EFFECTIVENESS OF OPERATIONAL MITIGATION IN REDUCING BAT MORTALITY AND AN ASSESSMENT OF BAT AND BIRD FATALITIES AT THE SHEFFIELD WIND FACILITY, VERMONT

by

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A Thesis

In

Wildlife, Aquatic, and Wildlands Science and Management

Submitted to the Graduate Faculty
of Texas Tech University in
Partial Fulfillment of
the Requirements for
the Degree of

MASTER OF SCIENCES

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ACKNOWLEDGMENTS

First off, I thank the funders and supporters of this project; Bat Conservation International, First Wind, National Renewable Energy Laboratory, U.S. Fish and Wildlife Service, and Vermont Department of Fish and Wildlife. I feel privileged to have worked on such a collaborative project with a great team; Josh Bagnato, Dave Cowan, Scott Darling, Cris Hein, Susi von Oettingen, Robert Roy, and Michael Schirmacher. This project would not have been possible without their support.

I am grateful to Dr. Warren Ballard for getting this project going and being willing to take me on as a student even though he had only met me once and his health was failing. I regret I never had the pleasure of getting to know you but I feel I got a glimpse of your spirit and vivacity through all the good stories told in NRM.

My committee members, Drs. Ed Arnett, Clint Boal, Tigga Kingston, and Mark Wallace have provided valuable guidance, assistance, and feedback during my time at Tech. Thank you for making the time for me when you were really busy and had a million other things you needed to be doing. Dr. Wallace made my transition between advisors easy when we lost Dr. Ballard and has often soothed my worries throughout the course of this project, for which I am most appreciative. I also thank Dr. Arnett for giving me my first opportunity to work with bats when he hired me as a field technician years ago, which eventually led to my being here.

I am grateful to Doni Schwalm and Nicole Quintana for helping me find my footing at the start of my project. I thank the graduate students in NRM for helping me get settled into Lubbock and for pestering them with questions about good veterinarians, doctors, and local restaurants, and for being welcoming even though I spent more time away at my field site on the other side of the country than at Tech.

A very special thank you to Dr. Kingston for adopting me into her bat lab. The members (Tigga Kingston, Ain Elias, Marina Fisher-Phelps, Nick Goforth, Joe Chun-Chia Huang, Kendra Phelps, Macy Madden, Maria Sagot, Juliana Senawi, Iroro Tanshi) have provided invaluable feedback and moral support. I greatly enjoyed the peek into the tropical world of bats that I got by working with you and loved the yummy potlucks that provided delicious tastes of cuisines from around the world. I will miss the potlucks and your company a lot!

I thank the great staff in NRM for answering all my questions and minimizing the amount of bumps I hit when working at a field site over 2,000 miles away, particularly Pam Bailey, Renee Dillon, Jeannine McCoy, and Nita Scott. Gim McClarren provided assistance whenever I had questions about my field vehicle, which I am grateful for.

To Dr. Richard Stevens and Manuela Huso for putting up with all my pestering statistics questions and for providing invaluable assistance. Micah-John Beierle was my GIS super hero and so kindly gave up part of his holiday season to help train me in making my maps. I could not have gotten that first annual report done without you!

The First Wind and Clipper crew were a pleasure to work with. Thank you for being so respectful of our plots and taking such care to make sure you didn't mess our transects up when you drove through them; it really was touching the effort you would make to put the rock back in "just the right spot." My crew and I appreciated the encouragement you would leave us during surveys, especially the bat drawings on our rocks and banana peels in the plots that looked just like bats when they dried and tricked us for months. Your enthusiasm about our project was much appreciated; thanks for caring about what we were doing out there and sharing your wildlife observations. A special thank you to Catherine Salazar for replacing the punctured tires on the Kubota on what felt like a weekly (and sometimes daily) basis. Robert Roy was always so prompt and good humored in responding whenever I had a question, even though I know he is extremely busy all the time.

I was lucky to have a wonderful, hardworking crew. Andrew Bouton, Zoe Bryant, Kaitlin Friedman, Gabriella Furr, Michael Iachetta, Kaylee Pollander, Gerardo Sandoval, Lauren Sherman, Jonathon Trudeau, and Melissa VanderLinden diligently walked transects day after day, staring at the ground looking for tiny carcasses hidden in vegetation, which I know from personal experience can be a challenging and tedious job. Not only did we work and live together day in and day out, but we still managed to enjoy each other's company enough to explore the Green Mountain State - getting lost in corn mazes, picking apples, cheese and wine tasting. I loved our cookouts and the challenge of making vegan, gluten-free, delicious recipes. Thank you for working hard, keeping good attitudes, waking up before sunrise, and dealing with rotten, maggot-infested carcasses. I wish you all the best in your future endeavors.

I thank the people of Caledonia County, VT who made living in a new state a great experience, especially the farmers at the farmers market, our post master, and our CSA farmers who treated us as "regulars." I will cherish the fall colors, the local, sustainable food community, seeing my first moose, discovering I love real maple syrup, and living in a cabin on top of a hill overlooking two ponds with a mountain vista. There will always be a special place in my heart for the Northeast Kingdom.

To my family for supporting me in my pursuits of a higher education and putting up with not seeing me for three years and only getting infrequent phone calls. My parents fostered and encouraged my love of learning. To my Papa Raymie, Nana, and Papa Joe for planting the seeds for a love of nature by giving me my first field guides when I was a wee little one and to Mr. Stellern, Mr. Buck, and Jay Boggiato for continuing to fuel that love as I made my way through school. The world needs more fabulous, inspiring teachers like you.

To my partner in life, Gerardo Sandoval, for his patience and understanding during my endeavors. Not only did you make sure that I had food to eat and clean clothes to wear while I pursued my degree, but you also put up with my sometimes not so sweet, stressed out attitude and loved me through it all just the same. I could not have done it without your love and support. And to the four-legged family members in our home, kitties Nip and Tuck, for no matter how grumpy or stressed out I was always having the ability to put a smile on my face by being so furry, fuzzy, and cute.

And lastly to all the researchers, agencies, and wind companies that have been being willing to work collaboratively and proactively to investigate and find answers to this troubling issue. May we find a solution to save these magnificent creatures before it is too late.

COMPOSITION OF THESIS

This thesis is a demonstration of my own efforts to investigate, analyze data, think critically, and interpret research results. Chapters II and III are written as manuscripts for publication. Chapter I follows the Texas Tech Graduate School formatting guidelines. Chapter II follows the formatting guidelines of Northeastern Naturalist and expected coauthors will include Colleen M. Martin, Edward B. Arnett, and Mark C. Wallace. Chapter III follows the formatting guidelines of Journal of Mammalogy and expected coauthors will include Colleen M. Martin, Edward B. Arnett, and Mark C. Wallace. Chapter I is an introduction to wind energy growth in North America and a review of bat and bird fatalities at wind facilities. Chapter II examines bat and bird fatalities at the Sheffield Wind Facility in Vermont, including fatality estimates, patterns of fatalities, and the relationship between fatalities and environmental and site conditions. Chapter III assesses the effectiveness of operational mitigation at reducing bat fatalities, while incorporating temperature as a covariate to fine-tune the design to weather conditions when bats are most active. The information in my thesis is intended to further the understanding of bat and bird fatalities at wind facilities and to guide future mitigation efforts to reduce turbine-related bat fatalities.

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ABSTRACT

Wind turbines have contributed to bird and bat fatalities across North America. In certain locations, such as the forested northeast, bat fatalities have been especially high. With current trends in bat fatalities and the exponential growth of wind installations across North America, immediate actions to reduce turbine-related bat fatalities is imperative to avoid potentially unrecoverable cumulative population-level impacts. In addition, further studies to investigate fatality estimates and patterns in regions across North America are needed to adequately assess impacts to bird and bat populations and inform and refine mitigation efforts. My objectives of this study were to: 1) estimate bird and bat fatalities at a wind facility in Vermont; 2) document patterns of birds and bats killed at turbines, including species composition, age, sex, and seasonal timing; 3) assess the relationship between bird and bat fatalities and environmental and site conditions; and 4) test the effectiveness of operational mitigation at reducing bat fatalities while incorporating temperature as a covariate to improve the design by fine-tuning it to weather conditions when bats are most active.

I initiated a two year study from spring 2012 through fall 2013 at the Sheffield Wind Facility located in Sheffield, Vermont, U.S. From 1 April to 2 June and 1–31 October eight of the 16 turbines were searched daily and from 3 June to 30 September all 16 turbines were searched daily. Searchers walked along transects within designated study plots looking for carcasses. When a carcasses was recovered data on carcass location within study plot (e.g., distance from turbine, azimuth) and carcass characteristics (species, age, sex) were collected. I estimated fatalities using the U.S. Geological Survey's Fatality Estimator software and adjusted for potential biases, including searcher efficiency, carcass persistence, and density-weight proportion areas. Bird fatalities occurred primarily during the spring and fall migration periods, with the majority of fatalities consisting of passerine species. Bird fatalities were estimated to be 211 (95% CI: 147, 321) for the site in 2012, with an estimated 5.27 per MW (95% CI: 3.68, 8.02), and 129 (95% CI: 60, 355) for the site in 2013, with an estimated 3.20 per MW (95% CI: 1.51, 8.86). Bat fatalities occurred primarily during the fall migration period and all bats recovered were migratory tree-roosting species,

the majority of which were adult males. Bat fatalities were estimated to be 235 (95% CI: 160, 361) for the site in 2012, with an estimated 5.86 per MW (95% CI: 4.02, 9.02), and 46 (95% CI: 31, 71) for the site in 2013, with an estimated 1.12 per MW (95% CI: 0.76, 1.76). Bird fatalities were negatively influenced by wind direction and moon illumination, whereas bat fatalities were negatively influenced by wind speed and positively influenced by temperature. I found no difference in bird or bat fatalities among turbines with or without Federal Aviation Administration lighting or turbines located on two different mountain ridges. I also found no difference in bat fatalities at turbines with different rotor diameter sizes, but I did find significantly higher bird fatalities at turbines with a larger rotor diameter.

I conducted the operational mitigation study from 3 June through 30 September of each year. I randomly selected 8 of the 16 turbines each night of the study for an equal number of nights at each turbine to cut-in at 6.0 m/s rather than the normal cut-in speed of 4.0 m/s. Treatments were implemented from half an hour before sunset to sunrise when wind speeds were <6.0 m/s and temperatures were >9.5° C. Bat mortalities at fully operational turbines were 2.7 times higher (95% CI: 1.9, 3.9) than mortalities at treatment turbines in 2012, resulting in an estimated 60% (95% CI: 29, 79) decrease in bat fatalities. In 2013, I found 1.5 times (95% CI: 0.38, 5.94) as many fatalities at fully operational turbines compared to treatment turbines. Few bats were found killed in 2013 and small sample sizes that year limited statistical power. Under the conditions of my study, incorporating temperature may not have reduced bat fatalities due to regional temperatures remaining above the 9.5°C threshold during peak bat fatality period. However, incorporating temperature did decrease the amount of unnecessary energy loss from implementing the treatment when bats are not active, particularly during late spring and early fall when temperatures normally drop below the 9.5°C threshold. As such, including temperature in the design can help improve the appeal of operational mitigation to wind companies by decreasing unnecessary costs. Energy loss from implementing the operational mitigation study was <3% for the study season and approximately 1% for the entire calendar year.

Based on my findings, I recommend that operational mitigation be implemented during high risk periods to mitigate cumulative impacts to bat populations. I also recommend that future research continue to focus on fine-tuning operational mitigation by using other covariates that I did not test. Given the high number of bat fatalities at many wind facilities and the projected future development of wind installations across North America, it is essential for impact reduction strategies to be effective at reducing bat fatalities while also being cost efficient for broad implementation by the wind industry.

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CHAPTER I
INTRODUCTION

Wind Energy in North America

Development of wind energy facilities has grown rapidly worldwide in recent decades (Leung and Yang 2012; GWEC 2015). As concerns with limited energy supplies, increased energy costs, and long-term environmental impacts of fossil fuel use become more prevalent in societies around the globe, interests in development of more sustainable energy options have increased (DOE 2008). Currently, wind energy is the only renewable energy source whose technology is mature enough to employ at a large-scale (Leung and Yang 2012). In addition, recent advances in technology have allowed for more cost-efficient production of wind energy (DOE 2014).

Although wind energy has been commercially used since the early 1980's, installation of wind facilities in North America has increased exponentially in recent years (Fig. 1; NRC 2007; AWEA 2015; CanWEA 2015). In 2012 alone, the U.S. wind industry grew by 28% and was the largest provider of new electric generating capacity, contributing 42% of installed megawatts (MW) in the power sector (AWEA 2013a). Installed capacity in the U.S. and Canada at close of 2014 was 65,879 and 9,694 MW, respectively (AWEA 2015; CanWEA 2015). Nameplate capacity (i.e., maximum output of electricity production, in MW) of contemporary turbines averages 1.87 MW (DOE 2014), totaling over 48,000 utility-scale operating turbines in the U.S. (AWEA 2015). Continued future development is projected in both countries, with proposed goals of reaching 20% of electricity production from wind energy by 2030 in the U.S and 2025 in Canada (CanWEA 2008; DOE 2008). If these goals are met, it would result in an increase of more than 290,000 and 55,000 MW installed capacity in the U.S. and Canada, respectively.

Wind energy is a promising source of clean energy and is in many respects "environmentally friendly," as it does not produce greenhouse gases or pollutants and uses little water (AWEA 2013b). However, development of wind facilities also has been associated with negative impacts to wildlife, including direct mortality from collisions, habitat loss, and displacement (Kuvlesky et al. 2007; NRC 2007). Of particular concern are the bird and bat fatalities that have been documented at facilities across North America (Kunz et al. 2007; Kuvlesky et al. 2007; Arnett and Baerwald 2013). Bat fatalities have been particularly high in certain regions of the continent, such as the midwest and forested northeast. There is a growing concern that observed bat fatality rates are not sustainable and that if current trends continue, cumulative population-level impacts to bats in North America are inevitable (Kunz et al. 2007; Arnett et al. 2008; Arnett and Baerwald 2013).

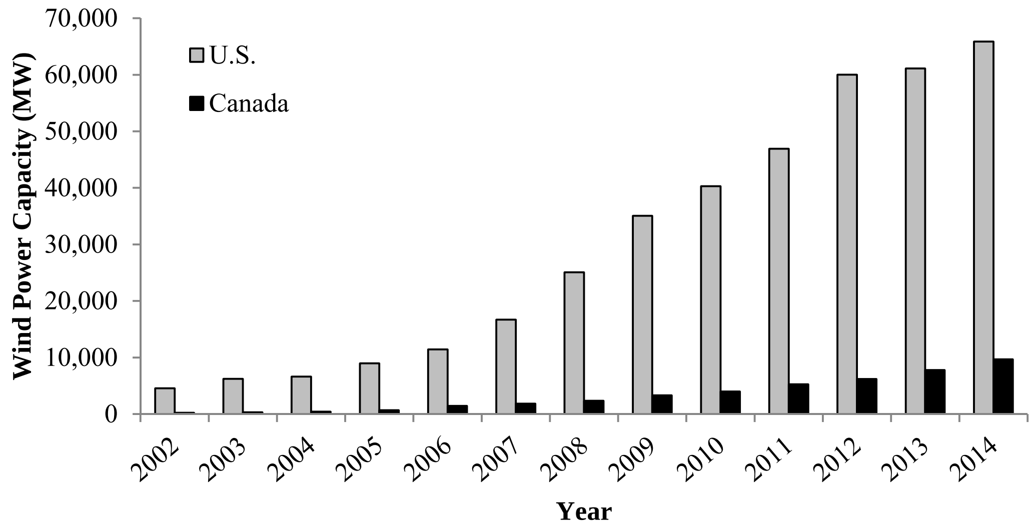

Figure 1. Wind power capacity growth in U.S. and Canada from 2002–2014.

Estimating Bird and Bat Fatalities at Wind Facilities

Estimating bird and bat fatalities can be challenging, as a number of factors must be considered. Rather than simply documenting the number of carcasses found beneath a turbine, variables such as search effort, carcass persistence, searcher efficiency, and density-weight proportion area must also be accounted for (Bernardino et al. 2013; Huso and Dalthorp 2014). In addition, there are at least 10 estimators that have been used in the literature, all of which use different statistical analyses to calculate fatality, each with inherent bias toward under- or over-estimation (Bernardino et al. 2013). Because of these confounding factors, fatality estimates are difficult to calculate and often not easily comparable from one study to the next or to make regional or continent-wide assessments of bird and/or bat fatalities.

Bird Fatalities at Wind Facilities

Bird collisions with wind turbines have been documented across North America (Kuvlesky et al. 2007; Loss et al. 2013; Erickson et al. 2014). Particularly high fatality rates have been observed at older wind facilities (i.e., late 1980's and 1990's), especially at the Altamont Pass Wind Resource Area in California, where annual fatalities were estimated to be 1,127 raptors and 1,045 passerines, with estimates as high as 2,277 raptors and 7,037 passerines (Smallwood and Thelander 2008). Older lattice-type towers, as well as poor facility placement and site configuration, have been associated with high collision risk (Marques et al. 2014). Adaptations to the construction and design of wind turbines, including changes in turbine structure (e.g., lattice to monopole towers), Federal Aviation Administration and project site lighting, and placement of turbines and facilities, have resulted in a decrease in bird fatality rates at newer wind facilities (Kuvlesky et al. 2007; Smallwood and Karas 2009; Marques et al. 2014).

Of all bird groups, passerines experience the highest rate of fatalities (>60%) at newer wind facilities in the U.S. (i.e., circa 2000 and on; Erickson et al. 2014). In a meta-analysis of 116 post-construction fatality studies from 71 wind facilities in the U.S. and Canada between 1996–2012 Erickson et al. (2014) found that among passerine families, larks (Alaudidae) and wood warblers (Parulidae) were killed at the highest rate, 13.7% and 10.8%, respectively. Of the 25 most commonly recovered passerine species, they determined that Horned Lark (21.9%; *Eremophila alpestris*), Red-eyed Vireo (8.5%; *Vireo olivaceus*), Western Meadowlark (5.1%; *Sturnella neglecta*), and Golden-crowned Kinglet (5.1%; *Regulus satrapa*) were killed at the highest rates. Fatalities were widely distributed among most other species, generally making up ≤1% of fatalities (Erickson et al. 2014). They estimated that 134,000–230,000 passerines were killed at wind facilities annually. A meta-analysis by Loss et al. (2013) produced a similar finding, with annual bird fatality estimates at 140,000–328,000.

