. D. Hein, M. R. Schirmacher, R. H. Diehl, M. M. Huso, D. T. S. Hayman, P. D. Fricker, F. J. Bonaccorso, D. H. Johnson, K. Heist, and D. Dalton. 2014. Behavior of bats at wind turbines. Proceedings of the National Academy of Sciences 111: 15126–15131.

Efroymson, R. A., R. J. Day, and M. D. Strickland. 2012. A retrospective tiered environmental assessment of the Mount Storm Wind Energy Facility, West Virginia, USA. Prepared for the US Department of Energy.

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.

Findley, J. S. 1993. Bats: a community perspective. Cambridge University Press, New York, USA.

Frick, W.F., J.F. Pollock, A. Hicks, K. Langwig, D.S. Reynolds, G. Turner, C. Butchkowski, T.H. Kunz. 2010. An emerging disease causes regional population collapse of a common North American bat species. Science, 329:679-682.

Fuller, N. W., J. D. Reichard, M. L. Nabhan, S. R. Fellows, L. C. Pepin, and T. H. Kunz. 2011. Free-ranging little brown myotis (Myotis lucifugus) heal from wing damage associated with white-nose syndrome. Ecohealth 8:154-162.

Good, R. E., W. Erickson, A. Merrill, S. Simon, K. Murray, K. Bay, and C. Fritchman. 2011. Bat monitoring studies at the Fowler Ridge Wind Energy Facility Benton County, Indiana. A report prepared for Fowler Ridge Wind Farm. Western EcoSystems Technology, Inc., 2003 Central Avenue, Cheyenne, Wyoming.

Good, R. E., A. Merrill, S. Simon, K. Murray, and K. Bay. 2012. Bat monitoring studies at the Fowler Ridge Wind Farm, Benton County, Indiana. An unpublished report submitted to the Fowler Ridge Wind Farm by Western EcoSystems Technology, Inc., 2003 Central Avenue, Cheyenne, Wyoming.

Hein, C. D., A. Prichard, T. Mabee, and M. R. Schirmacher. 2013. Effectiveness of an operational mitigation experiment to reduce bat fatalities at the Pinnacle Wind Farm, Mineral County, West Virginia, 2012. An annual report submitted to Edison Mission Energy and the Bats and Wind Energy Cooperative. Bat Conservation International. Austin, Texas, USA.

Hein, C. D., A. Prichard, T. Mabee, and M. R. Schirmacher. 2014. Efficacy of an operational minimization experiment to reduce bat fatalities at the Pinnacle Wind Farm, Mineral County, West Virginia, 2013. An annual report submitted to Edison Mission Energy and the Bats and Wind Energy Cooperative. Bat Conservation International, Austin, Texas, USA.

Horn, J.W., E.B. Arnett, and T. H. Kunz. 2008. Behavioral responses of bats to operating wind Turbines. Journal of Wildlife Management 72(1): 123–132.

Huso, M. M. P., and D. Dalthorp. 2014. Accounting for unsearched areas in estimating wind turbine-caused fatality. The Journal of Wildlife Management 78:347-358.

Huso, M. M. P, N. Som, and L. Ladd. 2012. Fatality Estimator User's Guide: U. S. Geological Survey Data Series 729, p. 32.

Jones, G., Jacobs, D., Kunz, T. H., Willig, M., and P. Racey. 2009. Carpe noctem: the importance of bats as bioindicators. Endangered Species Research 8:93–115.

Kunz, T. H., E. B. Arnett, W. P. Erickson, A. R. Hoar, 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.

Kunz, T. H., E. Braun de Torez, D. Bauer, T. Lobova, and T. H. Fleming. 2011. Ecosystem services provided by bats. Annals of the New York Academy of Sciences. 1223:1–38.

Ledec, G. C., K. W. Rapp, and R. G. Aiello. 2011. Greening the wind: environmental and social considerations for wind power development in Latin America and beyond. A full report submitted to the Sustainable Development Department, Latin America and Caribbean Region, The World Bank. 170 pp.

Martin, C., E. Arnett, and M. Wallace. 2015. Evaluating bat and bird post-construction impacts at the Sheffield Wind Facility, Vermont. Report prepared for Bat Conservation International and First Wind. Texas Tech University, Lubbock, Texas, USA.

National Research Council. 2007. Ecological impacts of wind-energy projects. National Academies Press, Washington, D.C., 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.

Pennsylvania Game Commission (PGC). 2012. Pennsylvania Game Commission wind energy voluntary agreement third summary report. Pennsylvania Game Commission, Harrisburg, Pennsylvania, USA.

Pierson, E. D. 1998. Tall trees, deep holes, and scarred landscapes: conservation biology of North American bats. Pages 309–325 *in* T. H. Kunz and P. A. Racey, editors. Bat biology and conservation. Smithsonian Institution Press, Washington, D.C., 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: 70:1219–1227.

Reichard, J. D., and T. H. Kunz. 2009. White-nose syndrome inflicts lasting injuries to the wings of little brown myotis (Myotis lucifugus). Acta Chiropterologica 11:457–464.

Rydell, J., L. Bach, M. Dubourg-Savage, M. Green, L. Rodrigues, and A. Hedenstrom. 2010. Bat mortality at wind turbines in northwestern Europe. Acta Chiropterologica 12: 261–274.

Spiegelhalter, D. J., N. G. Best, B. P. Carlin, and A. van der Linde. 2002. Bayesian measures of model complexity and fit. Journal of Royal Statistical Society B 64: 583–639.

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

Union of Concerned Scientists. 2011. Tapping into the Wind. Union of Concerned Scientists, Washington, DC, USA. http://www.ucsusa.org/assets/documents/clean_energy/tappingintothewind.pdf

Warren-Hick, W., J. Newman, R. Wolpert, B. Karas, and L. Tran. 2012 (unpublished results). Improving Methods for Estimating Fatality of Birds and Bats at Wind Energy Facilities. http://www.calwea.org/pdfs/2012/CalWEA_Webinar_Presentation_26Sept2012.pdf

Weller, T. J., and J. A. Baldwin. 2012. Using echolocation monitoring to model bat occupancy and inform mitigations at wind energy facilities. Journal of Wildlife Management 76: 619–631.