Bat Fatalities at Wind Facilities

Bat fatalities have been observed at all wind energy facilities in North America where post-construction surveys have been reported and high numbers of fatalities have been observed at many (Kunz et al. 2007; Arnett et al. 2008). Estimating fatalities can be challenging, as a number of factors must be considered. Rather than simply documenting the number of carcasses found beneath a turbine, variables such as search effort, carcass persistence, and searcher efficiency must also be accounted for (Bernardino et al. 2013). In addition, there are at least 10 estimators that have been used in the literature, all of which use different statistical analyses to calculate fatality, each with inherent bias toward under- or over-estimation (Bernardino et al. 2013). Because of these confounding factors, fatality estimates are difficult to calculate and often not easily comparable from one study to the next or to make regional or continent-wide assessments of bat fatalities.

Although it can be challenging to extrapolate bat fatalities beyond project sites, estimates of cumulative fatalities have been conducted and predict hundreds of thousands of fatalities annually at wind facilities in North American (Cryan 2011; Arnett and Baerwald 2013; Hayes 2013; Smallwood 2013). Based on reported bat fatality rates at wind facilities and 40,000 MW of installed capacity in the U.S. and Canada in 2011, Cryan (2011) estimated that 450,000 bats are killed by wind turbines per year in North America. Estimates of turbine-related fatalities in the U.S. in 2012 ranged from 600,000–888,000 bats (Hayes 2013; Smallwood 2013). In a synthesis of reported fatalities from peer-reviewed literature and publically available reports, Arnett and Baerwald (2013) estimated that from nearly 840,500 to more than 1.69 million turbine-related bat fatalities occurred in North America between 2000–2011. Additionally, proposed estimates are most likely conservative (Hayes 2013).

Certain areas in the American southwest that have high bat species richness and large colonies of Mexican free-tailed bats (*Tadarida brasiliensis*) have not been well studied and/or data have not been made publically available (O'Shea et al. 2003; Hayes 2013; USGS 2015), yet these regions have experienced, or are projected to experience, high levels of wind capacity installation (AWEA 2015). Although few studies have been reported, the limited data that is publically available shows high fatality rates of this species (Miller 2008; Piorkowski and O'Connell 2010; Arnett et al. 2013); as a result, estimates for this region are likely below actual fatality numbers. Additionally, many of the fatality estimates that have been calculated have used underestimated levels of MW capacity in the U.S. and, as such, the number of fatalities are likely underestimated as well (Hayes 2013). For example, both Hayes (2013) and Smallwood (2013) used approximately 51,000 MW of installed capacity in the U.S. for their 2012 fatality estimates, but by the end of that year over 60,000 MW were installed in the U.S. (AWEA 2015). Consequently, bat fatalities in North America are likely higher than reported estimates.

Post-construction surveys for bat fatalities at wind facilities across North America have shown that fatalities are not consistent across space, time or species, but rather show distinct geographic, demographic, and environmental patterns (Arnett et al. 2008; Baerwald and Barclay 2011; Arnett and Baerwald 2013). In a synthesis of post-construction fatality studies conducted between 1996–2006 at 19 wind facilities in the U.S. and Canada, Arnett et al. (2008) found that fatalities were highest at sites located along forested ridges in the northeast. While fatalities still appear to be highest in the northeast, recent studies have found that fatalities also are high in areas where they were previously believed to be low, including the midwest forest-agricultural region and the Great Plains (Arnett and Baerwald 2013). These increases may be a result of a greater number of studies conducted in the region, as well as an increase in wind capacity installation in areas with high bat activity (e.g., Mexican free-tailed bat colonies) over the past few years. Bat fatalities are generally lowest in southwest deserts, possibly because facilities in these areas are not located within migration corridors (Arnett and Baerwald 2013). Additionally, limited availability of roosting and foraging habitats in areas of the southwest where many of the wind facilities are built may result in limited bat activity, and thus lower levels of fatality risk in those areas (Arnett and Baerwald 2013).

Twenty-one of the 47 bat species that occur in North America have been documented to have been killed at wind facilities (Arnett and Baerwald 2013).

Approximately 75–80% of bat species killed are tree-roosting, migratory species; eastern red bat (*Lasiurus borealis*), hoary bat (*Lasiurus cinereus*), and silver-haired bat (*Lasionycteris noctivagans*; Johnson 2005; Kunz et al. 2007; Arnett et al. 2008; Arnett and Baerwald 2013). Fatalities occur primarily during fall migration season (mid-July to late September), with a peak in August, and most individuals killed are adult males (Arnett et al. 2008; Baerwald and Barclay 2011; Arnett and Baerwald 2013). Studies that have simultaneously measured bat activity and fatality at wind facilities have found fatalities to be higher on nights when bats were more active (Baerwald and Barclay 2009; Baerwald and Barclay 2011; Korner-Nievergelt et al. 2013).

Bat fatalities at wind facilities often occur on nights where wind speeds are low (<6 m/s) and temperatures are warm, coinciding with environmental conditions in which both bats and their prey (i.e., insects) are active (Baerwald and Barclay 2011; Jain et al. 2011; Grodsky et al. 2012; Weller and Baldwin 2012; Arnett and Baerwald 2013). Fatalities also have been associated with barometric pressure, relative humidity, wind direction, and moon illumination (Fiedler 2004; Baerwald and Barclay 2011; Amorim et al. 2012). There also is evidence that while broad patterns in environmental conditions and bat fatalities occur, species-specific fatalities vary in their correlation with weather variables (Baerwald and Barclay 2011).

Conservation Implications

The number of bird fatalities at wind facilities studied to date is generally lower compared to bats (Barclay et al. 2007; Kuvlesky et al. 2007; PGC 2012), and the development and implementation of mitigation measures to reduce the number of birds killed at wind facilities has led to a decrease in fatalities at some facilities in North America (Kingsley and Whittam 2005; Smallwood and Karas 2009). Although 134,000–328,000 birds are estimated to be killed annually at wind facilities (Loss et al. 2013; Erickson et al. 2014), it is not believed that these numbers are high enough to significantly affect most bird populations (Kuvlesky et al. 2007; Desholm 2009; Zimmerling et al. 2013; Erickson et al. 2014). A meta-analysis of bird fatalities from 43 wind facilities in Canada determined that <0.2% of the population of any bird species was impacted by wind energy (accounting for both mortality and displacement; Zimmerling et al. 2013). Another study that assessed bird fatalities from 71 wind facilities in North America estimated that continent-wide impacts from turbine-related mortality were between 0.001–0.043% of the population for all species considered (Erickson et al. 2014). It has been suggested that even fatalities from collisions with communication towers, which are estimated to kill 6.8 million birds annually (Longcore et al. 2012), do not have a significant effect on bird population trends (Arnold and Zink 2011). The majority of birds killed at wind facilities are short-lived, have a high reproductive rate, and are a small portion of a large reference population, thus having no palpable effect on long-term population dynamics (Desholm 2009; Arnold and Zink 2011; Zimmerling et al. 2013; Erickson et al. 2014).

However, bird fatalities at certain wind facilities are a concern (e.g., facilities located in migration corridors or areas with high raptor populations; Barrios and Rodriguez 2004; Drewitt and Langston 2006; Carrete et al. 2009; Bellebaum et al. 2013). Additionally, bird fatalities have been shown to increase with increased turbine height (Loss et al. 2013). Given that new technologies and designs are resulting in taller turbines (DOE 2014) and that installed capacity of wind facilities is expected to continue (CanWEA 2008; DOE 2008), bird fatalities at wind facilities may impact populations of some bird species, particularly long-lived and threatened species, and should not be disregarded (Desholm 2009; Loss et al. 2013).

Turbine-related fatalities pose numerous threats to North American bats, including take of endangered species and long-term population-level impacts (Kunz et al. 2007; Boyles et al. 2011; Arnett and Baerwald 2013). Two U.S. Fish and Wildlife Service (USFWS) federally-listed endangered species have been reported to have been killed at turbines; the Indiana bat (*Myotis sodalis*) and Hawaiian hoary bat (*L. cinereus semotus*; Arnett and Baerwald 2013). In addition, although fatalities of USFWS federally-listed endangered lesser-long nosed bats (*Leptonycteris yerbabuenae*) have not yet been documented at a wind facility, few post-construction fatality studies have been conducted at facilities located within the range of this species (i.e., southwestern deserts) and as such, it is possible that undocumented fatalities already have occurred. In addition, wind installation is projected to increase in this region and consequently future fatalities are likely (Arnett and Baerwald 2013).

Turbine-related bat fatalities also may have potential negative impacts on populations of cave-roosting bats. In general, fatalities of cave-roosting bats are relatively low at wind facilities, although some sites have reported high numbers of kills (Jain et al. 2011; Arnett and Baerwald 2013). However, given catastrophic declines of cave-roosting bats in eastern North American resulting from white-nose syndrome (WNS; *Pseudogymnoascus destructans*; Frick et al. 2010; Turner et al. 2011; BCI 2015), even small numbers of turbine-related fatalities may result in serious impacts to populations. It is estimated that over 5.5 million bats in North America have been killed by WNS, with 90–100% of populations extirpated in some areas (USFWS 2014). Frick et al. (2010) have projected that the regional extinction of some species could occur in <20 years, including little brown bat (*Myotis lucifugus*) populations, which prior to the introduction of WNS was a common species. Consequently, although turbine-related fatalities of cave-roosting bats are relatively low, even minimal fatalities may have a substantial impact on populations already threatened with extinction (Arnett and Baerwald 2013).

Although population numbers of migratory bats are unknown, it is projected that current levels of turbine-related fatalities are not likely sustainable, and if current trends continue, will result in cumulative population-level impacts (Kunz et al. 2007; Boyles et al. 2011; Arnett and Baerwald 2013). Most bats reproduce once a year and typically give birth to only 1–2 young (Altringham 1996). This low reproductive rate results in low intrinsic rates of population growth, making bats highly susceptible to population declines and limited in their ability to recover from serious losses (Barclay and Harder 2003).

Between turbine-related tree-roosting bat fatalities and cave-roosting bat fatalities from WNS, it is possible that certain regions of North America could experience severe losses or extinction of entire bat populations (Kunz et al. 2007; Frick et al. 2010; Boyles et al. 2011; Arnett and Baerwald 2013). Bats are important to healthy ecosystems, human health, and the economy, and reduction or losses of bat populations could result in a loss of biodiversity, a disruption of predator-prey relationships, and human benefits (Boyles et al. 2011; Kunz et al. 2011). The majority of bat species in North America are insectivorous and play a vital role in suppressing insect populations (Kunz et al. 2011). Bats feed on a variety of insects, many of which are considered pests to humans, including disease vectors (e.g., mosquitoes; Rydell et al. 2002; Reiskind and Wund 2009) and agricultural pests (e.g., cotton bollworm moth; Kunz et al. 2011). Boyles et al. (2011) estimated that insect suppression by bats contributes approximately $22.9 billion in savings per year in the U.S. agricultural industry through saved costs of pest control; with cost saving estimates ranging from $3.7–$53 billion, making bats one of the most economically influential wildlife species in North America. Also, by reducing insects and thus the amount of pesticide application required, bats may also help in preventing the evolution of pesticide resistance in insects and decreasing the amount of chemical pollutants released into the environment (Boyles et al. 2011; Kunz et al. 2011). In addition, Boyles (et al. 2011) used old turbine- related fatality estimates (Kunz et al. 2007) in their analysis. Newer estimates suggest even higher bat fatalities at wind facilities (Arnett and Baerwald 2013), and thus, greater potential economic and environmental impacts.

In response to growing concerns over the number of bat fatalities at wind facilities, conservationists have explored different mitigation measures that may reduce fatalities. The most promising mitigation measure is operational mitigation, which has been shown to result in a minimum of 50%, and as high as 93%, decrease in fatalities in most studies (Arnett et al. 2013). Operational mitigation reduces bat fatalities during low wind conditions, when fatalities have been observed to be highest, by raising turbine cut-in speed (defined as the lowest wind speed when electricity is generated into the power grid, usually 3.5–4.0 m/s for contemporary turbines). Based on an assessment of the 10 operational mitigation studies conducted to date, Arnett et al. (2013) determined that increasing turbine cut-in speed from 1.5–3.0 m/s above the manufacturer's cut-in speed (e.g., from 3.5–4.0 m/s to 5.0–6.5 m/s) can significantly reduce bat fatalities. To date, the majority of operational mitigation studies are only available in gray literature; the only published studies are those conducted by Arnett et al. (2011) in Pennsylvania, U.S. and Baerwald et al. (2009) in Alberta, Canada. Arnett et al. (2011) tested two raised cut-in speeds, 5.0 m/s and 6.5 m/s, and found that raised cut-in speed resulted in a 44–93% nightly reduction in fatalities, although they did not detect a significant difference among the two cut-in speeds. Baerwald et al. (2009) tested one raised cut-in speed, 5.5 m/s, which resulted in a 60% decrease in bat fatalities.

Some turbines are designed in a such a way that their blades spin when winds are below manufacturer's cut-in speed (i.e., free-wheeling), meaning that blades are spinning, and potentially killing bats, even when no electricity is being produced (Arnett et al. 2013). A study in West Virginia found that feathering turbine blades (defined as pitching the angle of the blades to be parallel with the wind so that they do not spin or only spin slowly) at or below the manufacturer's cut-in speed of 4.0 m/s yielded significant reductions in bat fatalities (Young et al. 2011). Additionally, Baerwald et al. (2009) found that feathering turbine blades to produce a low idling speed below the manufacturer's normal cut-in speed of 4.0 m/s resulted in approximately 60% fewer bat fatalities. These studies demonstrate that some bat fatalities can be avoided without any losses in energy production by changing the operation of turbines during low wind conditions when no electricity is generated into the power grid.

With current trends in bat fatalities and the exponential growth of wind installations across North America, immediate actions to reduce turbine-related bat fatalities is imperative to avoid potentially unrecoverable cumulative population-level impacts. In addition, further studies to investigate fatality estimates and patterns in regions across North America are needed to adequately assess impacts to bird and bat populations and inform and refine mitigation efforts. My objectives of this study were to: 1) estimate bird and bat fatalities at a wind facility in Vermont; 2) document patterns of birds and bats killed at turbines, including species composition, age, sex, and seasonal timing; 3) assess the relationship between bird and bat fatalities and environmental and site conditions; and 4) test the effectiveness of operational mitigation at reducing bat fatalities while incorporating temperature as a covariate to improve the design by fine-tuning it to weather conditions when bats are most active.

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CHAPTER II
BAT AND BIRD FATALITY ESTIMATES AND PATTERNS AT A WIND FACILITY IN VERMONT

Introduction

Wind energy has become the fastest growing energy sector in North America, with growing societal concerns regarding carbon emissions, climate change, and fossil fuel independence driving the development and advancement of renewable energies (AWEA 2015, CanWEA 2015, NRC 2007). In 2012 alone, the U.S. wind industry grew by 28% and was the largest provider of new electric generating capacity, contributing 42% of installed megawatts (MW) in the power sector (AWEA 2013a). Installed capacity in the U.S. and Canada at close of 2014 was 65,879 and 9,694 MW, respectively (AWEA 2015, CanWEA 2015). Continued future development is projected in both countries, with proposed goals of reaching 20% of electricity production from wind energy by 2030 in the U.S and 2025 in Canada (CanWEA 2008, DOE 2008). If these goals are met, it would result in an increase of more than 290,000 and 55,000 MW installed capacity in the U.S. and Canada, respectively. Assuming an average 2.0 MW turbine nameplate capacity, this is equivalent to an additional 145,000 turbines in the U.S. and 27,500 in Canada. Although wind energy emits no greenhouse gas emissions or pollutants and requires little water (AWEA 2013b), gaining it a reputation for being sustainable and environmentally friendly, the development of wind facilities has been associated with a high number of fatalities of both bats (e.g., Arnett and Baerwald 2013, Arnett et al. 2008, Kunz et al. 2007a) and birds (e.g., Kuvlesky et al. 2007, Loss et al. 2013, Smallwood and Thelander 2008).

Bat fatalities have been observed at all wind energy facilities in North America where post-construction surveys have been reported and high numbers of fatalities have been observed at multiple wind energy facilities (Arnett et al. 2008, Kunz et al. 2007a). Bats are killed at turbines from blunt force trauma via blade strikes and/or barotrauma due to rapid decreases in air-pressure surrounding moving blades, resulting in internal hemorrhaging and inner ear damage (Baerwald et al. 2008, Grodsky et al. 2007, Rollins et al. 2012). Current estimates of cumulative fatalities predict that hundreds of thousands of bats are killed on an annual basis at wind facilities in North America (Arnett and Baerwald 2013, Hayes 2013, Smallwood 2013). Of particular concern are bat fatalities at wind facilities in the midwest and on forested ridges in the eastern U.S., where fatalities at some projects have been quite high, especially for migratory tree-roosting bats (Arnett and Baerwald 2013, Arnett et al. 2008).

Advances in wind technology in the last few decades have resulted in larger turbines, with taller towers, longer blades, and increased rotor diameter (DOE 2014). Bat fatalities have been found to be highest at taller, larger turbines (Barclay et al. 2007, Georgiakakis et al. 2012, Rydell et al. 2010). Newer, taller turbines may be encroaching into the area of air space that migrating bats and birds travel in, increasing the risk of collision (Barclay et al. 2007). This poses great concern as wind technology continues to produce larger turbines (DOE 2014).

Birds are killed at turbines due to blunt force trauma from blade strikes or collision with monopole towers (Marques et al. 2014). The number of bird fatalities at wind facilities studied to date is generally lower compared to bats (Barclay et al. 2007, Kuvlesky et al. 2007, PGC 2012), and development and implementation of mitigation measures to reduce the number of birds killed at wind facilities has led to a decrease in fatalities at some facilities in North America (Kingsley and Whittam 2005, Smallwood and Karas 2009). Although bird fatalities at certain wind facilities are a concern (e.g., facilities located in migration corridors or areas with high raptor populations; Barrios and Rodriguez 2004, Bellebaum et al. 2013, Carrete et al. 2009, Drewitt and Langston 2006), it is not believed that wind-related bird fatalities occur at high enough numbers to significantly affect most bird populations (Desholm 2009, Erickson et al. 2014, Kuvlesky et al. 2007, Zimmerling et al. 2013). However, bird fatalities have been shown to increase with increased turbine height (Loss et al. 2013). Given that new technologies and designs are resulting in taller turbines (DOE 2014) and that installed capacity of wind facilities is expected to continue (CanWEA 2008, DOE 2008), bird fatalities at wind facilities may impact populations of some bird species and should not be disregarded (Desholm 2009, Loss et al. 2013).