Winhold, L., A. Kurta, and R. Foster. 2008. Long-term change in an assemblage of North American bats: are eastern red bats declining? Acta Chiropterologica 10: 359–366.

Young, D.P., Jr., K. Bay, S. Nomani, and W.L. Tidhar. 2011. Nedpower Mount Storm Wind Energy Facility Post-Construction Avian and Bat Monitoring: July - October 2010. Prepared for NedPower Mount Storm, LLC, Houston, Texas. Prepared by Western EcoSystems Technology, Inc. (WEST), Cheyenne, Wyoming.

Young, D.P., Jr., S. Nomani, Z. Courage, and K. Bay. 2012. NedPower Mount Storm Wind Energy Facility Post-Construction Avian and Bat Monitoring: July - October 2011. Prepared for NedPower Mount Storm, LLC, Houston, Texas. Prepared by Western EcoSystems Technology, Inc. (WEST), Cheyenne, Wyoming.

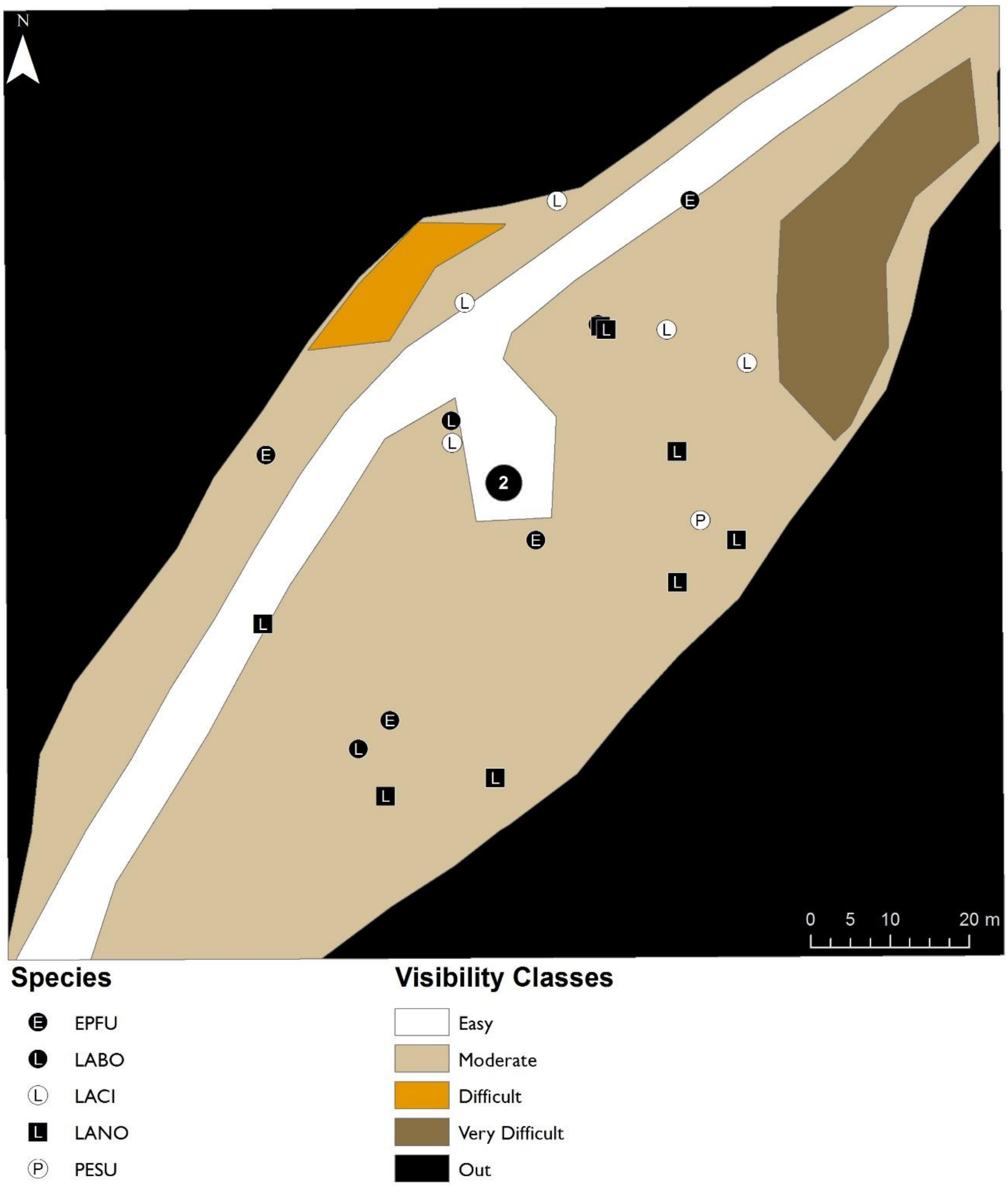
APPENDIX 1

MAPS OF TURBINE PLOTS, VISIBILITY CLASSES AND FATALITIES FROM 12 TURBINES SEARCHED DAILY AT THE PINNACLE WIND FARM, MINERAL COUNTY, WEST VIRGINIA, 2015

Turbine 1


N
1
L
0 5 10 20 m
Species
LABO
LACI
LANO
Visibility Classes
Easy
Moderate
Difficult
Very Difficult
Out