In 2011, Vermont experienced a 650% increase in proposed new wind installations; the second highest growth rate of wind energy in a U.S. state that year (AWEA 2012). The Sheffield Wind Facility is the first facility in Vermont to operate new generation turbines, which are substantially taller and have longer blades in comparison to older designs (DOE 2014). In addition, relatively few studies of bat and bird fatalities at wind facilities in forested areas of the northeastern U.S. are publically available. As such, the effects of newer turbines on bats and birds in Vermont is yet unknown.

To adequately assess impacts of current and proposed wind facilities on bat and bird populations across North America, further research in different regions and habitats, as well as assessing patterns of bat and bird fatalities in relation to environmental and site conditions, is imperative (Arnett et al. 2008; Kunz et al. 2007a, b). Our objectives of this study were to 1) estimate bat and bird fatalities at a wind facility in Vermont; 2) document patterns of bats and birds killed at turbines, including species composition, age, sex, and seasonal timing; and 3) assess the relationship between bat and bird fatalities and environmental and site conditions.

Field-Site Description

We conducted our study at the Sheffield Wind Facility (herein referred to as the "site"), located near the town of Sheffield in the Northeast Kingdom, Caledonia County, Vermont (44°39'47"N, 72°07'18"W; Fig. 1). The site occurs within the Northern Vermont Piedmont biophysical region, which is comprised of gentle, rolling foothills and river valley topography, dominated by calcareous rocks in the uplands, with sand and gravel deposits in the valleys (Thompson 2002). Rivers and streams are common throughout the region, flowing through dissected hills, which have created extensive but narrow floodplains dotted with small wetlands, lakes, and ponds (Thompson 2002).

The site occurs along a forested ridge, with elevations from 594–728 m (Fig. 2). Approximately two-thirds of the 1,012 ha site is located on land under a conservation easement. The area has previously been logged and consists primarily of new growth deciduous hardwood forest composed of *Acer saccharum* Marsh (Sugar Maple), *Betula alleghaniensis* Britton (Yellow Birch), and *Fagus grandifolia* Ehrh. (American Beech), with smaller patches of coniferous forest dominated by *Abies balsamea* (L.) Mill (Balsam Fir). Surrounding land uses include open space, rural residential, dairy farming, and logging.

The site is owned and operated by Vermont Wind, LLC (Vermont Wind), a subsidiary of First Wind, and consists of 16 Clipper 2.5 MW turbines for a total of 40 MW for the project. All 16 turbines have 80 m tall masts; 4 turbines have 96 m rotor diameter with a rotor-swept area of 7,238 m^2 and 12 turbines have 93 m rotor diameter with a rotor-swept area of 6,793 m^2. Half of the turbines have red flashing Federal Aviation Administration (FAA) lights on the nacelles, which are evenly distributed across the site. The wind facility consists of 2 “strings” of turbines, referred to as the “A String” and “B String”, which are located on 2 mountain ridges (Fig. 2). There is one 80 m tall meteorological tower on site, located on the B String near Turbine (T) 7 and T8. Operation of the site began in October 2011.

Methods

Post-construction fatality estimates

We conducted post-construction fatality searches from 1 April to 2 June and 23 April to 2 June in 2012 and 2013, respectively (hereafter referred to as “Period 1”); snow cover at the site delayed start of surveys in 2013. Searches were conducted from 3 June to 30 September (hereafter referred to as “Period 2”) and 1–31 October (hereafter referred to as “Period 3”) in both years. The study season was split into three periods in order to calculate fatality estimates (see Fatality Estimates subsection below). To assess fatality of migratory bat species, as well as resident bats, we designed the study to take place for the full length of the active bat season (early spring through late fall; Horn et al. 2008; Kunz et al. 2007a). We used survey methods similar to those in Arnett et al. (2009). During Period 2, we conducted an operational mitigation study from 3 June to 30 September each year to test the effectiveness of raising turbine cut-in speed at reducing bat fatalities while incorporating temperature as a covariate to improve the design by fine-tuning it to weather conditions when bats are most active (see Martin 2015).

Study plots. We established study plots around each turbine center, running 126 m east-west and 120 m north-south, with a total maximum area of 15,120 m^2 and 60 m from turbine mast in any direction (Appendix A). Only exposed areas where a bat would have 100% chance of landing on the ground were included in study plots; as a result the size of plots were dependent on vegetation present at each turbine. Areas that were wooded or densely vegetated were not included. We established transects every 6 m, running north-south, using wooden stakes, flagging, and spray paint (Appendix A). We measured percent of ground cover, habitat type, and slope at each study plot to determine visibility classes and their combined influence on carcass detectability (Appendix B; Arnett et al. 2009). Environmental permitting conditions for facility construction required all exposed soil areas to be hydroseeded with an erosion control plant mixture following construction to prevent soil erosion. Some species that were planted, such as *Trifolium* spp. L. (Clover), are low growing but very dense in nature, resulting in almost 100% ground cover and little to no visibility of potential carcasses. As such, we did not factor vegetation height into visibility class designation. We used Global Positioning System to map survey plots, including actual searched area (i.e., survey plot) and visibility classes (Appendices C and D).

Fatality searches. We randomly selected 8 of the 16 turbines for daily post-construction fatality searches during Periods 1 and 3. These included T1, T3, T4, T6, T8, T10, T12 and T16 in 2012 (Appendix E, Fig. E.1) and T1, T3, T4, T7, T9, T13, T14, and T16 in 2013 (Appendix E, Fig. E.2); an operational mitigation study was conducted during Period 2 (see Martin 2015), at which time all 16 turbines were searched. We varied the order in which study plots (e.g., T1, T2, etc.) and transects within a study plot (e.g., north to south starting on the west end) were surveyed on a daily basis to account for potential biases such as changes in daylight and carcass detectability in different conditions. Surveys began at sunrise and ceased only if severe or otherwise unsafe weather or site conditions (e.g., heavy rain, lightning, turbine maintenance) were present. All personnel were trained on search techniques (following Arnett et al. 2009) and identification of locally occurring bat and bird species (following Kays and Wilson 2002, Sibley 2000, Williams et al. 2002).

Each searcher surveyed 8 study plots per day. Searchers recorded date, start and end time, weather conditions, and observer for each study plot surveyed. Searchers walked along each transect at approximately 10–20 m/min looking for carcasses, with a search image of approximately 3 m on each side of the transect. Search time per survey plot ranged from 42–69 minutes, depending on plot size. When a carcass was located, the searcher contacted the field crew leader (Colleen M. Martin) to confirm that it was a new carcass rather than a trial carcass (see Bias Trials below). Upon survey completion, data were recorded on a fatality data sheet for each new carcass found (Appendix F), including date, time found, turbine number, observer name, species, age, sex, carcass condition (i.e., entire, partial, scavenged), estimated time of death, visible signs of cause of death, and immediate surrounding habitat. Location of each carcass within the study plot was measured and recorded, including transect number, perpendicular distance from transect, azimuth from turbine, and distance from turbine. Three photographs of each carcass were taken; from the transect line, a 1 m^2 overview of the carcass, and a close-up of the carcass. Carcasses were labeled with an identification code (date_species code_turbine_number found that day, e.g., 6/21/13_LABO_T14_1) and placed in a resealable plastic bag, which was taken back to the field station to either be redistributed as a trial carcass or frozen for submission to Vermont Department of Fish and Wildlife (VDFW). The field crew leader was responsible for confirming species identification at the end of each day. Incidental observations of carcasses found within the site, either by searchers or Vermont Wind employees, were recorded and collected using the same methods.

Searchers wore rubber gloves whenever handling carcasses. The appropriate wildlife salvage and handling permits were obtained from the necessary agencies, including VDFW (Authorization #: SR-2012-05), U.S. Fish and Wildlife Service (USFWS; Permit #: MB75107A-0), and Texas Tech University Animal Care and Use Committee (ACUC #: 12030-03), prior to handling any carcasses. All bat carcasses were examined for white-nose syndrome (WNS) using the wing damage index per Reichard and Kunz (2009).

Bias trials. We conducted searcher efficiency and carcass persistence trials to account for bias and calculate corrected estimates of total bat fatalities. To account for changes in weather patterns, scavenger presence and density, and grounds maintenance, we implemented field bias trials throughout the entire field season (Johnson 2005). To avoid detection bias, searchers did not know which study plots had trial carcasses or the number of trial carcasses being used at any given time.

We used both bat and bird carcasses found during daily searches in the bias trials. To distinguish between new and trial carcasses within survey plots outer toes were removed from all trial carcasses. Rubber gloves were used when handling all carcasses to avoid leaving traces of human scent, which may attract scavengers. Only fresh carcasses (i.e., died on previous night) were used in carcass persistence trials whereas both fresh and non-fresh (i.e., died >1 night) carcasses were used for searcher efficiency trials.

The field crew leader distributed trial carcasses at survey plots using a randomly generated list of turbine numbers, azimuths from turbines, and distances from turbines. Date of placement, distance and azimuth from turbine, and visibility class surrounding the carcass were recorded. A maximum number of 4 trial carcasses were placed at a single survey plot at one time.

The field crew leader checked on all trial carcasses daily (as feasible) until it was either found by a searcher, removed by a scavenger, or 20 days had elapsed since it was initially placed in the survey plot. When a trial carcass was found by a searcher, the day that it was located was recorded. At that time, all crew members were notified and they then reported on its status during daily searches for the remainder of the 20-day trial period to monitor carcass persistence rates.

Statistical analyses

Fatality estimates. We used the U.S. Geological Survey (USGS) Fatality Estimator software (Data Series 729) to estimate bat and bird fatalities at the site (Huso et al. 2012). The Fatality Estimator (herein referred to as the “estimator”) software uses data from bias trials to estimate searcher efficiency and carcass persistence, which are then used to adjust for bias and calculate estimated fatalities per turbine and for the entire site based on data from fresh carcasses found during fatality searches; carcasses found incidentally (i.e., not during official surveys) were not included in the data used to estimate fatality. The estimator only uses searcher efficiency data based on 1 day (i.e., only the first search attempt); as such, only fresh fatality carcasses were used when estimating fatalities to minimize overestimates. This estimator inputs parameters for site and study information, including total number of turbines at the site and total number of turbines used in the study. Because 8 of the 16 turbines were searched during Periods 1 and 3 and all 16 turbines were searched during Period 2, separate datasets had to be analyzed for the study periods.

We combined the Difficult and Very Difficult visibility classes for both the fatality data and bias trials for bats and for birds as sample size for Very Difficult was too small. We used 95% confidence intervals (CI; alpha 0.05) with 5,000 bootstrap resamples for all datasets and ranked models using Akaike’s Information Criterion (AIC_c). We used AIC_c values and differences between AIC_c values (ΔAIC_c) to determine the most parsimonious model; that is models with the lowest AIC_c values and ΔAIC_c equal to 0, with >2 ΔAIC_c units difference from other models (Anderson 2008, Burnham and Anderson 2002).

We modeled searcher efficiency as a function of visibility class for both bat and bird bias trials (lowest AIC_c with ΔAIC_c >10 units compared to modeling with no explanatory variables). We fit carcass persistence data to a series of 4 distribution models: 1) Weibull, 2) exponential, 3) loglogistic, and 4) lognormal using both no explanatory variables and visibility class as an explanatory variable. Due to small sample sizes for some of the study periods for bat and/or bird carcasses, searcher efficiency and carcass persistence datasets and models differed between 2012 and 2013. The specific datasets and models used for each study season and carcass type are described below.

To adjust for areas within survey plots that were not searchable and to extrapolate estimates to the entire study plot (i.e., density-weighted proportion areas), we set a 200 m^2 fishnet map around each turbine center and rasterized the area beneath each turbine into 1 m^2 units, calculated its distance from turbine, its visibility class, and recorded whether a carcass had been found within the unit or not (Appendix G, Fig. G.1). We fit the data to a series of 5 logistic regression models increasing in complexity: 1) null model, 2) visibility class, 3) distance + visibility class, 4) distance + $distance^2$ + visibility class, and 5) distance + $distance^2$ + $distance^3$ + visibility class. We modeled density-weight proportion areas using the linear distance model. We were unable to calculate density-weighted proportion areas for bird carcasses due to a lack of available literature and research in this subject. As a result, we made our best estimate and used the density-weight that was calculated using bat fatalities. Although bat and bird carcasses differ, using bat density-weight is a more accurate estimate as opposed to calculating fatality using the default density-weight of 1.0, which would likely result in an underestimate of bird fatalities (Huso et al. 2012; see Appendix G, Table G.1 for density-weighted proportion area results).

2012 bias trial datasets and models. In 2012, sample sizes of both bat and bird carcasses were large enough to analyze each dataset independently (i.e., Periods 1, 2, and 3). As a result, fatality estimates for 2012 are provided separately for each study period. Because our USWFS permit to handle and collect migratory birds was not received until 5 July in 2012, all birds found prior to that time were left in place and fresh carcasses were used in carcass persistence trials only. After receiving the permit, all bird carcasses were used in both bias trials.

Due to a small sample size for fresh bird carcasses available for bias trials in 2012 (18 total; equaling <10 samples for each visibility class), searcher efficiency was assumed to be the same for bat and bird carcasses and both carcass types were used in estimating searcher efficiency for the 2012 bird fatality estimates. We believe this to be a justifiable assumption as almost all bird carcasses found were in the "Small" size category (≤6 cm in length; n = 31, 94%), as are bats, and thus bat carcasses were representative of bird carcass size. Also, most bird carcasses we found were drab and neutral in color, either due to species, age, seasonal plumage, or the way they landed (e.g., belly down), as were the bat carcasses. If bird carcasses had been bright colors (e.g., reds, yellows, oranges) then this assumption could bias bird fatality estimates as searcher efficiency would presumably have been higher for birds than for bats, overestimating fatalities, but this was not a concern for our dataset.

We modeled carcass persistence for bats with no explanatory variables assuming a lognormal distribution. We modeled carcass persistence for birds assuming a Weibull distribution. Sample size of bird carcasses in 2012 was too small to model carcass persistence with visibility class as an explanatory variable, so carcass persistence was modeled with no explanatory variables for birds.

2013 bias trial datasets and models. Insufficient sample sizes of both bat and bird carcasses for Periods 1 and 3 limited our ability to analyze each study period independently in 2013. As a result, we combined and analyzed fatalities for each taxa for those periods as one dataset in the estimator. Consequently, fatality estimates for 2013 are provided separately for Periods 1 and 3 combined, and Period 2.

Due to small sample sizes for both bat and bird carcasses in 2013 ($n = 18$ and $n = 21$, respectively; equaling <10 samples for each visibility class per taxa), searcher efficiency was assumed to be the same across seasons and data for bias trials from both 2012 and 2013 were used in estimating searcher efficiency for both bat and bird fatality estimates. We believe this to be a justifiable assumption as training, survey methodology, and searcher capabilities were consistent among both field seasons.

In 2013, our carcass persistence model with the minimum AIC_c was a lognormal distribution with visibility class as an explanatory variable. However, ΔAIC_c was <2 ΔAIC_c units different between modeling with and without an explanatory variable. Because sample sizes for carcass persistence trials were low, modeling with an explanatory variable resulted in broad confidence intervals (e.g., 95% CI: 20–39545 for Moderate visibility class). Because there was not a strong difference in AIC_c values (<2

ΔAIC_c units and <10% difference in AIC_c values), we chose to model carcass persistence as a lognormal distribution with no explanatory variable.

Samples of fresh carcasses for both bat and bird carcass persistence trials were low in 2013 (n = 13 and n = 19, respectively). When carcass persistence was modeled by taxa (i.e., bats only and birds only), there was a substantial overlap in the distributions. Because distributions overlapped and sample sizes were small, we chose to combine carcass persistence data for bats and birds to estimate fatality. We were able to combine both taxa because, with the exception of 1 carcass, all bird carcasses that disappeared during trials were gone in entirety on the same day as scavenged so that no remains (i.e., feather spots) were left behind. If feather spots had occurred, then bird persistence data would have biased bat persistence estimates by extending the time a carcass remains in the field because feather spots can continue to persist for an extended period of time after the body disappears. This could then overestimate persistence time for bat carcasses, which do not leave visible remains in the field after being scavenged. However, this was not a concern for our carcass persistence data. We did not combine 2012 and 2013 carcass persistence trial data as we did with searcher efficiency because of differences in persistence between the two years. For example, bat persistence time almost tripled from 2012 to 2013 (6.92 vs. 21.85 days). Although combining carcass persistence data for bats and birds may have slightly biased fatality estimates, it was better to make the assumption that carcass persistence was the same for both taxa than to estimate carcass persistence per taxa using small sample sizes. In addition, combining 2012 and 2013 carcass persistence trial data or not adjusting for carcass persistence would have resulted in even greater biases. Consequently, our best option given the data we had was to make the assumption that carcass persistence was the same for both taxa.

Environmental conditions

We evaluated the relationship between bat and bird fatalities and various environmental conditions, including wind speed, wind direction, temperature, barometric pressure, relative humidity, moon illumination, and regional precipitation. Data for wind speed (m/s), wind direction (azimuth °), temperature (°C), and barometric pressure (millibar [mb]) were collected from anemometers located on turbine nacelles from sunset to sunrise. We calculated the median of each of these weather variables from 10-min increment measurements for each turbine for each night of the study. We then calculated average nightly median across all 16 turbines. Relative humidity (%) was collected at 10-min increment measurements from the meteorological tower on site and we calculated nightly median for each night of the study. We obtained nightly percent moon illumination from the Astronomical Applications Department of the U.S. Naval Observatory. Because site-specific precipitation data was not available, we collected daily precipitation from regional stations located within an approximate 32-km radius of the site from the National Climatic Data Center's (NCDC) Climate Data Online (CDO) historical records. We calculated regional daily average of precipitation in 10^{ths} of mm from 20 stations. We removed 2 days (17 and 18 October 2012) from the analysis due to missing weather recordings from anemometers; missing data was due to losses in the communication system. No bat fatalities occurred on either of those days; however, one bird fatality occurred on 17 October and was unable to be included in the analysis. A total of 48 bat and 22 bird carcasses were used; only fresh carcasses from fully operational turbines were included. Due to small sample sizes of both bat and bird carcasses in 2013, we only analyzed data for the 2012 season.

For most nights of the study fatalities were zero, resulting in a distribution that was heavily skewed. Because carcass data was a non-normal distribution consisting of count data, we used a generalized linear mixed model (GLMM) where bat/bird fatalities per night was the response variable and the selected environmental conditions were the predictor variables. We fit the data to a Poisson loglinear and negative binomial distribution with a log link function and used hierarchal model selection with AIC_c to select the most parsimonious model. The negative binomial distribution was the best fit model for bat carcasses/environmental conditions analysis. For our analysis of bird carcass/environmental conditions, AIC_c values for the Poisson and negative binomial distribution models were almost identical (145.531 and 145.265, respectively). Because the model with the Poisson distribution had a deviance to degrees of freedom ratio (i.e., value/df) closer to 1.0, as well as a lower Omnibus Test significance value (indicating overall model significance), we chose to model bird carcass/environmental conditions data using a Poisson distribution. All analyses were performed in Program SPSS.

Turbine and site characteristics analysis

To evaluate the relationship between bat and bird fatalities and various turbine and site characteristics, we modeled the data using a one-way Analysis of Variance (ANOVA) where bat/bird fatalities per turbine was the response variable and the selected turbine/site characteristic was the predictor variable. We looked at differences in bat and bird fatalities between: 1) turbines that had FAA lighting (n = 8) and those than had no FAA lighting (n = 8); 2) turbines with a 93 m rotor diameter (n = 12) and turbines with a

96 m rotor diameter (n = 4); and 3) turbines located on 2 different mountain ridges, String A (n = 5) and String B (n = 11). For the analyses we used fatalities from the entire season (April to October) and combined data from both years. All carcass conditions were used in the analysis for Periods 1 and 3; only fresh carcasses from fully operational turbines were used during Period 2 due to the operational mitigation study. Carcasses found during official surveys and incidental finds were included. Analyses were performed in Program SPSS.

Post hoc analysis

We conducted a post hoc analysis to determine if there was a difference in storm events between the 2012 and 2013 field seasons. We modeled daily regional precipitation using a one-way ANOVA where year was the response variable and daily precipitation was the predictor variable. We also used NCDC Next-Generation Radar (NEXRAD) historical reflectivity maps to document nightly storm events. We examined reflectivity maps at 10-min intervals for each night (sunset to sunrise) of the study and assigned a "Yes" or "No" for whether or not precipitation was present over the site for each interval based on decibels relative to Z (dBZ; Z = equivalent reflectivity) scale recordings (Appendix H). The Blue reflectivity category was not included in the "Yes" designation for precipitation present at the site due to its low rainrate intensity (i.e., hardly noticeable to mist; Appendix H, Fig. H.1) because this level of precipitation would not prohibit bat activity. We then modeled the data using a chi-square test on binary events data (storm event: Yes/No) comparing groups (year: 2012/2013). Analyses were performed in Program SPSS.

Results

Fatality searches

We surveyed a total of 394 out of 406 possible search days, for a total of 5,074 out of 5,168 possible searches for both years combined. Surveys not conducted were either not completed or not attempted due to severe weather conditions and turbine maintenance. Search times per survey plot averaged 42–69 minutes, depending on plot size. Average search area within survey plots ranged from 24–38% of the total maximum search area of 15,120 m^2.

Bat fatalities

We found a total of 106 bats of 3 species during the study (Table 1; Appendix I, Tables I.1 to I.4). All bats found were migratory tree-roosting bats: *Lasiurus cinereus* Palisot de Beauvois (Hoary Bat), *L. borealis* Müller (Eastern Red Bat), and *Lasionycteris noctivagans* Le Conte (Silver-haired Bat); no cave-roosting species were discovered during the study. Fifty-three percent (n = 56) of the bats found were Hoary Bat, 25% (n = 27) were Eastern Red Bat, and 22% (n = 23) were Silver-haired Bat (Table 1). Ninety-two percent (n = 98) of the bats were adults, of which 63% (n = 67) were male, 25% (n = 27) were female, and 4% (n = 4) were of unknown sex (Fig. 3). Only one juvenile bat, a female Eastern Red Bat, was found (1%; n = 1). The remaining 7% (n = 7) of bats were of unknown age, primarily due to partial carcasses or late stages of decomposition. Sixty-five of the 87 and 12 of the 19 bat carcasses found were fresh in 2012 and 2013, respectively. Eighty-nine percent (n = 77) and 47% (n = 9) of bat carcasses found in 2012 and 2013, respectively, occurred during the fall migration season (Fig. 4; Appendix I, Fig. I.1 and I.2).

We found 4 bats that were alive at the time of surveys over the course of the study. These bats were assessed to determine if they either required rehabilitation or euthanasia. None of the 4 bats had visible signs of injury and we attempted to rehabilitate them via rest and rehydration (Klug and Baerwald 2010). Two of the bats died in captivity shortly after being recovered and 2 were successfully released. All 4 of these bats were included in the fatality estimates, as we assumed they would have died in the field without rehabilitation.

Eighty-five percent (n = 90) and 66% (n = 70) of the bat carcasses we found were within 40 and 30 m of the turbine base, respectively (Appendix I, Tables I.1 to I.4). The farthest distance we found a carcass during surveys was 56 m. We found 2 incidental carcasses at 97 and 112 m. Bat carcasses were relatively evenly distributed among all compass-bearing directions from turbine base, ranging from 8–14% for the 8 intercardinal directions (Appendix I, Table I.5).

2012 bat bias trials. We used 73 bat carcasses in the 2012 searcher efficiency trials. All 10 carcasses that were placed in Easy visibility class were found by surveyors, 12 of 28 in Moderate, and 13 of 35 in Difficult/Very Difficult. Overall searcher efficiency was estimated to be 48%, with 100% (95% CI: 100, 100), 43% (95% CI: 25, 61), and 37% (95% CI: 23, 54), for Easy, Moderate, and Difficult/Very Difficult visibility classes, respectively.

We used 61 fresh bat carcasses in the 2012 carcass persistence trials, of which 4 were scavenged prior to first check, 16 remained for the total 20-day trial period, and 41 were scavenged between first check and before the end of the trial. Average persistence time for bat carcasses was estimated to be 6.92 days (95% CI: 4.85, 10.53).

2013 bat bias trials. We used 91 bat carcasses (2012 and 2013 combined) in the 2013 searcher efficiency trials. All 15 carcasses that were placed in Easy visibility class were found by surveyors, 17 of 35 in Moderate, and 14 of 41 in Difficult/Very Difficult. Overall searcher efficiency was estimated to be 61%, with 100% (95% CI: 100, 100), 49% (95% CI: 31, 66), and 34% (95% CI: 20, 49), for Easy, Moderate, and Difficult/Very Difficult visibility classes, respectively.

We used 31 fresh carcasses (bats and birds) in the carcass persistence trials, of which 2 were scavenged prior to first check, 15 remained for the total 20-day trial period, and 14 were scavenged between first check and before the end of the trial. Average persistence time for all carcasses was estimated to be 17.43 days (95% CI: 9.13, 48.28).

2012 bat fatality estimates. After adjusting for carcass persistence, searcher efficiency, and density-weight proportion areas, we estimated bat fatality for the site for the 2012 season to be 235 (95% CI: 160, 361), with an estimated 14.65 bats killed per turbine (95% CI: 10.06, 22.56) and 5.86 per MW (95% CI: 4.02, 9.02). No bat carcasses were found until 18 June; consequently we were unable to estimate bat fatalities for Period 1. An estimated 12.34 bats were killed per turbine (95% CI: 8.18, 19.84) and 4.94 per MW (95% CI: 3.27, 7.94), with 198 (95% CI: 131, 318) bat fatalities for the site during Period 2 and 2.31 per turbine (95% CI: 0.80, 4.92) and 0.92 per MW (95% CI: 0.32, 1.97), with 37 (95% CI: 13, 79) bat fatalities for the site during Period 3 (Appendix I, Table I.6).

2013 bat fatality estimates. After adjusting for searcher efficiency, carcass persistence, and density-weight proportion areas, we estimated bat fatality for the site for the 2013 season to be 46 (95% CI: 31, 71), with an estimated 2.80 bats killed per turbine (95% CI: 1.90, 4.40) and 1.12 per MW (95% CI: 0.76, 1.76). Bat fatality estimates for Periods 1 and 3 combined were 0.70 bats per turbine (95% CI: 0.48, 1.19) and 0.28 per MW (95% CI: 0.19, 0.48), with 12 (95% CI: 8, 19) bat fatalities for the site. Bat fatality estimates for Period 2 were 2.10 bats per turbine (95% CI: 1.20, 3.69) and 0.84 per MW (95% CI: 0.48, 1.48), with 34 (95% CI: 20, 60) bat fatalities for the site (Appendix I, Table I.7).

Bird fatalities

We found a total of 64 birds of 20 species, plus 8 unidentified birds, with 35 birds consisting of 12 species in 2012 and 29 birds consisting of 15 species in 2013 (Table 2; Appendix J, Tables J.1 to J.4). *Vireo olivaceus* (L.) (Red-eyed Vireo) and *Regulus satrapa* Lichtenstein (Golden-crowned Kinglet) were the most common bird species found in both years; 22% (n = 14) and 19% (n = 12), respectively (Table 2). Twenty-eight of 35 and 16 of 29 birds we found were fresh in 2012 and 2013, respectively. We found most bird carcasses during the spring (31%, n = 20) and fall (53%, n = 34) migration seasons (Fig. 5; Appendix J, Fig. J.1 and J.2). We did not find any live or state- or federally-listed birds during surveys.

Sixty-three percent (n = 40) and 23% (n = 15) of the bird carcasses found were within 40 and 30 m of the turbine base, respectively. The farthest distance a bird carcass was found from a turbine was 69 m (Appendix J, Tables J.1 to J.4). We found 41% (n = 26) of bird carcasses in the NE cardinal direction from the turbine base and 57% (n = 36) in the NNE, ENE, and ESE intercardinal directions (Appendix J, Table J.5).

2012 bird bias trials. We used 73 carcasses (bats and birds) in our 2012 searcher efficiency trials. All 14 carcasses placed in Easy visibility class were found by surveyors, 13 of 34 in Moderate, and 14 of 43 in Difficult/Very Difficult. Overall searcher efficiency was estimated to be 45%, with 100% (95% CI: 100, 100), 38% (95% CI: 21, 56), and 33% (95% CI: 19, 47), for Easy, Moderate, and Difficult/Very Difficult visibility classes, respectively.

Thirty-four fresh bird carcasses were used in the 2012 carcass persistence trials, of which 8 were scavenged prior to first check, 10 remained for the total 20-day trial period, and 16 were scavenged between first check and before the end of the trial. Average persistence time for all bird carcasses was estimated to be 12.51 days (95% CI: 5.26, 32.73).

2013 bird bias trials. We used 39 bird carcasses (2012 and 2013 combined) in the 2013 searcher efficiency trials. Nine of the 10 carcasses placed in Easy visibility class were found by surveyors, 4 of 11 in Moderate, and 3 of 18 in Difficult/Very Difficult. Overall searcher efficiency was estimated to be 48%, with 90% (95% CI: 70, 100), 36% (95% CI: 9, 64), and 17% (95% CI: 0, 33), for Easy, Moderate, and Difficult/Very Difficult visibility classes, respectively.

Thirty-one fresh carcasses (bats and birds) were used in the 2013 carcass persistence trials, of which 2 were scavenged prior to first check, 15 remained for the total 20-day trial period, and 14 were scavenged between first check and before the end of the trial.

Average persistence time for all carcasses was estimated to be 17.43 days (95% CI: 9.13, 48.28).

2012 bird fatality estimates. After adjusting for carcass persistence, searcher efficiency, and density-weighted proportion areas, bird fatality estimates for the site for the 2012 season was 211 (95% CI: 147, 321), with an estimated 13.17 birds killed per turbine (95% CI: 9.20, 20.05) and 5.27 per MW (95% CI: 3.68, 8.02). Bird fatality estimates during Period 1 were 6.32 birds per turbine (95% CI: 3.08, 12.00) and 2.53 per MW (95% CI: 1.23, 4.80), with 102 (95% CI: 50, 192) bird fatalities for the site; 3.87 per turbine (95% CI: 2.12, 6.93) and 1.55 per MW (95% CI: 0.85, 2.77), with 62 (95% CI: 34, 111) bird fatalities for the site during Period 2; and 2.97 per turbine (95% CI: 1.71, 5.25) and 1.19 per MW (95% CI: 0.68, 2.10), totaling 48 (95% CI: 28, 84) for the site during Period 3 (Appendix J, Table J.6).

2013 bird fatality estimates. After adjusting for searcher efficiency, carcass persistence, and density-weighted proportion areas, bird fatality estimates for the site for the 2013 season was 129 (95% CI: 60, 355), with an estimated 8.01 birds killed per turbine (95% CI: 3.78, 22.16) and 3.20 per MW (95% CI: 1.51, 8.86). Bird fatality estimates during Periods 1 and 3 combined were 2.72 birds per turbine (95% CI: 0.51, 11.04) and 1.09 per MW (95% CI: 0.20, 4.42), totaling 44 (95% CI: 9, 177) for the site. Bird fatality estimates during Period 2 were 5.29 per turbine (95% CI: 2.43, 17.52) and 2.12 per MW (95% CI: 0.97, 7.01), totaling 85 (95% CI: 39, 281) for the site (Appendix J, Table J.7).

Fatality relationships

Environmental conditions. Bat fatalities in 2012 were negatively influenced by wind speed (χ^2 = 8.22, p = <0.01) and positively influenced temperature (χ^2 = 11.55, p = <0.01; Table 3). Other environmental conditions (i.e., wind direction, barometric pressure, relative humidity, moon illumination, and regional precipitation) did not appear to have an influence on bat fatalities at the site.

Bird fatalities in 2012 were negatively influenced by wind direction and moon illumination (χ^2 = 7.69, p = 0.01; χ^2 = 4.30, p = 0.04; Table 4). However, when we modeled the data using a negative binomial distribution, moon illumination was just above the significance level (χ^2 = 3.26, p = 0.07). Other environmental conditions (i.e., wind speed, temperature, barometric pressure, relative humidity, and regional precipitation) did not appear to have an influence on bird fatalities at the site.

Site characteristics. There was no significant difference in bat fatalities at turbines with or without FAA lighting, at turbines with different rotor diameters, or at turbines that were located on different mountain ridgelines (F = 2.15, p = 0.17; F = 2.75, p = 0.12; F = 0.63, p = 0.44; respectively; Tables 5 and 6). There was also no significant difference in bird fatalities at turbines with or without FAA lighting or at turbines that were located on different mountain ridgelines (F = 1.66, p = 0.22; F = 0.71, p = 0.41; respectively; Tables 7 and 8). An average of 4.50 birds were killed at turbines with a 96 m rotor diameter compared to 2.08 birds at turbines with a 93 m rotor diameter, resulting in a significant difference in bird fatalities at turbines with different rotor diameters (F = 4.55, p = 0.05), although the p-value was right at the 0.05 significance cut-off level (Tables 7 and 8). There were uneven sample sizes for the turbine rotor diameter (n = 4 vs. n = 12) and mountain ridgeline (n = 5 vs. n = 11) datasets; as such, care should be taken when interpreting the results.

Post hoc analysis

Anecdotal observations during the study suggested there was more nightly precipitation in the 2013 than 2012 season. There was no significant difference in daily regional precipitation between years ($F = 0.46$, $p = 0.50$). However, when we examined only nightly precipitation rather than 24-hr measurements we found significantly more nightly storm events in the 2013 field season ($\chi^2 = 51.52$, $p = <0.01$).

Discussion

Bat fatalities

Our findings at the Sheffield Wind Facility corroborate other studies that indicate bat fatality at wind facilities in North America are not uniform across species or time but rather exhibit distinct patterns (Arnett et al. 2008, Johnson 2005, Kunz et al. 2007a). All of the bat carcasses we detected were migratory tree-roosting bats, most of which were lasiurine species, with over half of those being Hoary Bats. Additionally, adult males constituted the majority of all 3 bats species. Eighty-five percent of our bat carcasses were found during the fall migration season (mid-July to late September). In an analysis of bat fatalities at wind energy facilities across the U.S., Kunz et al. (2007a) determined that approximately 75% of bat species killed were migratory tree-roosting bats. Syntheses conducted by Arnett and Baerwald (2013), Arnett et al. (2008), and Johnson (2005) found similar results. Furthermore, Arnett et al. (2008) reported that at most studies, lasiurine species experienced the highest rate of fatalities, with Hoary Bats often being the dominant species found. In addition, they reported that males were killed at higher rates than females and adults more than juveniles. Syntheses of bat fatality data in the U.S. and Canada also have reported that the majority of bat fatalities (90%) at wind facilities occur between late summer (mid-July) and early fall (late September), with over 50% occurring in August, which coincides with the fall migration season (Arnett and Baerwald 2013, Arnett et al. 2008, Johnson 2005). Similar patterns exhibiting uneven distributions of fatalities among species and peak fatality periods in late summer and early fall have been documented in Europe as well (Amorim et al. 2012, Camina 2012, Georgiakakis et al. 2012, Rydell et al. 2010). However, there is less of a clear pattern among sex and age. A synthesis of studies in northwestern Europe found no difference in fatalities between males and females or adults and juveniles, although sample size was limited (Rydell et al. 2010), whereas in Greece the majority of fatalities were adult males (Georgiakakis et al. 2012) and, conversely, in Germany females were predominately killed among migratory individuals and juvenile fatalities rates were higher than adults among local residents (Lehnert et al. 2014).

In contrast to other studies and syntheses of data from the eastern U.S. (e.g., Arnett and Baerwald 2013, Arnett et al. 2008, Kunz et al. 2007a) that reported smaller proportions of fatalities of other bat species as well as lasiurine species, we did not find any cave-roosting bats during our study. However, since 2006 the spread of WNS throughout the eastern U.S. has decimated cave-roosting bat populations (Frick et al. 2010, Turner et al. 2011). WNS has been discovered in all hibernacula in Vermont and the state's population of *Myotis lucifugus* Le Conte (Little Brown Bat) and *M. septentrionalis* Trouessart (Northern Long-eared Bat) have experienced >90% decline since 2009, resulting in the listing of both species as state endangered in 2011 (VDFW 2014). Consequently, it is possible that our surveys did not detect any cave-roosting bats because few individuals remain in the area.