Turbine 2

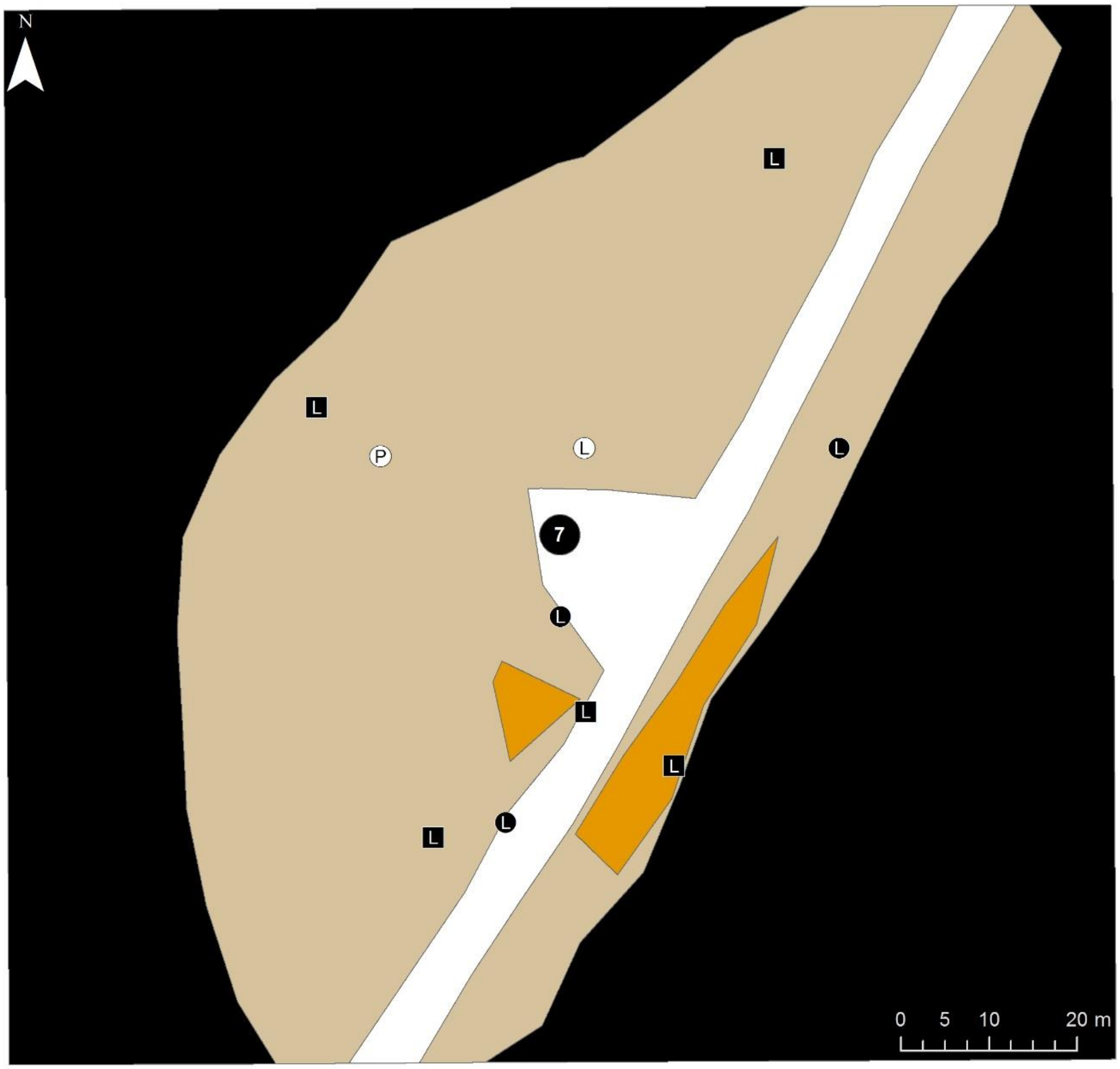


N
2
0 5 10 20 m
Species
EPFU
LABO
LACI
LANO
PESU
Visibility Classes
Easy
Moderate
Difficult
Very Difficult
Out

Turbine 5


N
5
E
E
E
L
L
0 5 10 20 m
Species
EPFU
LABO
LACI
Visibility Classes
Easy
Moderate
Difficult
Very Difficult
Out