Bat fatality estimates for the site during the 2013 season were substantially lower than the 2012 season (1.12 and 5.86 bats/MW, respectively), which coincided with a marked decrease in bat carcass finds. Our fatality estimates were similar to those reported for a wind facility located in central Maine (0.28–1.65 bats/MW; Normandeau Associates 2010, 2011; Stantec 2009). However, they were lower than those reported by Arnett and Baerwald (2013; 8.30 bats/MW) and Kunz et al. (2007a; 15.3–41.1 bats/MW) in syntheses from wind facilities in the forested east and a synthesis of projects in Pennsylvania (PGC 2012; 2–29 bats/MW), as well as a regional study conducted in central New York (Stantec 2010, 2011; 3.36–26.69 bats/MW). This supports the observation by Arnett and Baerwald (2013) that "there appears to be a pattern of latitudinal decline" in fatalities in the southern and northern portions of the northeast, with higher fatalities in the south and lower fatalities in the north. However, 8 of the 16 turbines at our site had a raised cut-in speed during Period 2 because of our operational mitigation study, resulting in half of the turbines on site not being fully operational during the fall migration season. As a result, fatality at the site had all 16 turbines been fully operational would likely have been higher during the fall migration season. Conversely, starting in 2014 through the life of the project, the Sheffield Wind Facility now implements the same operational mitigation design as our study, and as such, bat fatalities at the site will likely be lower in future years than estimates we report.

Differences in study methodologies, including number of seasons, search intervals, bias adjustments, accounting for unsearched areas, and type of fatality estimator used make fatality comparisons between studies challenging or infeasible (Bernardino et al. 2013, Huso and Dalthorp 2014, Kunz et al. 2007a, Piorkowski et al. 2012). Unlike other studies in this region, we conducted daily fatality searches throughout the entire study period, whereas in Maine weekly searches were performed (Normandeau Associates 2010, 2011; Stantec 2009). In New York, researchers only conducted daily searches at 5 of the 17 turbines surveyed; weekly searches were conducted at the remaining 12 turbines (Stantec 2010, 2011). Also, although all of the projects conducted searcher efficiency and carcass persistence trials, ours was the only project to conduct bias trials throughout the entire survey period, with checks done on a daily basis rather than every few days. Because we conducted bias trials throughout the study, our sample size was larger than those used in other projects. In addition, our bias trials tested and adjusted for different visibility classes, whereas the other projects did not. Also, we adjusted for areas within study plots that were not searchable and extrapolated estimates to the entire study plot using density-weighted proportion areas, taking into account that carcass density generally decreases farther away from the turbine base (Hull and Muir 2010, Huso and Dalthrop 2014). Although the New York project did correct for areas of study plots that were not searched, the correction factor did not account for differences in carcass density in relation to distance from turbine (Stantec 2010, 2011). In Maine, researchers did not account for areas not searched within the study plots at all (Normandeau Associates 2010, 2011; Stantec 2009). Another major difference between projects was in statistical analyses used to estimate fatalities. The New York and Maine projects all modeled fatality estimates based on methods described by Jain et al. (2007, 2008, 2009). In contrast, we used the USGS Fatality Estimator (Data Series 729), based on Huso (2010) and Huso and Dalthrop (2014), which can produce higher fatality estimates (Bernardino et al. 2013). Due to these differences in study methodologies and statistical analyses, direct comparisons between fatality estimates cannot be made.

Our findings indicated that bat fatalities were negatively influenced by wind speed and positively influenced by temperature, whereas wind direction, barometric pressure, relative humidity, moon illumination, and regional precipitation did not appear to have an effect. Wind speed has been reported to negatively influence bat fatality in most studies that have assessed the relationship between bat fatalities and environmental conditions (Arnett et al. 2009, Fiedler 2004, Kerns et al. 2005, Young et al. 2011), as well as bat activity and environmental conditions (Baerwald and Barclay 2011, Cryan et al. 2014, Reynolds 2006). The majority of studies that have included temperature into their weather analyses have found it to positively influence bat activity (Brooks 2009, Erickson and West 2002, Johnson et al. 2011, Wolbert et al. 2014, Wolcott and Vulinec 2012) and fatalities (Fiedler 2004, Grodsky et al. 2012, Young et al. 2011), although a few have found no effect (Arnett et al. 2009, Baerwald and Barclay 2011, Kerns et al. 2005).

There does not appear to be a clear pattern between bat activity and/or fatalities and other environmental conditions however. Moon illumination was reported as significant in positively influencing activity and/or fatalities by Baerwald and Barclay (2011), Cryan et al. (2014), and Erickson and West (2002), but not by Fiedler (2004), nor was it at our site. Neither Grodsky et al. (2012), Kerns et al. (2005), or we found relative humidity to influence fatality but Johnson et al. (2011) found it to negatively influence activity whereas Wolcott and Vulinec (2012) found it to positively influence activity. In addition, Amorim et al. (2012) reported that relative humidity was positively correlated with activity and negatively correlated with fatality in a study in Portugal. Kerns et al. (2005) and our study reported barometric pressure as non-significant; however, Baerwald and Barclay (2011) found change in barometric pressure to influence fatality. Johnson et al. (2011) reported activity to be negatively correlated with barometric pressure; in contrast, Wolcott and Vulinec (2012) found it to positively influence activity. Amorim et al. (2012) and Fiedler (2004) found that wind direction positively influenced fatalities but not activity, but Baerwald and Barclay (2011) found the opposite (i.e., activity but not fatalities). Reynolds (2006) reported no association between wind direction and activity. Precipitation was not found to be significant by either Grodsky et al. (2012) or our study in relation to fatalities, but Erickson and West (2002) and Johnson et al. (2011) reported precipitation to negatively influence activity.

A study using thermal video to observe bat activity and behavior at turbines found higher levels of activity around turbines on nights with greater moon illumination and during periods of low wind speed and blade rotation speed, but no relationship between activity and wind direction (Cryan et al. 2014). They also found that most bats approached turbines from the leeward (i.e., downwind) rather than windward side of the turbines during periods of low wind speed; however, this pattern was not observed when turbines were stationary or spinning quickly (Cryan et al. 2014). Data collection methodologies, sample sizes, and statistical analyses varied greatly among these studies, which likely explains the incongruent relationships between bat activity and/or fatalities and environmental conditions, with the possible exception of wind speed and temperature which are usually found to be significant. In addition, regional differences in environmental conditions and bat activity likely also influence the difference in findings among sites.

It has been hypothesized that FAA lighting on turbines may contribute to higher bat fatalities by attracting bats to aggregations of insects around the lights or to the lights themselves (Cryan and Barclay 2009). However, our findings corroborated those of other studies that found no difference in bat activity and/or fatalities at turbines with or without FAA lighting (Baerwald and Barclay 2011; Horn et al. 2008; Jain et al. 2011; Johnson et al. 2003, 2004). In addition, a study at a large wind facility in north-central Texas found a greater number of Eastern Red Bat fatalities at turbines without FAA lighting and no difference in fatalities of other bat species at turbines with or without FAA lighting (Bennett and Hale 2014). Given the lack of consistent pattern between FAA lighting and bat fatalities, FAA lighting would not be a good mitigation option at reducing turbine-related bat fatalities.

Recent advances in wind technology to improve efficiency, increase revenue, and allow for turbines in low wind speed areas have produced newer turbines that have taller towers and longer blade lengths (DOE 2014). In 2012, average turbine height was 83.8 m and rotor diameter was 93.5 m, an increase of 50% and 96% from 1998, respectively

(DOE 2013). Although increase in turbine height began to slow in 2013, rotor diameter continued to increase, with 75% of turbines in the U.S. having a rotor diameter of 100 m or larger (DOE 2014). This is of grave concern as higher numbers of bat fatalities have been reported to occur at taller, larger turbines (Baerwald and Barclay 2009, Barclay et al. 2007, Johnson et al. 2003). Data compiled and analyzed by Barclay et al. (2007) for 33 wind facility sites located in North America found that bat fatalities increased exponentially with increased turbine height, with highest fatalities at turbines 65 m or taller. A wind facility in Minnesota reported greater fatalities at taller turbines with larger rotor diameters than at shorter turbines with smaller rotor diameters (Johnson et al. 2003). Similarly in Europe, bat fatalities were found to be correlated with turbine height (Georgiakakis et al. 2012, Rydell et al. 2010) and rotor diameter (Rydell et al. 2010). Our findings did not show increased fatalities at turbines with larger rotor diameters; however, we had uneven samples sizes between the 2 rotor diameter sizes, which may have influenced the finding of no significance among turbine size and fatalities at our site.

Bird fatalities

Our bird fatality findings demonstrate similar trends to those reported in other post-construction bird fatality studies at wind facilities in North America (Erickson et al. 2014, Grodsky et al. 2013, PGC 2012). The majority of bird fatalities at our site were night-migrating passerine species and corresponded with migration, with a larger peak in fall and a smaller peak in spring. Fatalities were relatively evenly distributed among species with only 1–3 individuals of each species found per season, with the exception of Red-eyed Vireos and Golden-crowned Kinglets. A single raptor fatality was recovered during the study.

Of all the bird groups, passerine species experience the highest rate (>60%) of fatalities at newer wind facilities in the U.S. (i.e., circa 2000 and on; Erickson et al. 2014). A synthesis of bird fatalities at wind facilities in Pennsylvania from 2007–2011 reported that 73% of bird fatalities were passerine species, with most species only making up ≤1% of fatalities, with the exception of Red-eyed Vireos and Golden-crowned Kinglets, which were 25% and 7% of the bird fatalities, respectively (PGC 2012). Twenty-six percent and 50% of fatalities occurred during spring and fall migrations, respectively. Older wind facilities (i.e., late 1980's and 1990's) in North America killed raptor species in high numbers (up to 68% of bird fatalities; Erickson et al. 2001). However, adaptations to the construction, design, and placement of wind turbines have resulted in a decrease in raptor fatality rates at newer wind turbines and facilities (Kuvlesky et al. 2007, Marques et al. 2014, Smallwood and Karas 2009).

Our 2012 and 2013 estimates for bird fatalities (5.27 and 3.20 birds/MW, respectively) were similar to other wind facilities located in the region with comparable topography, elevational ranges, and habitat types (0.55–3.13 birds/MW), as were the composition of fatalities among species (Normandeau Associates 2010, 2011; Stantec 2009, 2010, 2011). Our estimates are also consistent with those from meta-analyses, which estimated that 2.10–3.35 birds are killed per MW in North America, 4.12/MW in the contiguous U.S., and 3.86/MW in the east (Erickson et al. 2014, Loss et al. 2013). However, study objectives and methodology differed among projects, including daily versus weekly searches, adjustment for visibility classes in bias trial data, correction for areas of the survey plots that were not searched, and different statistical methods used to estimate fatality; see above. Consequently, direct comparisons between the studies cannot be made.

Our findings indicated that bird fatalities were negatively influenced by wind direction and moon illumination, whereas wind speed, temperature, barometric pressure, relative humidity, and regional precipitation did not appear to have an effect. Limited studies have been conducted on bird fatalities at wind facilities in relation to environmental conditions (Marques et al. 2014). Grodsky et al. (2013) reported that temperature, relative humidity, wind speed, and precipitation did not influence bird fatalities at a wind facility in Wisconsin; wind direction and moon illumination were not included in their analyses. However, high fatality events at utility structures, including turbines, have been reported during periods of inclement weather (e.g., strong winds, low cloud ceilings, thick fog, precipitation), which may reduce visibility, hinder flight maneuverability, and push birds into lower altitudes, bringing them into contact with utility structures (Bevanger 1994, Drewitt and Langston 2006, Marques et al. 2014, PGC 2012, Steelhammer 2011). This appears to be exacerbated by attraction to the lighting on structures, which can disorient birds and "trap" them in the illuminated area, causing them to circle the structure and increasing collision risk, as well as exhaustion and increased risk of predation (Drewitt and Langston 2008, Marques et al. 2014, Newton 2007).

High rates of bird collisions due to lighting on a wide range of structures, including lighthouses, oilrigs, ceilometers, and communication towers, have been amply documented (Avery 1979, Bevanger 1994, Drewitt and Langston 2008, Newton 2007) and concerns about increased fatalities at turbines due to FAA lighting have been expressed (Drewitt and Langston 2006, Kuvlesky et al. 2007). However, a meta-analysis of bird fatalities at 30 wind facilities across North America with and without FAA lighting reported no difference in fatalities at lit and unlit turbines (Kerlinger et al. 2010). Our study found the same. This may be due to the use of flashing rather than steady-burning FAA lights on turbines (Kerlinger et al. 2010). A study that assessed different types of FAA lighting on communication towers found significantly more fatalities at towers that had both flashing and steady-burning lights compared to towers with only flashing lights (red or white; Gehring et al. 2009). This may explain the higher numbers of bird collisions at communication towers, which often use steady-burning lights, compared to turbines (Erickson et al. 2014, Longcore et al. 2012, NRC 2007); the fact that turbines are shorter than communication towers and lack guy wires probably also contributes to lower turbine-related fatalities (Kerlinger et al. 2010).

Few studies have assessed the effect moonlight has on bird collision risk with structures (Verheijen 1981). One study analyzed fatalities at man-made structures from 229 nights between 1924–1928 and 1935–1973 and reported that none occurred on nights close to a full moon, proposing that this was due to moonlight minimizing the disorienting effect of artificial lights (Verheijen 1981). In contrast, another study that examined fatalities in relation to moon phase from 683 nights between 1956–1980 found

2 periods of high fatalities, one on nights near the full moon and the other on nights near the new moon (Crawford 1981). Studies of seabirds on islands in developed areas have found significantly higher numbers of grounded birds on nights near the new moon, when the sky is dark and artificial lights cause confusion, attracting birds inland to villages rather than flying out to sea, where they then die from injuries, predation, and starvation, and less frequently by collision with structures (Le Corre et al. 2002, Miles et al. 2010, Rodriguez and Rodriguez 2009, Tefler et al. 1987). However, if landbirds are not attracted to flashing FAA lights on turbines (Kerlinger et al. 2010), then the seabird study findings would not explain the relationship between moon illumination and bird fatalities at our study, leaving the reasons for this finding of significance unclear. Perhaps influence of moon illumination on fatalities could be a result of poorer turbine visibility during dark moon phases, resulting in birds not being able to detect turbines from a far enough distance to alter course and avoid a collision.

It has been suggested that taller, larger turbines would result in greater bird fatalities, although to date no consistent pattern has been demonstrated (Drewitt and Langston 2006, Kuvlesky et al. 2007, Marques et al. 2014). We found mean fatality rates of birds was higher at turbines with larger rotor diameters. One synthesis in the U.S. and Canada found no difference between bird fatalities in relation to turbine height or rotor diameter (Barclay et al. 2007) whereas another reported increased fatalities with increased turbine height (Loss et al. 2013). Thelander et al. (2003) found significantly more fatalities at taller turbines and larger rotor diameters at Altamont Pass Wind Resource Area, California, but only raptors were included in the analysis. Higher rates of fatalities were also found at taller turbines in Spain, but again only raptor fatalities were examined (de Lucas et al. 2008).

A number of factors must be considered when viewing our fatality estimates for both bats and birds. Due to the small sample size of bird carcasses available to use in the 2012 searcher efficiency trials, we made the assumption that searcher efficiency for bird carcasses was the same as for bat carcasses and used both bat and bird carcasses found at the site in our searcher efficiency trial data to adjust bird fatality estimates. In 2013, we made the assumption that searcher efficiency was consistent across seasons and used searcher efficiency trial data from both 2012 and 2013 to adjust fatality estimates due to the small sample size of bat and bird carcasses. Sample sizes of fresh bat and bird carcasses were also low for the carcass persistence bias trails in 2013. As a result, we made the assumption that carcass persistence was the same for bat and bird carcasses at the site and combined the trial data for a single persistence time for both types of carcasses to adjust fatality estimates in 2013.

In addition, in both 2012 and 2013 we assumed that searcher efficiency and carcass persistence was consistent throughout the season. Our sample sizes were too small to separate our bias trial data into the three study periods, so we used data from the bias trials to estimate searcher efficiency and carcass persistence for the entire field season rather than for each period. It is possible that searcher efficiency and carcass persistence varied for the different study periods (e.g., snow during Period 1 and fall leaves in Period 3 could decrease searcher efficiency and scavenging rates could vary during different seasons). However, we feel these changes in variation would be accounted for and reflected throughout the entire season's data.

We were unable to calculate density-weighted proportion areas for bird carcasses due to a lack of available literature and research in this subject; calculating density-weight for birds is complicated and can be misleading if done improperly. As a result, we made our best estimate and used the density-weight that was calculated using bat fatalities. The majority of bird fatalities found at the site (61/64; 95%) were in the "Small" size category, as are all of the bat carcasses, so density-weight should be similar, although bird carcasses have a different mass and wind resistance than bat carcasses (Hull and Muir 2010). However, using the bat density-weight is a more accurate estimate as opposed to calculating fatality using the default density-weight of 1.0, which would likely result in an underestimate of bird fatalities (Huso et al. 2012).

Carcass finds for both bats and birds were low in 2013 during Periods 1 and 3, so the periods were combined into one dataset for each taxa. Even when combined however, the total number of carcasses (n = 2 and n = 4, respectively) were below the recommended 5 per group when using the estimator. Consequently, care should be taken when considering the fatality estimates in 2013 for Periods 1 and 3 as they may only roughly reflect actual bat and bird fatalities at the site during those time periods.

Sample sizes in the analyses of differences between bat/bird fatalities among both turbine and site characteristics and environmental conditions may have influenced our findings. Turbine rotor diameter (n = 4 vs. n = 12) and mountain ridgeline (n = 5 vs. n = 11) datasets were small and uneven. Because we could only use fresh carcasses at fully operational turbines for our environmental conditions analysis, we only had 48 bat and 22 bird carcasses for 212 survey nights. As a result, caution should be used when interpreting these results.

The operational mitigation study was conducted during Period 2, at which time 8 of the 16 turbines at the site had a raised cut-in speed. As such, the bat fatality estimates that we present are likely lower than would have occurred had the facility been fully operational for the entire study period. Conversely, starting in 2014, the Sheffield Wind Facility will implement operational mitigation at all 16 turbines during the fall migration season. Consequently, bat fatalities at the site will likely be lower in future years than the estimates we observed.

With concerns over cumulative effects to bat populations from turbine-related fatalities (Arnett and Baerwald 2013, Arnett et al. 2008), as well as to certain high risk bird species (Bellebaum et al. 2013, Carrete et al. 2009, Smallwood and Thelander 2008), there is a need to better understand potential population-level impacts by putting site-specific and local fatalities into a regional and continent-wide context. To do this, however, fatality estimates must be comparable between years, studies, and locations. It is essential that recommendations and guidelines (e.g., Kunz 2007a, b; Piorkowski et al. 2012) are followed when conducting post-construction fatality studies, otherwise the information is limited in its applicability and inference. For example, studies should conduct proper bias trials, account for study intervals and unsearched areas, use standardized fatality estimators, and estimate fatalities per MW rather than per turbine as different turbine designs vary in MW capacity. We saw significant differences in carcass finds between both seasons and study years, supporting the need for studies to take place throughout the active bat and bird seasons and across multiple years. In addition, there is a great need for research in areas where impacts have not been well studied, such as the southwest U.S.