Turbine 7



Species

- LABO
- LACI
- LANO
- PESU

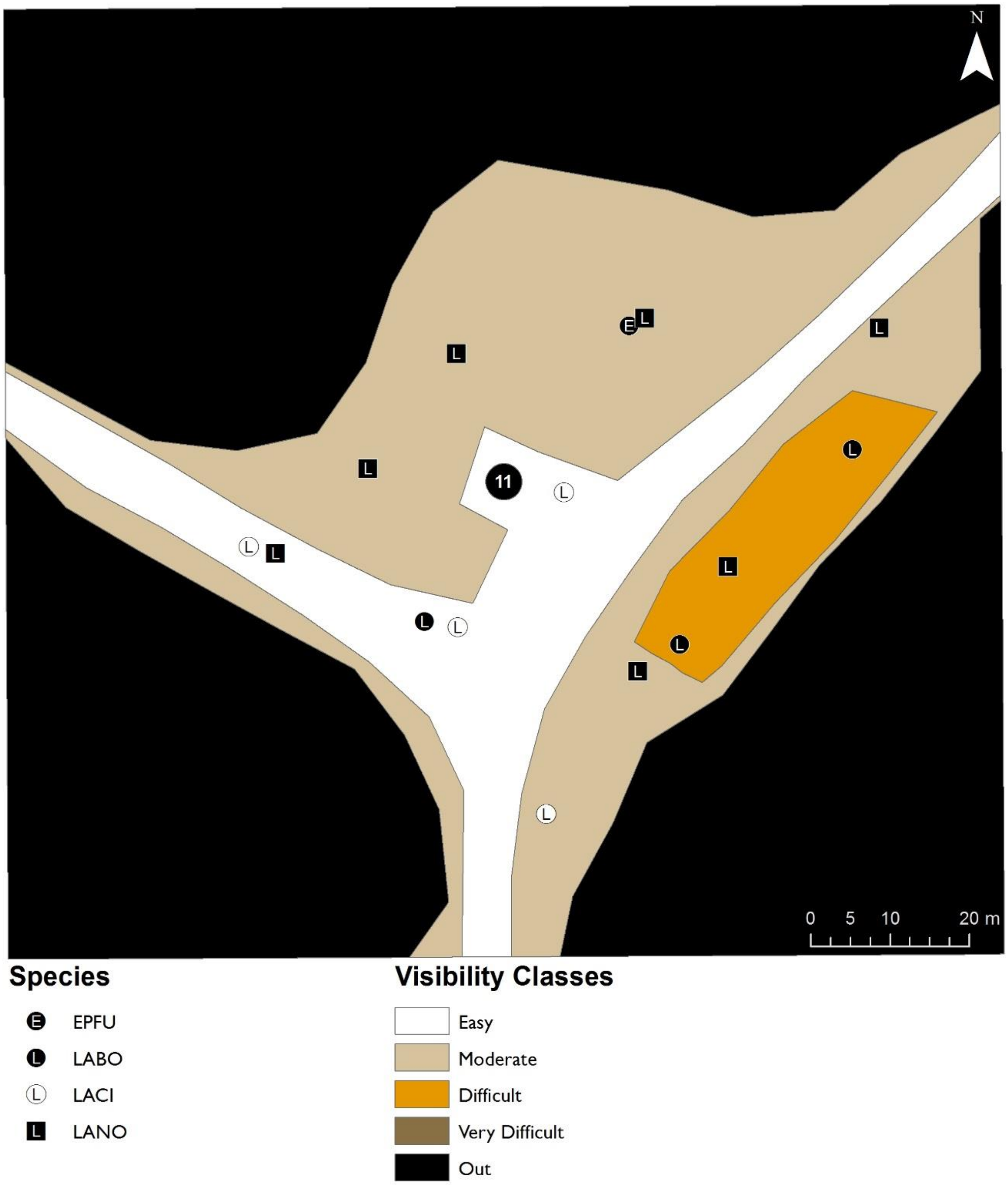
Visibility Classes

- Easy
- Moderate
- Difficult
- Very Difficult
- Out

Turbine 9

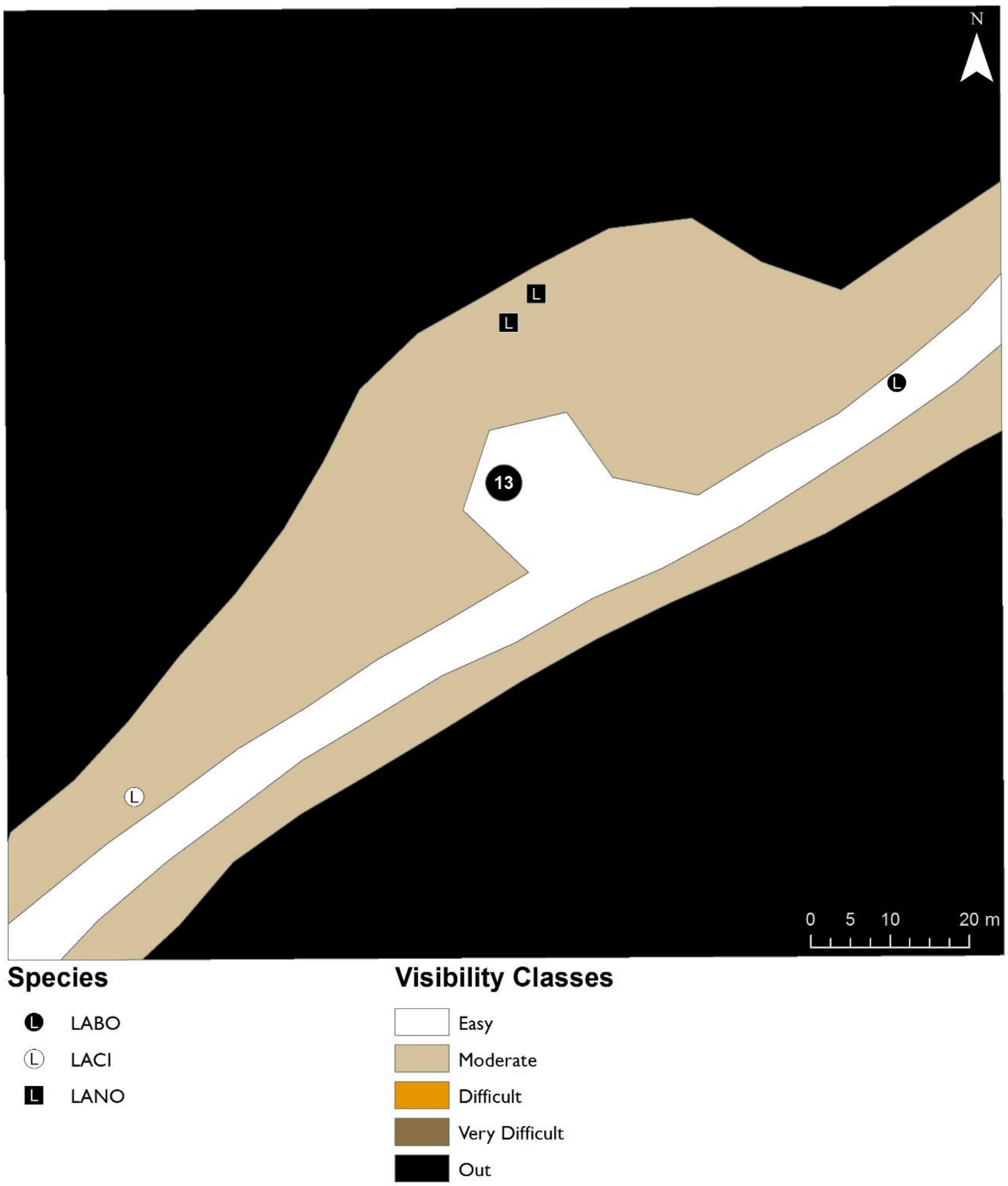
N
L
L
9
L
E
0 5 10 20 m
Species
E EPFU
L LABO
L LACI
Visibility Classes
Easy
Moderate
Difficult
Very Difficult
Out

Turbine 11



N
11
E
L
0 5 10 20 m
Species
EPFU
LABO
LACI
LANO
Visibility Classes
Easy
Moderate
Difficult
Very Difficult
Out

Turbine 13


N
13
0 5 10 20 m
Species
LABO
LACI
LANO
Visibility Classes
Easy
Moderate
Difficult
Very Difficult
Out