There is clearly still great uncertainty in the relationship between some environmental conditions and bat and/or bird activity and/or fatalities. These interactions should continue to be researched, with a focus on conducting studies across different regions and environments where wind installation is high or projected to grow. A better understanding of the relationship between environmental conditions and bat/bird fatalities will allow for more accurate predictions of mortality risks at wind facilities, and thus inform and improve mitigation efforts to reduce turbine-related bat and bird fatalities.

Acknowledgments

We express our thanks to Vermont Wind, LLC and Clipper employees for their support in the field and to First Wind for providing housing and site vehicles. We also thank the First Wind employees in the Distributed Asset Control Center for providing the weather data. A big thank you to our crew, A. Bouton, Z. Bryant, K. Friedman, G. Furr, M. Iachetta, K. Pollander, G. Sandoval, L. Sherman, J. Trudeau, and M. VanderLinden for working so diligently in the field to collect the data for this research. We are grateful to S. Darling, VDFW, and S. von Oettingen, USFWS, for their help and support during this study. We thank Bat Conservation International (BCI), particularly C. Hein and M. Schirmacher, for lending us equipment for our research and their assistance throughout the field season. In addition, a special thank you to C. Hein for his helpful review and feedback. We are grateful to M. Beierle, Texas Tech University, for his ArcGIS training in creating the maps for this report. M. Huso, USGS, and R. Stevens, Texas Tech University, both generously donated their time to provide invaluable guidance and assistance with analyses of the data. Funding for this project was provided by BCI, First Wind, National Renewable Energy Laboratory, USFWS, and VDFW.

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Table 1. Total number of bat carcasses found and percent species composition. Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012 and 23 April to 31 October 2013. Carcasses found both incidentally and during official surveys are included.

			2012		2013	
Species	Total # found	%	Total # found	%	Total # found	%
Hoary Bat	56	52.83	47	54.02	9	47.37
Eastern Red Bat	27	25.47	26	29.89	1	5.26
Silver-haired Bat	23	21.70	14	16.09	9	47.37
Total	*106*		*87*		*19*	

Table 2. Total number of bird carcasses found and percent species composition.Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012 and 23 April to 31 October 2013. Carcasses found both incidentally and during official surveys are included.

			2012		2013	
Species	Total # found	%	Total # found	%	Total # found	%
American Redstart	2	3.13	0	0.00	2	6.90
Blackburnian Warbler	1	1.56	0	0.00	1	3.45
Blackpoll Warbler	1	1.56	1	2.86	0	0.00
Black-capped Chickadee	1	1.56	1	2.86	0	0.00
Black-throated Blue Warbler	2	3.13	0	0.00	2	6.90
Cedar Waxwing	1	1.56	0	0.00	1	3.45
Common Yellowthroat	1	1.56	0	0.00	1	3.45
Dark-eyed Junco	1	1.56	0	0.00	1	3.45
Golden-crowned Kinglet	12	18.75	7	20.00	5	17.24
Magnolia Warbler	4	6.25	2	5.71	2	6.90
Northern Waterthrush	1	1.56	0	0.00	1	3.45
Red-breasted Nuthatch	5	7.81	3	8.57	2	6.90
Red-eyed Vireo	14	21.88	10	28.57	4	13.79
Ruby-crowned Kinglet	1	1.56	1	2.86	0	0.00
Ruffed Grouse	2	3.13	1	2.86	1	3.45
Sharp-shinned Hawk	1	1.56	1	2.86	0	0.00
Tennessee Warbler	1	1.56	1	2.86	0	0.00
White-throated Sparrow	2	3.13	1	2.86	1	3.45
Yellow-bellied Sapsucker	1	1.56	0	0.00	1	3.45
Yellow-rumped Warbler	2	3.13	1	2.86	1	3.45
Unknown bird*	8	12.50	5	14.29	3	10.34
Total	*64*		*35*		*29*	

** Partial carcass, feather spot, juvenile.*

Table 3. Generalized linear mixed model (negative binomial distribution) statistics for bat fatalities per night for different environmental characteristics. Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012.

Variable	Estimate	df	SE	χ^2	P-value
Intercept	-32.12	1	40.49	0.63	0.43
Wind speed, median	-0.31	1	0.11	8.22	<0.01
Wind direction, median	0.01	1	<0.01	1.94	0.16
Temperature, median	0.15	1	0.04	11.55	<0.01
Barometric pressure, median	0.03	1	0.04	0.51	0.48
Relative humidity, median	0.01	1	0.01	0.32	0.57
Moon illumination	0.46	1	0.53	0.73	0.39
Regional precipitation, average	<0.01	1	<0.01	1.12	0.29

Table 4. Generalized linear mixed model (Poisson distribution) statistics for bird fatalities per night for different environmental conditions.Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012.

Variable	Estimate	df	SE	χ^2	P-value
Intercept	41.30	1	41.27	1.00	0.32
Wind speed, median	-0.14	1	0.09	2.21	0.14
Wind direction, median	-0.01	1	0.01	7.69	0.01
Temperature, median	0.01	1	0.05	0.10	0.75
Barometric pressure, median	-0.04	1	0.04	0.99	0.32
Relative humidity, median	0.02	1	0.01	1.30	0.26
Moon illumination	-1.36	1	0.65	4.30	0.04
Regional precipitation, average	-0.02	1	0.01	2.81	0.09

Table 5. Descriptive statistics for bat fatalities per turbine for different turbine and site characteristics.Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012 and 23 April to 31 October 2013.

Parameter	Variable	n	Mean	SE
Lit vs. unlit	FAA lights	8	2.88	0.91
	No FAA lights	8	4.50	0.63
Size A vs. Size B	Size A (96 m rotor diameter)	4	5.25	1.18
	Size B (93 m rotor diameter)	12	3.17	0.61
String A vs. String B	String A	5	3.00	1.18
	String B	11	4.00	0.66

Table 6. One-way ANOVA statistics for bat fatalities per turbine for different turbine and site characteristics. Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012 and 23 April to 31 October 2013.

Parameter	Source of variation	df	SS	MS	F-statistic	P-value
Lit vs. unlit	Among groups	1	10.56	10.56	2.15	0.17
	Within groups	14	68.88	4.92		
	Total	15	79.44			
Size A vs. Size B	Among groups	1	13.02	13.02	2.75	0.12
	Within groups	14	66.42	4.74		
	Total	15	79.44			
String A vs. String B	Among groups	1	3.44	3.44	0.63	0.44
	Within groups	14	76.00	5.43		
	Total	15	79.44			

Table 7. Descriptive statistics for bird fatalities per turbine for different turbine and site characteristics.Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012 and 23 April to 31 October 2013.

Parameter	Variable	n	Mean	SE
Lit vs. unlit	FAA lights	8	2.00	0.78
	No FAA lights	8	3.38	0.73
Size A vs. Size B	Size A (96 m rotor diameter)	4	4.50	0.87
	Size B (93 m rotor diameter)	12	2.08	0.58
String A vs. String B	String A	5	2.00	0.84
	String B	11	3.00	0.70

Table 8. One-way ANOVA statistics for bird fatalities per turbine for different turbine and site characteristics. Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012 and 23 April to 31 October 2013.

Parameter	Source of variation	df	SS	MS	F-statistic	P-value
Lit vs. unlit	Among groups	1	7.56	7.56	1.66	0.22
	Within groups	14	63.88	4.56		
	Total	15	71.44			
Size A vs. Size B	Among groups	1	17.52	17.52	4.55	0.05
	Within groups	14	53.92	3.85		
	Total	15	71.44			
String A vs. String B	Among groups	1	3.44	3.44	0.71	0.41
	Within groups	14	68.00	4.86		
	Total	15	71.44			

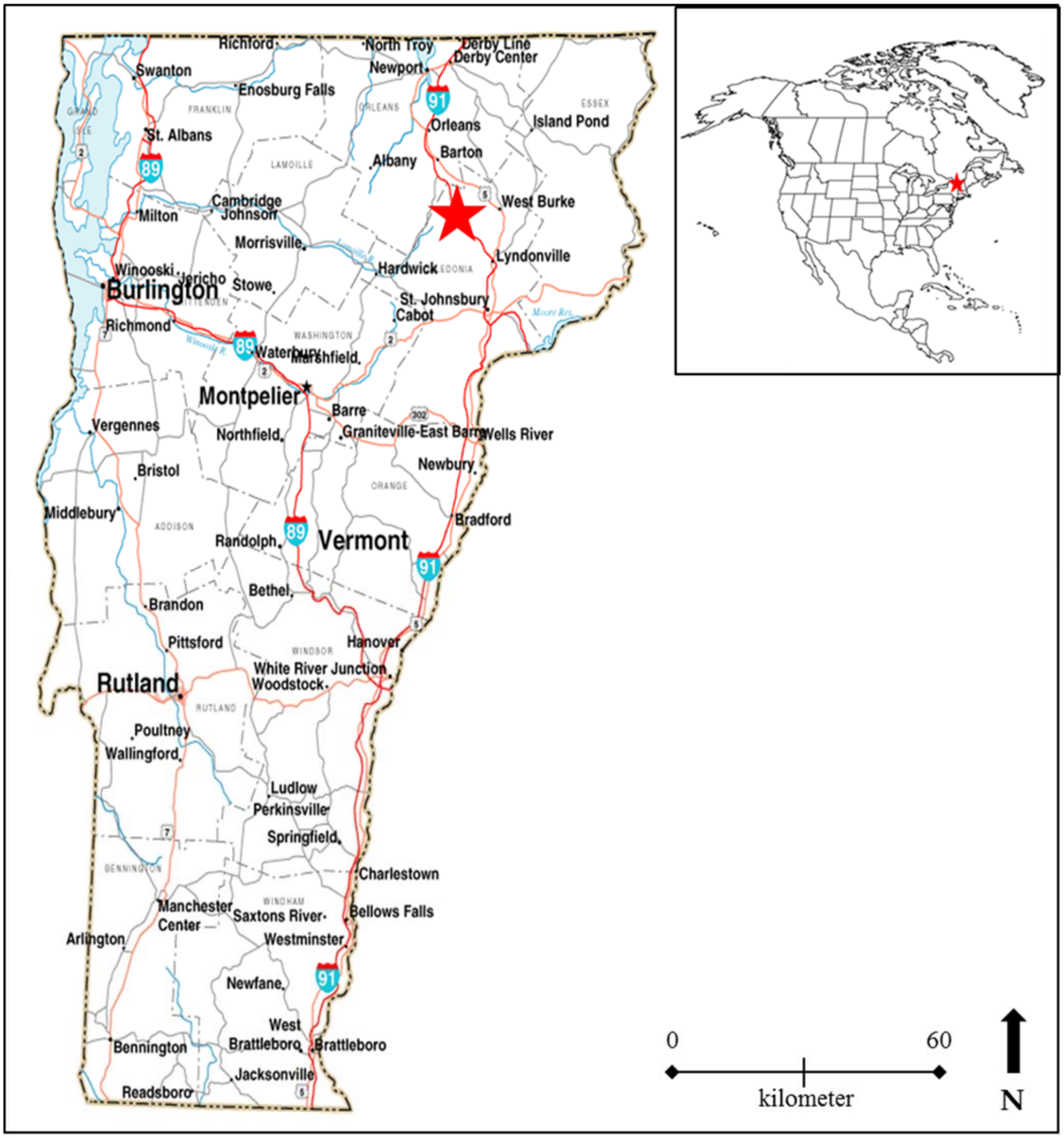

Figure 1. Location of the Sheffield Wind Facility, Caledonia County, Vermont.

Figure 2. Aerial view of the site and surrounding area for the Sheffield Wind Facility, Caledonia County, Vermont.

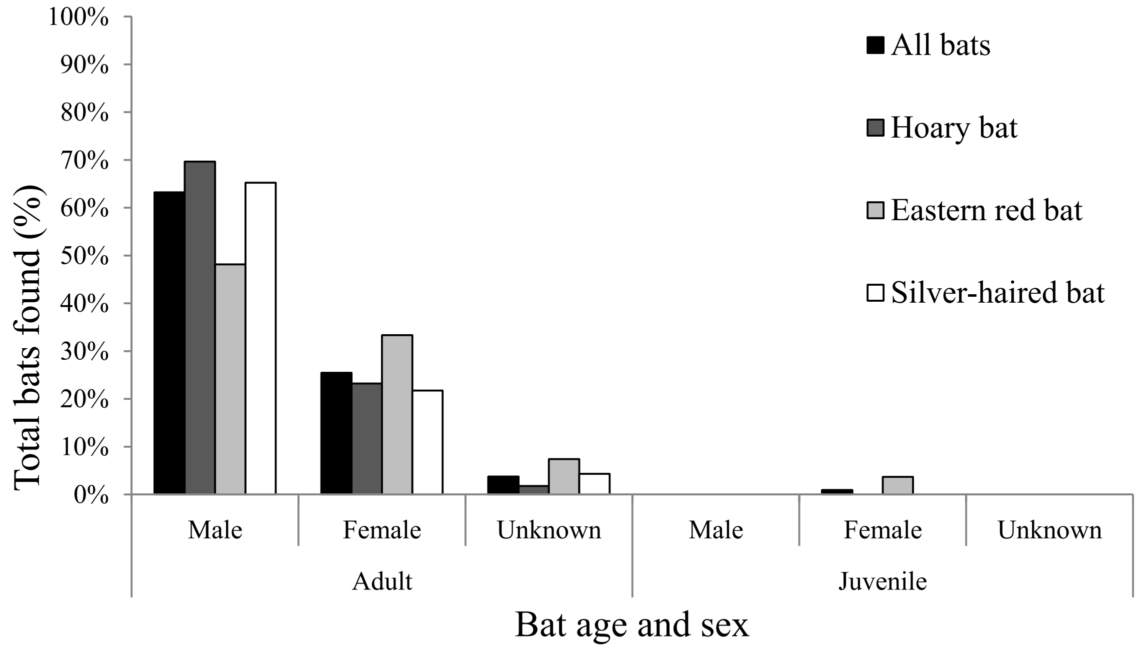

Figure 3. Percent of bat ages and sexes found. Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012 and 23 April to 31 October 2013. 2012 and 2013 data combined.

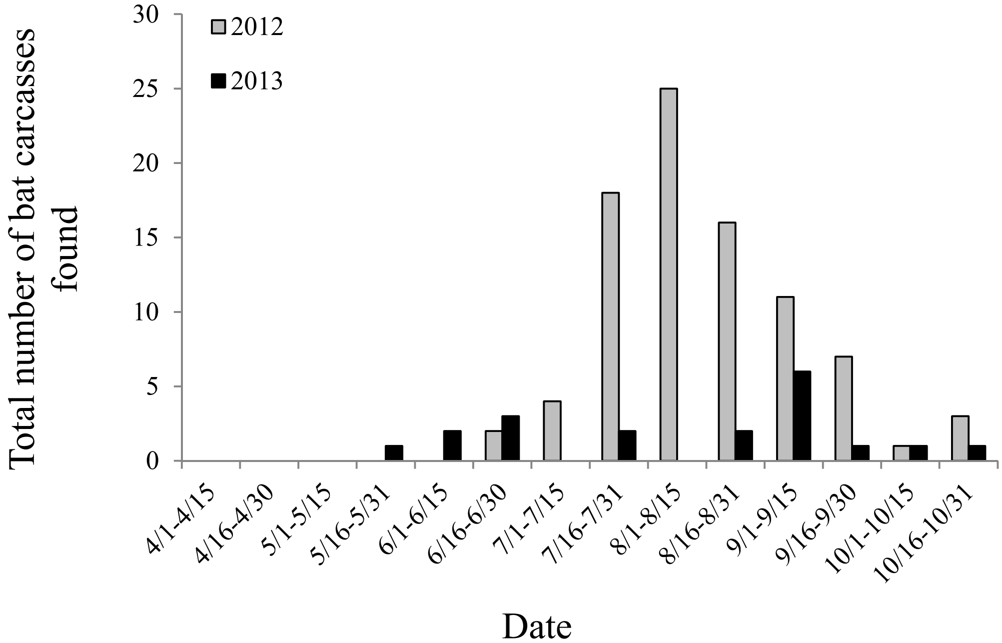

Figure 4. Total number of bat carcasses found per two week interval. Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012 and 23 April to 31 October 2013. All species and decay conditions combined.

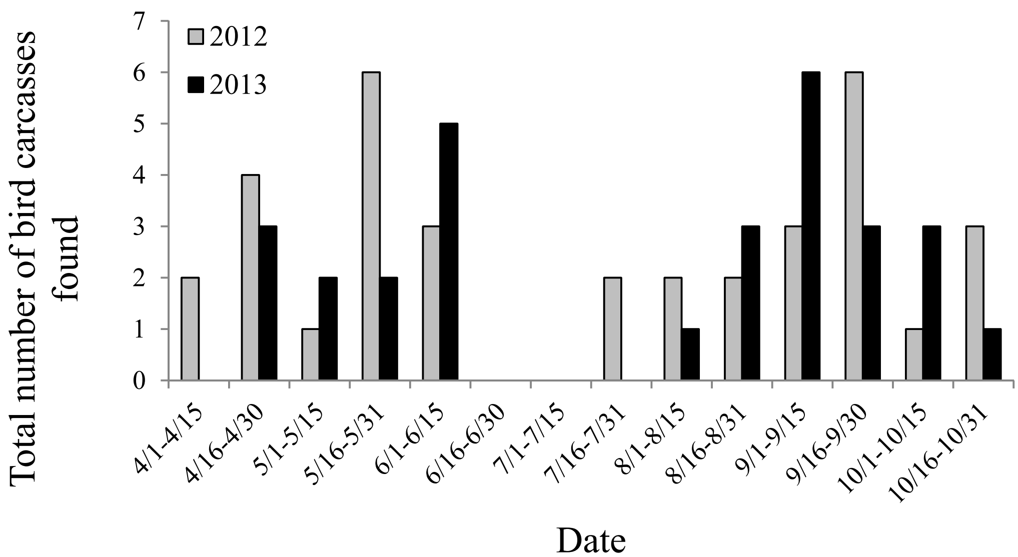

Figure 5. Total number of bird carcasses found per two week interval. Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012 and 23 April to 31 October 2013. All species and decay conditions combined.