Turbine 14

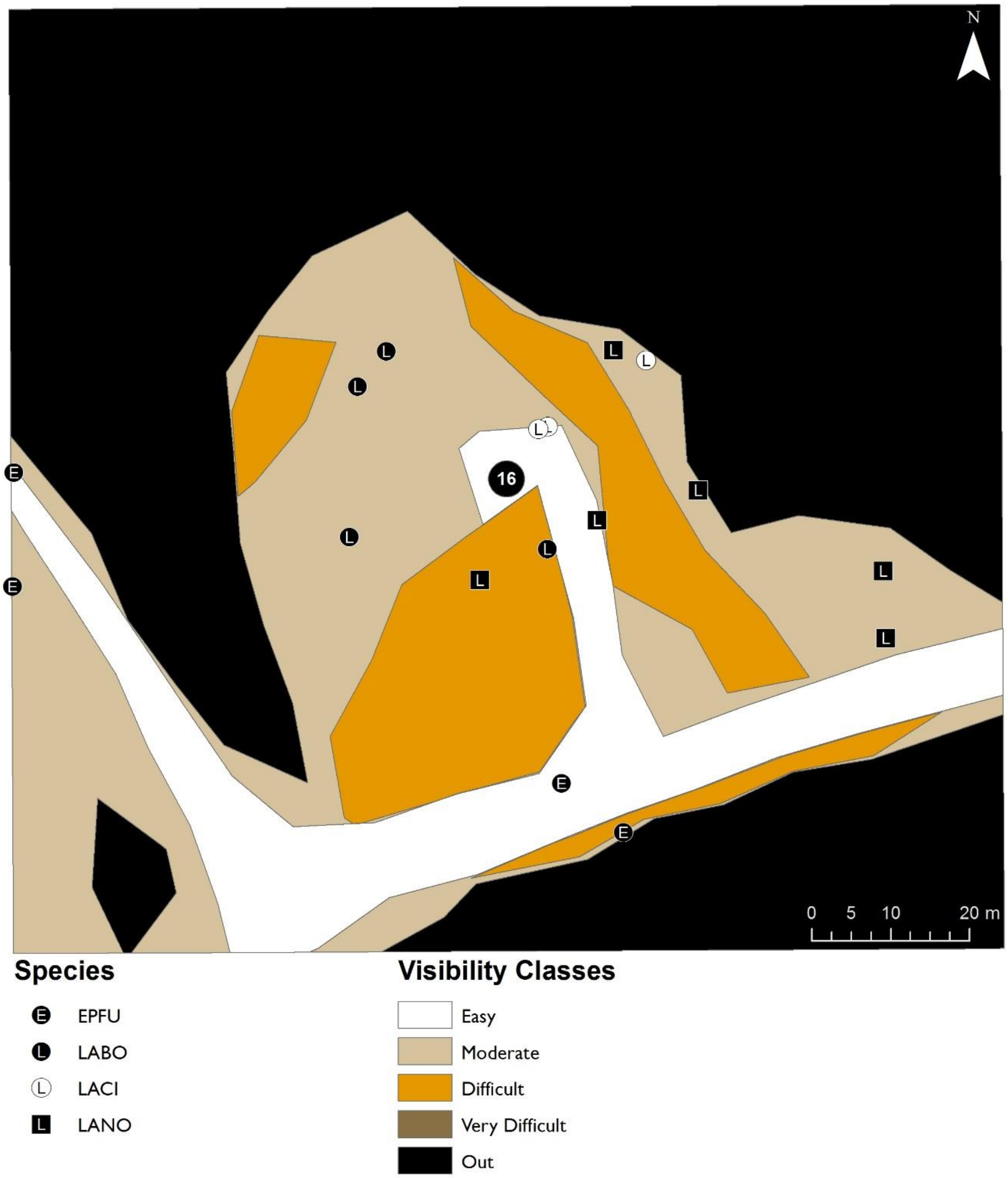
Species

- E EPFU
- L LABO
- L LACI
- L LANO

Visibility Classes

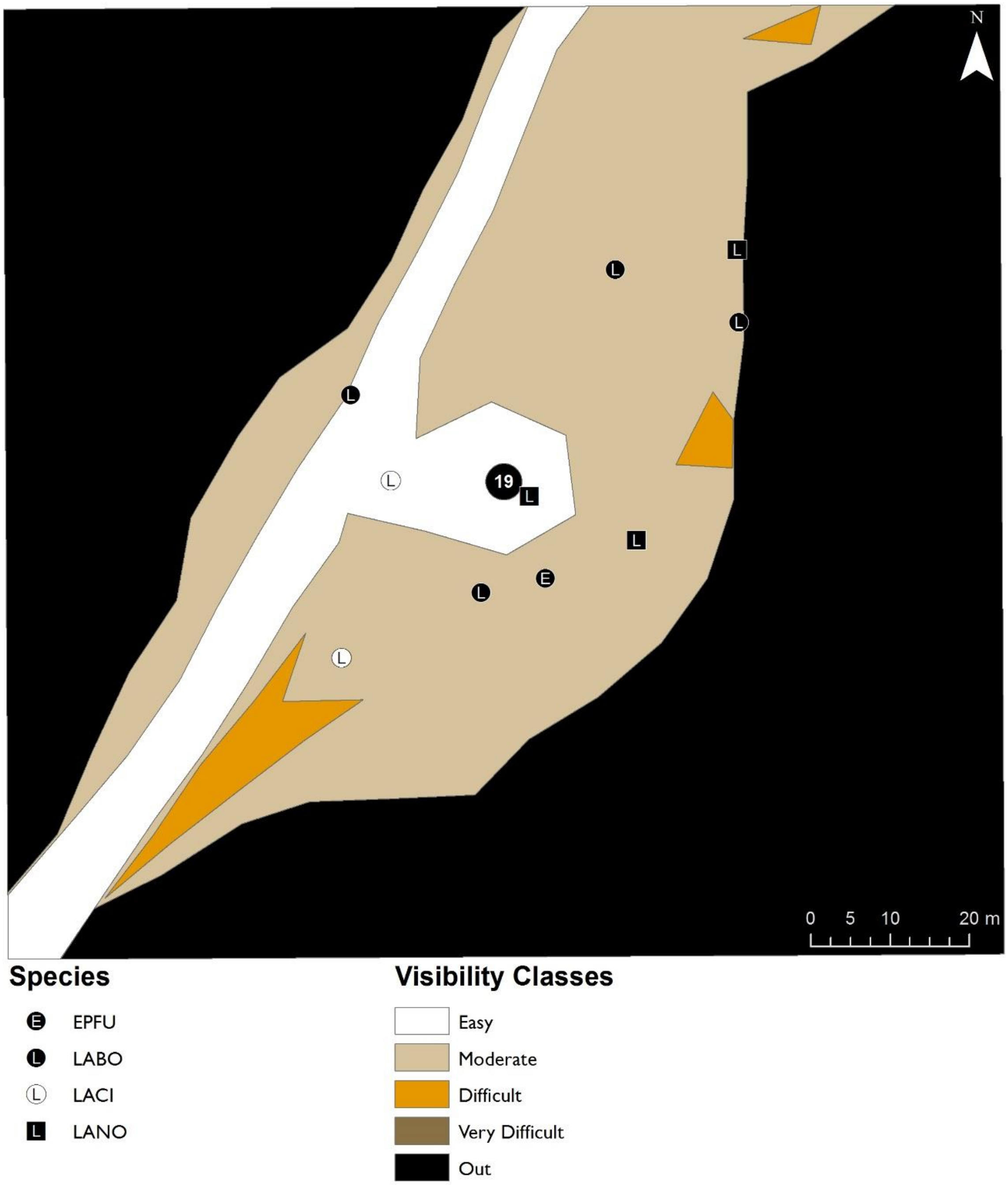
- Easy
- Moderate
- Difficult
- Very Difficult
- Out