CHAPTER III
OPERATIONAL MITIGATION REDUCES BAT FATALITIES AT A WIND FACILITY IN VERMONT

Introduction

Installation of wind energy capacity in North America has grown exponentially in the last decade and is now the largest provider of new generating energy capacity in the U.S. (AWEA 2015; CanWEA 2015). Installed capacity at close of 2014 was over 48,000 utility-scale operating turbines in the U.S., totaling 65,879 megawatts (MW; AWEA 2015). In addition, installed capacity in Canada is currently reported to be 9,694 MW (CanWEA 2015). Continued development has been proposed for both countries, with the goal that 20% of electricity be produced by wind energy by 2030 and 2025 in the U.S. and Canada, respectively (CanWEA 2008; DOE 2008).

Unprecedented numbers of bat fatalities have been observed at wind facilities across North America, with particularly high fatalities in the midwest and forested northeast (Arnett et al. 2008; Arnett and Baerwald 2013). Estimating turbine-related fatalities can be challenging, as a number of factors must be considered (e.g., search interval, bias trials, adjustment for unsearched areas, estimator used) and different methodologies can under or over bias estimations (Bernardino et al. 2013). This can make it difficult to calculate estimates and poses a challenge when comparing studies or making regional or continent-wide assessments. However, every estimate that has been conducted has predicted that annual fatalities are in the hundreds of thousands (Arnett et al. 2008; Hayes 2013; Smallwood 2013). In a synthesis of reported fatalities from peer-reviewed literature and publically available reports, Arnett and Baerwald

(2013) estimated that 650,000–1,308,000 turbine-related bat fatalities occurred in North America between 2000–2011.

Although population numbers of migratory bats are unknown, it is projected that current levels of turbine-related fatalities are not sustainable, and if trends continue, will result in cumulative population-level impacts (Kunz et al. 2007; Boyles et al. 2011; Arnett and Baerwald 2013). Most bats reproduce once a year and typically give birth to only 1–2 young (Altringham 1996). This low reproductive rate results in low intrinsic rates of population growth, making bats highly susceptible to population declines and limited in their ability to recover from serious losses (Barclay and Harder 2003). Additionally, stable isotope analysis of bat carcasses found at wind facilities in both North American (Baerwald et al. 2014; Cryan et al. 2014a) and Europe (Voigt et al. 2012; Lehnert et al. 2014) have determined that bats killed at turbines include long distant migrants, as well as local residents, affecting bats over a large geographic range and threatening broad-scale impacts to populations and ecosystems.

In response to these concerns, studies have assessed operational mitigation that raises cut-in speed of turbines (defined as the lowest wind speed when electricity is generated into the power grid, usually 3.5–4.0 m/s for contemporary turbines) to reduce operating time during slow wind periods of the night and have demonstrated reduced bat fatalities (Baerwald et al. 2009; Arnett et al. 2011; Arnett et al. 2013). Raising turbine cut-in speed from 4.0 m/s to 5.5 m/s in Alberta, Canada, and from 3.5 m/s to 5.0 and 6.5 m/s in Pennsylvania, U.S., resulted in 60% and 44–93% reductions in bat fatalities, respectively (Baerwald et al. 2009; Arnett et al. 2011). However, this approach has only been tested in relation to wind speed. Bat activity is known to vary with other environmental conditions including temperature, wind speed, and precipitation (Erickson and West 2002; Reynolds 2006; Wolbert et al. 2014). As a result, researchers have called for further studies which would incorporate other weather variables in addition to wind speed to fine-tune the design (Baerwald et al. 2009; Arnett et al. 2011; Weller and Baldwin 2012). An effective covariate would be one that predicts bat activity, is set at a threshold that would reduce fatality, and would avoid unnecessary losses from non-operational turbines when bats would not be active.

Given high bat fatalities at many wind facilities, it is essential for impact reduction strategies to be effective at reducing bat fatalities while also being cost efficient for broad implementation by the wind industry. As such, the objective of our study was to test the effectiveness of operational mitigation at reducing bat fatalities while incorporating temperature as a covariate to improve the design by fine-tuning it to weather conditions when bats are most active.

Material and Methods

We conducted our study at the Sheffield Wind Facility (herein referred to as the “site”) in Sheffield, Caledonia County, Vermont (44°39'47"N, 72°07'18"W). The site occurs at 594–728 m elevation along 2 mountain ridges consisting primarily of new growth deciduous hardwood forest. Topography in the region consists of gentle, rolling foothills and river valleys (Thompson 2002). Surrounding land uses include open space, rural residential, dairy farming, and logging. The site is owned and operated by Vermont Wind, LLC (Vermont Wind), a subsidiary of First Wind, and began operation in October 2011. It is a 40 MW facility, consisting of 16 Clipper 2.5

MW wind turbines. All of the turbines have 80 m tall masts; 4 turbines have a 96 m rotor diameter with a rotor-swept area of 7,238 m^2 and 12 turbines have 93 m rotor diameter with a rotor-swept area of 6,793 m^2.

Fatality Surveys

We conducted daily fatality searches at all 16 turbines from 3 June to 30 September 2012 and 2013. We established rectangular study plots around each turbine center. Maximum plot size was 126 m east-west by 120 m north-south and all plots had 6 m transects oriented north-south. Searchers walked along each transect searching out to 3 m on each side for casualties. When a carcass was located, data were recorded on the fatality data sheet, including date, time found, turbine number, carcass location, observer name, species, age, sex, carcass condition (i.e., entire, partial, scavenged), estimated time of death, visible signs of cause of death, and immediate surrounding habitat. All surveyors were trained on proper search techniques and identification of locally occurring bat and bird species. Prior to handling any carcasses, wildlife salvage and handling permits were obtained from Vermont Department of Fish and Wildlife (VDFG; Authorization #: SR-2012-05), U.S. Fish and Wildlife Service (USFWS; Permit #: MB75107A-0), and Texas Tech University Animal Care and Use Committee (ACUC #: 12030-03). Detailed methodology for fatality searches can be found in Martin (2015).

Operational Mitigation

We conducted an operational mitigation study to test the effectiveness of raising turbine cut-in speed to reduce bat fatalities during a 120 night period between 3 June to 30 September in 2012 and 2013. There were 2 turbine treatments: 1) fully operational (i.e., cut-in speed at 4.0 m/s) and 2) cut-in speed at 6.0 m/s. We used a randomized block design (Hurlbert 1984) and treatments were randomly assigned to turbines each night of the study for an equal number of nights at each turbine, with the night when treatments were applied being the experimental unit. To do this, each of the 16 turbines was randomly assigned to 1 of 2 treatments, with each treatment having 8 replicates on each night of the study. Treatments were balanced every 8 nights to achieve a balanced assignment of treatments over the entire study period, for a total of 60 nights of treatment for each turbine.

The Supervisory Control and Data Acquisition (SCADA) system for the turbines were programmed to incorporate raised cut-in speed treatments into their daily operation. Treatments were implemented from half an hour before sunset to sunrise during periods when ambient air temperature was >9.5°C and wind speeds were <6.0 m/s. We chose this temperature threshold because regional studies suggest little or no bat activity below 10°C (Reynolds 2006; Brooks 2009; Wolbert et al. 2014). These variables were programmed into the turbine's software and whenever both conditions were met for a total of 5 continuous minutes the turbine was placed in "wind sense", which is a non-generating state with the blades in a stand-by pitch of 80°. In this state, blades were not locked in place but only moved slightly due to the 80° pitch, which prevented them from being affected by air flow. Once one of the weather conditions (i.e., temperature or wind speed) stopped being met for a total of 10 continuous minutes the turbines went back to being fully operational.

Statistical Analyses

Effectiveness.—The experimental unit in our analysis was the turbine-night and turbines were considered a random blocking factor. Total number of fresh fatalities in each treatment at each turbine was modeled as a Poisson random variable. We summed the total number of fresh carcasses found beneath each turbine for each treatment for each night of the study (n = 60 nights per treatment each). We fit these data to a generalized linear mixed model (GLMM; SAS PROC GLIMMIX), assuming a Poisson distribution with a log link for carcass count, treatment as a fixed effect, and turbine as a random effect. Analyses were performed in Program SAS.

Incorporating temperature as a covariate.—Because the treatment in our design included both wind speed and temperature as variables, we were not able to statistically isolate the independent effect that incorporating temperature as a covariate had on reducing bat fatalities. To assess the effect that temperature may have had on determining whether or not the treatment was implemented, we graphically examined median nightly temperature and wind speed for the site for each night of the study to see what weather patterns were occurring and if treatment thresholds (i.e., wind speed <6.0 m/s and temperature >9.5°C) were being met. We then compared this to peak fatality occurrences for the site.

To evaluate the influence of incorporating temperature as a covariate may have had in reducing unnecessary energy losses we used wind speed and temperature data. Weather data was collected from the anemometers located on turbine nacelles in 10-

min increments from sunset to sunrise to compare a wind speed-temperature and wind speed-only treatment design. To do this, we wrote a code in Program MatLab that assigned a "Yes" when thresholds were met and a "No" when thresholds were not met for both design types, meaning that for the wind speed-temperature design a "Yes" was assigned when both temperature was >9.5°C and wind speed was <6 m/s and for the wind speed-only design a "Yes" was assigned when wind speed was <6 m/s. For each design type, we then determined hypothetical percent of night the treatment would have been implemented based on the weather data for each turbine for each night of the study. We then calculated average percent of night the treatment would have been implemented for the entire site for each night of the study. We modeled the data using a one-way Analysis of Variance (ANOVA) where treatment design was the response variable and percent of night treatment would have been implemented as the predictor variable. Analyses were performed in Program MatLab and Program SPSS.

Financial costs.—Financial cost of operational mitigation was assessed based on percent of energy loss due to implementing the treatment. We used operational information from the turbines to calculate the percentage of a night that a treatment was implemented for each turbine for each night. This was calculated by dividing the amount of time the turbine was non-operational (in total seconds then converted to hours) by total nightly hours of the operational mitigation study (i.e., half an hour before sunset to sunrise) for each night of the study. We refer to this variable as treatment percentage night.

Percentage of energy loss was calculated by dividing energy loss at the Point of Interconnect (POI; in megawatt hours [MWh]), which was based on treatment percentage night, by the expected energy at POI (MWh), which was based on company projections. This was determined for the 8 treatment turbines each night of the study and estimated for the remaining 8 turbines had the treatment been implemented. As such, it had to be assumed that sunset was 18:00 and sunrise was 6:00 for all months, which could upwardly bias the estimate. Percentage energy loss was determined for the study period (3 June to 30 September) and the entire calendar year.

Results

We conducted surveys daily at all 16 turbines from 3 June to 30 September 2012 and 2013. We surveyed a total of 231 complete days out of 240 possible search days, for a total of 3,793 out of 3,840 possible searches for both years combined. Surveys not conducted were either not completed or not attempted due to thunderstorms, severe wind, a tornado watch, and turbine maintenance.

In 2012, we found a total of 83 bats, of which 62 were fresh, and 16 bats in 2013, of which 10 were fresh. In 2012 a minimum of one fresh bat was found at all 16 turbines, whereas in 2013 a fresh bat carcass was only found at 7 of the 16 turbines. Forty-five of the 62 (73%) and 6 of the 10 (60%) fresh carcasses were found at fully operational turbines in 2012 and 2013, respectively.

Effectiveness.—We found that operational mitigation had a significant effect on bat fatalities in 2012 ($F_{1,15}$ = 11.09, p = <0.01; Fig. 1). An average of 1.00 (95% confidence interval [CI]: 0.60, 1.80) fresh bats per turbine were found at treatment turbines compared to 2.70 (95% CI: 1.90, 3.90) fresh bats per turbine found at fully operational turbines. There were 2.60 (95% CI: 1.40, 4.80) times as many fatalities at fully operational turbines than there were at treatment turbines, resulting in an estimated 60% (95% CI: 29, 79) decrease in bat fatalities from operational mitigation in 2012.

In 2013, an average of 0.25 (95% CI: 0.09, 0.73) fresh bats per turbine were found at treatment turbines compared to 0.38 (95% CI: 0.16, 0.90) fresh bats per turbine found at fully operational turbines (Fig. 1). There were 1.50 (95% CI: 0.38, 5.94) times as many fatalities at fully operational turbines than there were at treatment turbines. The difference between bat fatalities at fully operational and treatment turbines in 2013 was not statistically significant ($F_{1,15} = 0.39$, $p = 0.54$).

Incorporating temperature as a covariate.—Temperature only dropped below the threshold of >9.5°C at the beginning and end of the study season (Fig. 2). In contrast, wind speed oscillated above and below the <6.0 m/s threshold throughout the season (Fig. 3). Periods when temperature dropped below the threshold (late spring and early fall) fell outside of the period of high bat fatality at the study site (mid-July to mid-September; Fig. 4). Graphs of the temperature and wind speed data are shown for the 2012 season (Figs. 2, 3, and 4); the 2013 season exhibited similar patterns.

Overall, there was only a minimal difference in potential energy production loss (i.e., cost) between the 2 operational mitigation designs (i.e., wind speed-temperature and wind speed-only) across the entire season. The average percent of night treatment was implemented for the wind speed-temperature design was 44% compared to 49% for the wind speed-only design (Fig. 5). This resulted in only a 5% difference for the entire season, which was not significant ($F = 2.95$, $p = 0.09$).

However, temperature fell below the threshold primarily in late spring and early fall. When only those 2 periods were examined, the average percent of night treatment was implemented for the wind speed-temperature design was 28% compared to 46% for the wind speed-only design (Fig. 6). This resulted in an 18% difference in percent of night turbines were non-operational for the late spring and early fall season, which was significant ($F = 7.27$, $p = <0.01$).

Financial costs.—Energy loss due to operational mitigation during the field season when 8 of the 16 turbines had a raised cut-in speed was 2.79% in 2012 and 2.69% in 2013. This resulted in a 0.67% and 0.60% energy loss for the 2012 and 2013 calendar years, respectively. Energy losses had the treatment been implemented every night at all 16 turbines were estimated to be 4.67% and 5.34% for the field season and 1.13% and 1.20% for the calendar year in 2012 and 2013, respectively (Table 1). In addition to decreased revenue from energy losses due to operational mitigation, there were also minor costs resulting from the time that First Wind staff spent on implementing the study.

Discussion

Raising cut-in speed of turbines in our study significantly reduced bat fatalities by 60%, corroborating other research that tested the effectiveness of raising turbine cut-in speed to decrease bat fatalities (Baerwald et al. 2009; Arnett et al. 2011; Arnett et al. 2013). Although the studies varied in design, such as type of treatments (e.g., assigned cut-in speed), number of treatments, treatment assignment, and methods of conducting fatality searches, most reported a reduction in bat fatalities of at least 50% and as high as 93% (Arnett et al. 2013). Arnett et al. (2011) tested two raised cut-in speeds, 5.0 m/s and 6.5 m/s, and found that operational mitigation resulted in a 44–93% nightly reduction in fatalities, although they did not detect a significant difference among the two cut-in speeds. Baerwald et al. (2009) tested two treatments; 1) feathering turbine blades (defined as pitching the angle of the blades to be parallel with the wind so that they do not spin or only spin slowly) to produce a low idling speed below the manufacturer's normal cut-in speed of 4.0 m/s, and 2) raising turbine cut-in speed to 5.5 m/s. They found a 60% decrease in bat fatalities at treatment versus control turbines, although they did not find a significant difference between the two treatments (Baerwald et al. 2009).

Some turbines are designed in a such a way that their blades spin when winds are below manufacturer's cut-in speed (i.e., free-wheeling), meaning that blades are spinning, and potentially killing bats, even when no electricity is being produced (Arnett et al. 2013). A study in West Virginia found that feathering turbine blades at or below the manufacturer's cut-in speed of 4.0 m/s yielded significant reductions in bat fatalities (Young et al. 2011). Arnett et al. (2013) demonstrated that turbines included in their synthesis were spinning between 20–100% of the night when wind speeds were below normal cut-in speed and that feathering blades up to normal cut-in speed could substantially reduce the amount of time that turbines spun (see Figure 2 in Arnett et al. 2013). These studies demonstrate that some bat fatalities can be avoided without any losses in energy production by feathering blades during low wind conditions when no electricity is being generated. This is a possible mitigation option that could be used retroactively at turbines that do not have a SCADA system that would allow for easy employment and management of raising cut-in speed above the manufacturer's setting.

Studies investigating mitigation measures to reduce turbine-related bat fatalities have also been conducted in Europe, including raising turbine cut-in speed and developing operation algorithms (Rydell et al. 2010; Lagrange et al. 2013; Behr et al. 2014). However, most of the research is available only in gray literature and presentations, with few reports available in English (e.g., Behr and von Helversen 2006; Behr et al. 2011; Brinkmann et al. 2011). In one published study from Germany, Korner-Nievergelt et al. (2013) designed a mixture model using Bayesian methods to predict bat fatalities and collision risk by incorporating two sub-models; one for the observation process (e.g., searcher efficiency, carcass persistence, area searched, number of carcasses found) and one for the collision process, that is, conditions which contribute to fatalities (e.g., bat activity, wind speed). They determined that fatality estimates from their model are unbiased and are as precise as conventional "corrected count" methods. Additionally, their model can predict fatality rates at non-searched turbines, as long as new turbines are similar (e.g., turbine size, bat activity, weather conditions) to the dataset used for model fitting (Korner-Nievergelt et al. 2013). This model can help inform mitigation methods to improve effectiveness in reducing fatalities, such a developing operation algorithms (Korner-Nievergelt et al. 2013). Studies in Europe have assessed using operation algorithms to stop turbines from spinning during periods of high fatality risks by incorporating bat activity (acoustic and thermal video), timing (nightly and seasonal), weather conditions (wind speed and temperature), and turbine height into algorithms that predict collision risk. These algorithms are incorporated into SCADA systems, which regulate turbine operation and can stop turbines during high fatality risk periods (Lagrange et al. 2013; Behr et al. 2014). Studies found 60–97% less bat fatalities at regulated turbines (Lagrange et al. 2013). Operation algorithms are becoming the standard form of mitigation in Germany, where bats are strictly protected (Behr et al. 2014).