Turbine 16



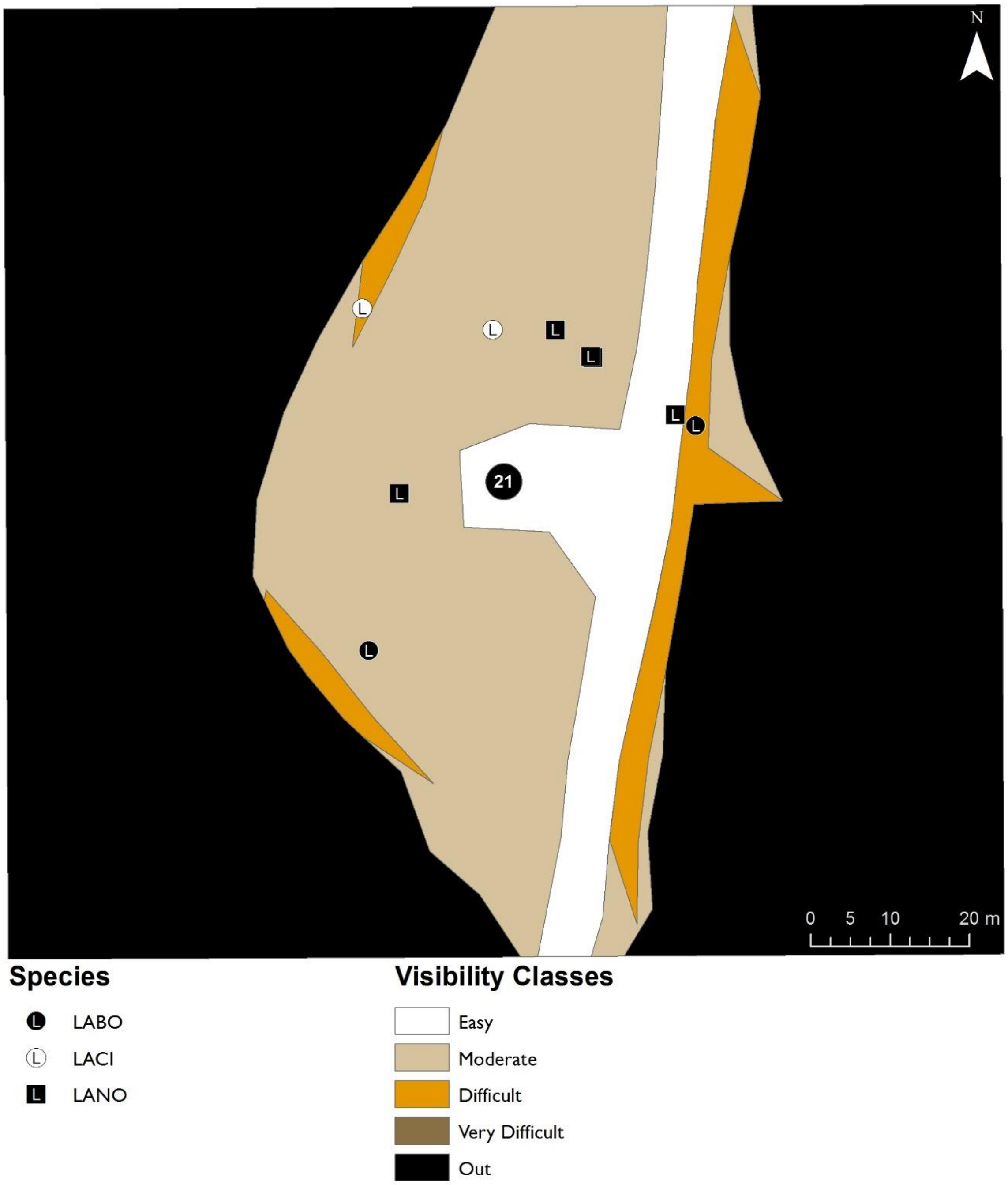
N
16
0 5 10 20 m
Species
EPFU
LABO
LACI
LANO
Visibility Classes
Easy
Moderate
Difficult
Very Difficult
Out

Turbine 19

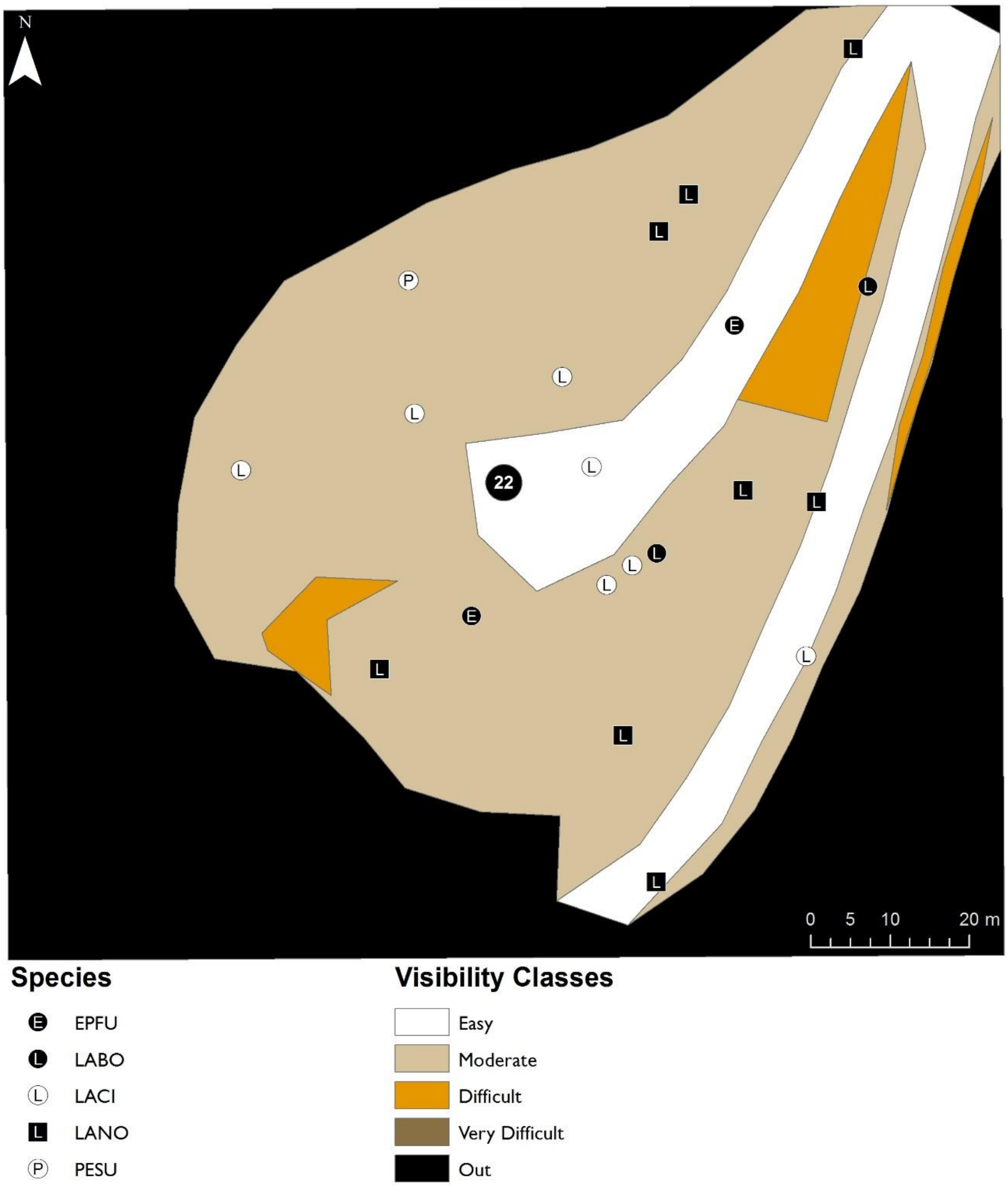


N
19
L
E
0 5 10 20 m
Species
EPFU
LABO
LACI
LANO
Visibility Classes
Easy
Moderate
Difficult
Very Difficult
Out

Turbine 21


N
21
L
0 5 10 20 m
Species
LABO
LACI
LANO
Visibility Classes
Easy
Moderate
Difficult
Very Difficult
Out

Turbine 22


N
22
0 5 10 20 m
Species
EPFU
LABO
LACI
LANO
PESU
Visibility Classes
Easy
Moderate
Difficult
Very Difficult
Out

APPENDIX 2

POST-CONSTRUCTION FATALITY MONITORING RESULTS FROM 15 TURBINES SEARCHED DAILY AT THE PINNACLE WIND FARM, MINERAL COUNTY, WEST VIRGINIA, 2015

In accordance with the guidance from the Pinnacle Technical Advisory Committee, we conducted a bat fatality monitoring study at the Pinnacle Wind Farm (PWF), Mineral County, West Virginia. Monitoring was conducted before (2 June–14 July 2015) and after (1–15 October 2015) the operational minimization study (15 July–30 September). We conducted daily searches at 10 turbines (Turbines 1, 4, 5, 7, 9, 13, 16, 19, 22, and 23) (see Methods section for details on search protocol). All turbines were operating normally with a cut-in speed of 3.0 m/s from 2 June to 14 July and 1 to 15 October 2015. All turbines were operating under conditions of Treatment A (described above) from 1 July–30 September 2015.

During these additional fatality monitoring periods, we found a total of 52 bats of 4 species, including big brown bats, eastern red bats, hoary bats, and silver-haired bats (Table A2). Hoary bats made up the highest proportion of raw fatalities (44%), followed by eastern red bats (27%), silver-haired bats (17%), and big brown bats (12%). This is consistent with similar findings in the West Virginia and the region, fatalities were skewed toward migratory tree-roosting bats (Efroymson et al. 2012, Arnett and Baerwald 2013). Twelve bats were found in June, 28 in July, and 12 in October (Figure A2). A peak in fatalities was observed just prior to the start of the operational minimization study with 10 and 8 bats found on 11 and 12 July, respectively.

We found several fatalities of big brown bats, but no carcasses of tri-colored bats or the genus *Myotis* were found, although we did find a tri-colored bat during the operational minimization study. In the eastern U.S., tri-colored bat and *Myotis* fatalities can each sometimes exceed 25% of all carcasses found (Arnett and Baerwald 2013). Although none of the bats found during this study exhibited signs of WNS, the small percentage of these species found at the PWF may be attributed to the population decline caused by the disease (Turner et al. 2011). In Pennsylvania, Arnett et al. (2010) reported a dramatic decline in the occurrence of these bats between 2009 (pre-WNS in the state) and 2010 (post-WNS), with tri-colored bat fatalities falling from 24% to 10%, and little brown bat fatalities falling from 24% to 4% between years.

It is important to note that these are only raw fatalities and they have not been adjusted for searcher efficiency, carcass persistence, or density-weighted proportion. We did not feel it was appropriate to estimate fatality for either of these two periods or combined, particularly since there were differences in turbine operations between the two periods. Thus, it is difficult to put these fatalities into context with other studies at the PWF or elsewhere in the region because of the fragmented timing in which they occurred. Similar fatality monitoring studies typically are conducted continuously without a gap between monitoring periods.

Table A2. Bat fatalities found during post-construction fatality monitoring conducted at 10 turbines before (2 June–14 July 2015) and after (1–15 October 2015) the operational minimization study at the Pinnacle Wind Farm, Mineral County, West Virginia.

Monitoring period	Turbine cut-in speed	big brown bats	eastern red bats	hoary bats	silver-haired bats	**Total**
2 June–14 July	3.0 m/s	6	8	22	4	**40**
1–15 October	3.0 m/s	0	6	1	5	**12**
Total		**6**	**14**	**23**	**9**	**52**

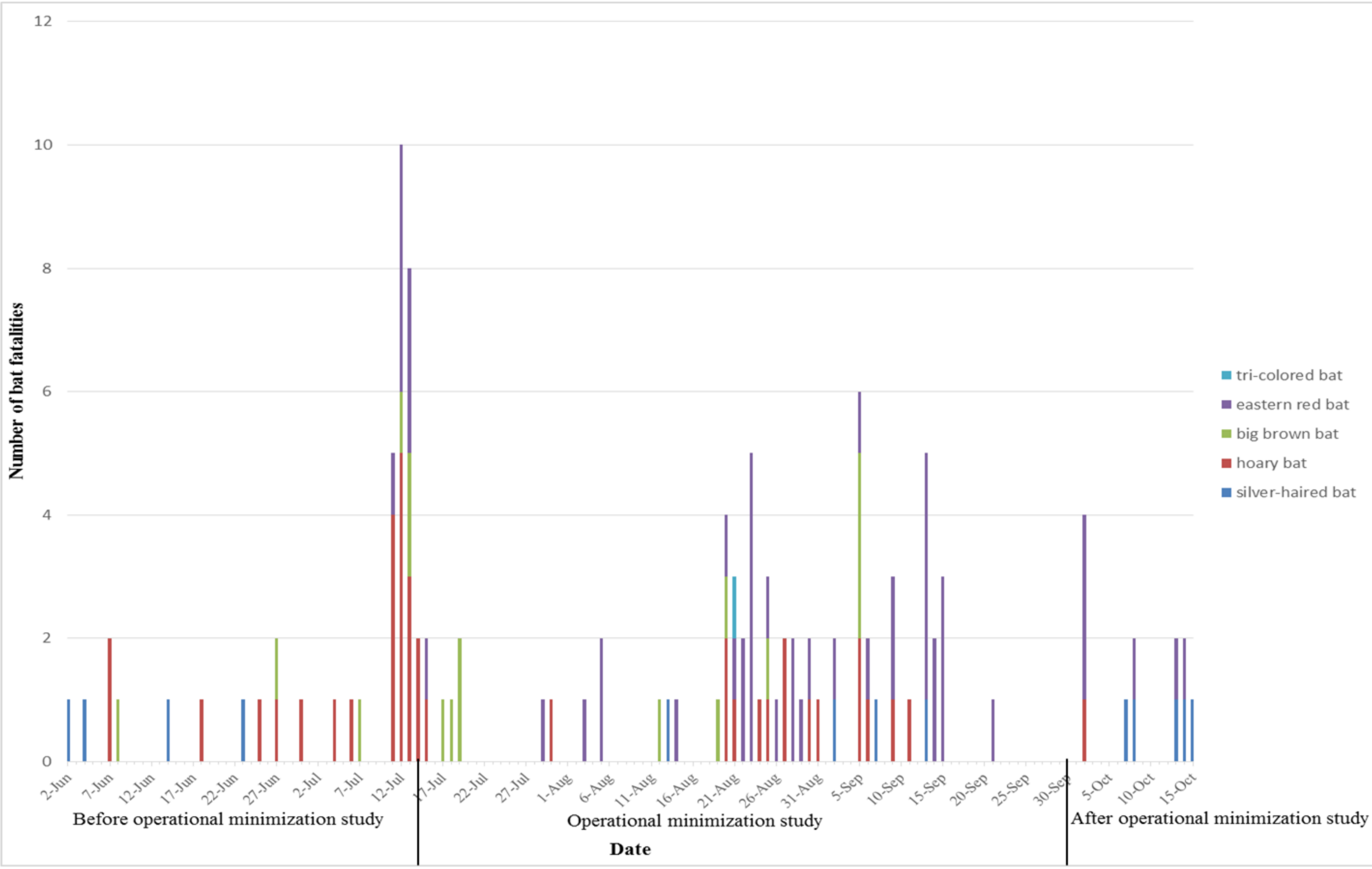


Figure A2. Number of bat fatalities found during post-construction fatality monitoring conducted at 10 turbines fully operational turbines (fully feathered up to 3.0 m/s) before (2 June–14 July 2015) and after (1–15 October 2015) and 15 experimental turbines (15 July–30 September 2015) at the Pinnacle Wind Farm, Mineral County, West Virginia.

APPENDIX 3

IMPACT REDUCTION STRATEGIES TESTED AT THE PINNACLE WIND FARM, MINERAL COUNTY, WEST VIRGINIA, 15 JULY–30 SEPTEMBER 2012–2013, 2015

Table A3. Summary of estimated bat fatality, corrected for detection bias, using Huso et al. (2012) by treatment and decision framework for 15 July–30 September 2012–2015 at the Pinnacle Wind Farm, Mineral County, West Virginia. Control – fully operational turbine, feathered to 3 m/s, for the entire night.

Year	Treatment	Estimated bat fatalities/turbine/study period (95% CI)	Treatment decision framework
2012	Control	74.5 (50.8–105.3)	3-minute average from turbine
	5.0 m/s (first 4 hours)	72.7 (49.6–104.4)	3-minute average from met tower[1]
	5.0 m/s (all night)	39.8 (25.9–59.7)	3-minute average from met tower
2013	Control	90.9 (57.2–153.5)	10-minute average from turbine
	5.0 m/s (all night)	38.4 (18.4–68.9)	10-minute average from met tower
	6.5 m/s (all night)	23.0 (11.3–45.9)	10-minute average from met tower
2015	A: 5.0 m/s (all night)	17.18 (8.10–29.63)	10-minute average from met tower
	B: 5.0 m/s (all night)	13.05 (6.08–24.00)	20-minute average from met tower
	C: 5.0 m/s (all night)	30.75 (15.38–70.95)	20-minute average from turbine

[1]After the first four hours of the night, turbines were fully operational based on a 3 minute average from the turbine