A few studies discussed by Arnett et al. (2013) did not detect significant reductions in fatality. A study in West Virginia that tested feathering turbine blades up to manufacturer's cut-in speed of 4.0 m/s experienced weather conditions that greatly limited the amount of time treatments were implemented during the study (<10% of the time); consequently, they were unable to detect a difference between treatments (Young et al. 2012; Arnett et al. 2013). An anonymous study located in USFWS Region 8 (Pacific Southwest) that tested raising cut-in speed from 3.0 m/s to 4.0, 5.0, and 6.0 m/s found a high proportion of Mexican free-tailed bat fatalities (*Tadarida brasiliensis*; 73.5%; Arnett et al. 2013). This species is active at higher wind speeds than most other bat species, and as a result, treatments may not have been as effective (Arnett et al. 2013). In 2013, although we found a greater number of estimated bat fatalities at fully operational turbines compared to treatment turbines, the difference was not statistically significant. We believe that this resulted from low numbers of bat fatalities, notably fresh bat carcasses, found that year, which impeded our statistical analysis for that season. Searcher effort (e.g., number of surveys, length of field season, training of technicians, searcher efficiency) was consistent during the study and we do not believe search bias contributed to differences in number of bat carcasses found between 2012 and 2013. We conducted a post hoc analysis that found a significant difference in nightly storm events between the 2 seasons, with more events in 2013 (Martin 2015). Although we cannot conclude whether this contributed to low bat fatalities that year, Erickson and West (2002) and Johnson et al. (2011) found that bat activity was lowest during precipitation events. Other possible causes could include natural yearly variation in bat activity in the area, learned behavior by bats to avoid collisions with turbines, or a reduction in bat populations. Similar patterns in fatalities in 2012 and 2013 was reported at other wind facilities in the region as well (Rhett Good, WEST Inc., Bloomington, Indiana, personal communication, September 2014), so regardless of the cause, differences in fatalities among the 2 years were not a site specific pattern or occurrence.

Ninety percent of the bat fatalities occurred from mid-July to mid-September. Regional temperatures during this period remained above the >9.5°C threshold for the operational mitigation design. Temperature only dropped below the threshold in early June and late September, when few bats were killed. This means that the temperature requirement for the treatment was almost always met and, as a result, wind speed was the driving factor in determining when treatment was implemented during the peak fatality period. Consequently, under the conditions of our study, it is unlikely that including temperature as a covariate had much contribution in reducing bat fatalities at treatment turbines.

Incorporating temperature did, however, decrease the amount of unnecessary energy loss from implementing the treatment when bats were presumably not active, particularly during late spring and early fall when temperatures in the northeast normally drop below 9.5°C. Therefore, although during peak risk periods it did not contribute to reduced bat fatality, temperature was still a useful covariate to incorporate into the operational mitigation design by helping to reduce costs incurred by the wind company.

Starting in 2014, the site will implement the same operational mitigation design at all 16 turbines for the life of the project. In addition to incorporating temperature as a covariate, unnecessary energy losses from treatment implementation when bat fatalities are minimal could be reduced by adjusting the operational mitigation dates. Because this site was the first new generation facility in Vermont and few post-construction fatality studies had been conducted in the region, anticipated turbine-related bat fatalities were uncertain. Our study was, therefore, designed to be conservative and operational mitigation started in early June. In contrast, all other operational mitigation studies that have been reported began between mid-July to early August (Arnett et al. 2013). We only found 1 fatality in early June in both years of our study. The majority of fatalities at our site occurred from mid-July to mid-September, which is consistent with patterns reported at other facilities in the forested northeast (Arnett et al. 2008; Arnett and Baerwald 2013). As a result, eliminating raised cut-in speed treatments in June would not likely compromise effectiveness of reducing bat fatalities at this site while minimizing energy losses. Additionally, although incorporating temperature into the operational mitigation design may not have contributed to reducing bat fatalities at our site, we recommend temperature remain in the design to assist with reducing unnecessary energy losses during late September when temperature does fluctuate above and below 9.5°C.

Studies of bat activity in the Northeast Deciduous Forest region (per Arnett and Baerwald 2013) have documented minimal to no bat activity when temperatures are below approximately 10°C (Reynolds 2006; Brooks 2009; Wolbert et al. 2014). A study in western New York found that bat activity was highest on days where mean temperature was 23.9°C and that activity was nonexistent on days when temperature was below 10.5°C (Reynolds 2006). In northeastern Pennsylvania, bat activity began at temperatures greater than 10°C, with maximum activity occurring through 18°C, at which point it again decreased (Wolbert et al. 2014). Maximum bat activity was documented to be between 17–21°C in central Massachusetts, with minimal activity at temperatures below 15°C, and none below 5°C (Brooks 2009). A study in Portugal found similar results, with maximum bat activity occurring at temperatures above 15°C (Amorim et al. 2012). Other studies in our region have reported a significant association between bat activity and temperature as well, although they did not include temperature measurements (Johnson et al. 2011; Wolcott and Vulinec 2012). In addition, similar findings have been reported in the Pacific northwest (Erickson and West 2002), midwest (Grodsky et al. 2012), southwest (Weller and Baldwin 2012), and southeast (Fiedler 2004). We did not collect activity data for our study, so it is not possible to correlate bat activity at our site with temperature. However, our fatality data shows the same pattern as the activity-temperature studies conducted in our region. When we examined fresh carcasses (i.e., died the previous night) that occurred at fully operational turbines, making it possible to pair them with nightly median temperature, 81% died on nights were median temperature was >9.5°C. However, this is the median temperature for the entire night and exact time of death is unknown; it could have occurred during the early part of the evening when temperatures were warmer. When looking at 10-min temperature increments for these nights, the majority of kills occurred on nights that had a high >9.5°C in the early evening, suggesting bats could have been active, and thus killed, near dusk when temperatures were warmer. For the entire study, only 0.05% (n = 2) of fatalities occurred on nights where temperature was <9.5°C for the entire evening. Because the >9.5°C threshold is lower than the reported temperature where there is minimal bat activity in our region (i.e., ~10°C; Reynolds 2006; Brooks 2009; Wolbert et al. 2014) and because we observed almost no fatalities on nights where temperature remained <9.5°C, we contend that >9.5°C is a sufficient threshold to reduce bat fatalities at our site.

To our knowledge, our study was the first to incorporate temperature in addition to wind speed into an operational mitigation design. Studies that have monitored bat activity and environmental conditions have shown that activity is influenced by variables other than wind speed and temperature as well. Higher levels of activity have been reported on nights with greater moon illumination (Erickson and West 2002; Cryan et al. 2014b) and lower activity has been found to be associated with precipitation (Erickson and West 2002; Johnson et al. 2011). Relative humidity (Johnson et al. 2011; Amorim et al. 2012; Wolcott and Vulinec 2012), barometric pressure (Johnson et al. 2011; Wolcott and Vulinec 2012), and wind direction (Baerwald and Barclay 2011) also may significantly influence activity as well. Future research should continue focusing on improving predictability of high risk periods and incorporating covariates (combined with wind speed) that we did not test which may reduce lost energy while maintaining or improving biological effectiveness.

Studies also should consider incorporating multiple covariates into the design. Weller and Baldwin (2012) found improved model performance in predicting bat activity when including variables in addition to wind speed and temperature, such as moon illumination and date. Additionally, operational mitigation studies should be designed to fit the region the facility occurs in. If the area experiences regular changes in wind direction or it frequently rains, perhaps wind direction or precipitation would be a good covariate to include. Also, the relationship between some environmental conditions and bat activity can depend on the region. Wolbert et al. (2014) found a stronger relationship between temperature and bat activity at higher elevations. Bats remain active at lower temperatures in some areas, such as at higher latitudes in North America. As such, different covariates and threshold settings, combined with wind speed, may be more appropriate and effective at reducing bat fatalities than others depending on where a wind facility is located. A review of bat activity and weather studies conducted in the region or monitoring pre-construction activity and weather conditions could be helpful in determining the best covariate(s) and threshold(s) for a site.

Our study site only consisted of 16 turbines, which limited the number of treatments we could test. Future studies at a larger site could test multiple treatments with different wind speed and temperature thresholds to fine-tune what settings would be most effective. Imprecise time of death determination also makes it challenging to assess the relationship between fatalities and weather conditions under some circumstances, such as when temperature is above the threshold near dusk but median nightly temperature is below. Although weather conditions are available in 10-min increments, we only know that the bat died sometime the previous night, which can constrain analyses. A study that could more precisely determine time of death, perhaps through infrared video monitoring, could provide a more detailed picture of the relationship between fatalities and weather conditions and better guide the selection of effective covariates and threshold settings.

Observed energy loss due to operational mitigation during the study season for our site (2.79% and 2.69%) was slightly higher than a similarly designed study (2%; Arnett et al. 2011). This is likely because they had treatments with cut-in speeds at both 5.0 and 6.5 m/s and their season was a month shorter than ours. Both studies showed ≤1% energy loss for the calendar year as a result of the studies.

Given that bat fatalities have been documented at wind facilities across North America (Kunz et al. 2007; Arnett et al. 2008; Arnett and Baerwald 2013), that development of wind facilities is projected to continue (CanWEA 2008; DOE 2008), and that cumulative impacts to bat populations are expected (Kunz et al. 2007; Arnett and Baerwald 2013), we recommend that operational mitigation be implemented broadly during high risk periods at wind facilities to reduce bat fatalities and lessen potential impacts to bat populations. Turbine manufacturers should continue to work closely with wind energy developers and operators and researchers to determine logistically feasible and cost-efficient approaches to operational mitigation at wind facilities. Operational mitigation is not always simple to implement; however, many SCADA systems allow for easy employment and management of the design. With greater coordination between manufacturers, researchers, and wind companies in designing new turbines with SCADA systems, as well as making it possible to update older turbines, operational mitigation can become a more accessible technology. With the high number of bat fatalities at many wind facilities, it is essential for impact reduction strategies to be effective at reducing bat fatalities while also being cost efficient for broad implementation by the wind industry.

Acknowledgments

Funding for this project was provided by Bat Conservation International (BCI), First Wind, National Renewable Energy Laboratory, USFWS, and VDFW. We thank BCI, Clipper, First Wind, USFWS, and VDFG employees for their assistance and support throughout this project. C. Hein, BCI, provided helpful review and feedback throughout the project, for which we are very grateful. We also thank the First Wind employees in the Distributed Asset Control Center for providing the weather data and their assistance in the operational mitigation study and financial cost assessment. Our crew worked tirelessly in the field to collect the data for this research; we thank A. Bouton, Z. Bryant, K. Friedman, G. Furr, M. Iachetta, K. Pollander, G. Sandoval, L. Sherman, J. Trudeau, and M. VanderLinden. We are inordinately grateful to M. Huso, U.S. Geological Survey, and R. Stevens, Texas Tech University, for their guidance and assistance with analyses of the data.

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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. Western EcoSystems Technology, Inc., Cheyenne, Wyoming.

Table 1. Estimated energy loss due to the operational mitigation study. Sheffield Wind Facility, Caledonia County, Vermont; 3 June to 30 September 2012 and 2013. POI = Point of Interconnect.

		8 turbines		16 turbines*	
Year	Expected energy at POI (MWh)	Energy loss at POI (MWh)	Percent loss	Energy loss at POI (MWh)	Percent loss
Field season only (3 June–30 September)					
2012	23,520	656	2.79%	1,098	4.67%
2013	22,319	601	2.69%	1,191	5.34%
Entire calendar year					
2012	97,375	656	0.67%	1,098	1.13%
2013	99,651	601	0.60%	1,191	1.20%

** Values for all 16 turbines are estimates. It was necessary to assume that sunset was at 18:00 and sunrise was at 6:00 for all months, which could overestimate power loss.*

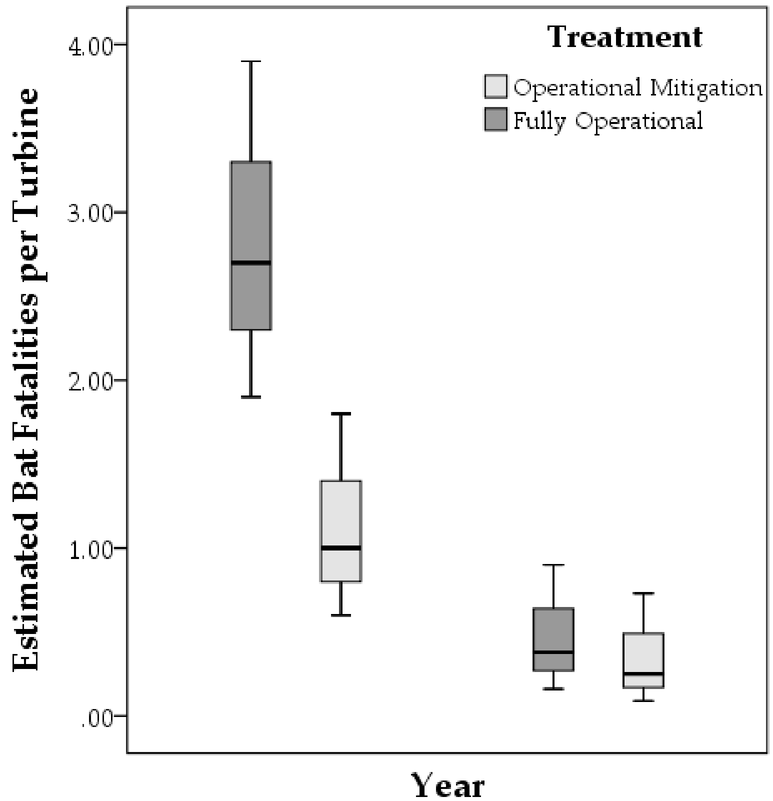


Figure 1. Effectiveness of operational mitigation at reducing bat fatalities. Sheffield Wind Facility, Caledonia County, Vermont; 3 June to 30 September 2012.

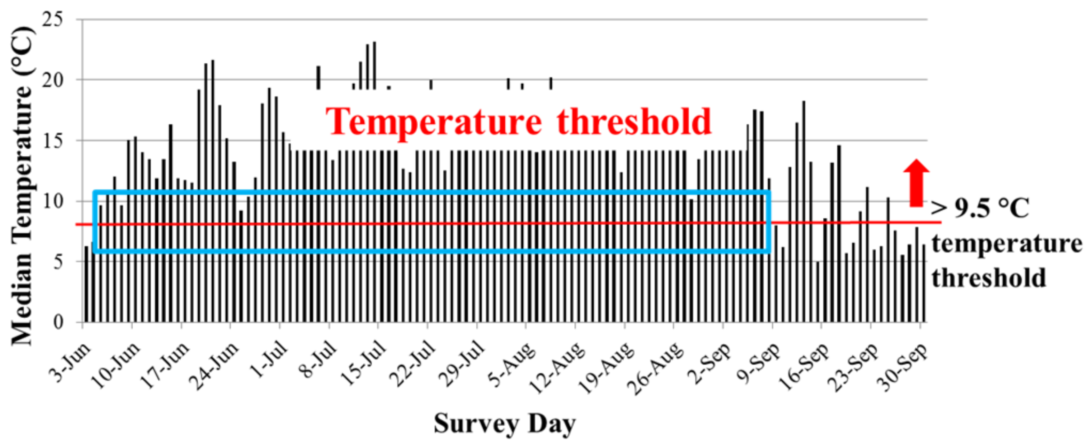


Figure 2. Median nightly temperature during the operational mitigation study where the threshold for the temperature covariate was >9.5°C. Sheffield Wind Facility, Caledonia County, Vermont; 3 June to 30 September 2012. Blue: >9.5°C threshold.

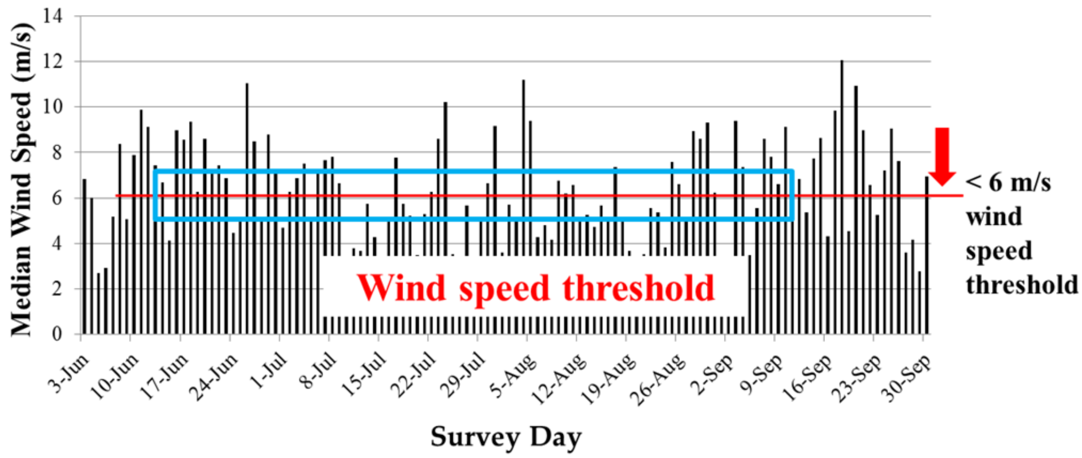


Figure 3. Median nightly wind speed during the operational mitigation study where the threshold for the wind speed variable was <6 m/s. Sheffield Wind Facility, Caledonia County, Vermont; 3 June to 30 September 2012. Blue: >9.5°C threshold.

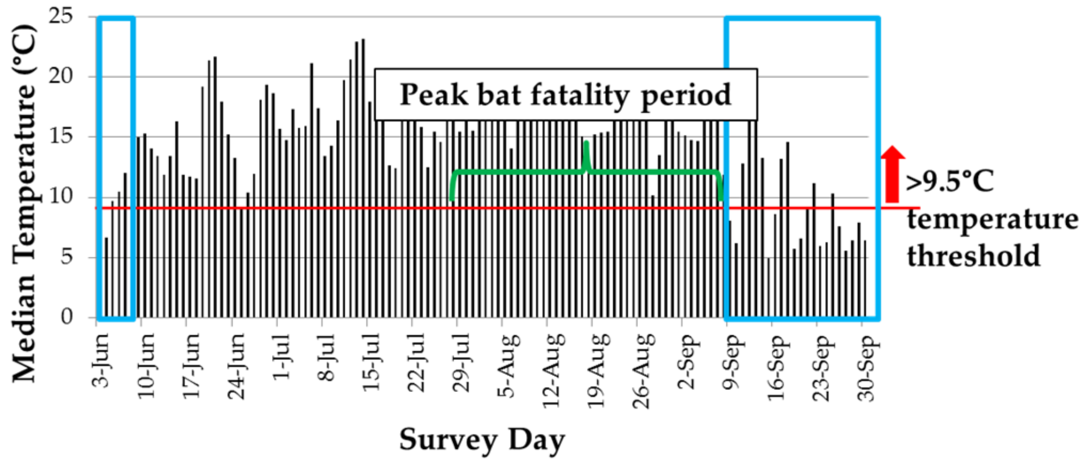


Figure 4. Peak bat fatality period and time periods during the study season where the temperature covariate dropped below the >9.5°C threshold during the operational mitigation study. Sheffield Wind Facility, Caledonia County, Vermont; 3 June to 30 September 2012.Green: peak bat fatality period (mid-July to mid-September); Blue: >9.5°C threshold.

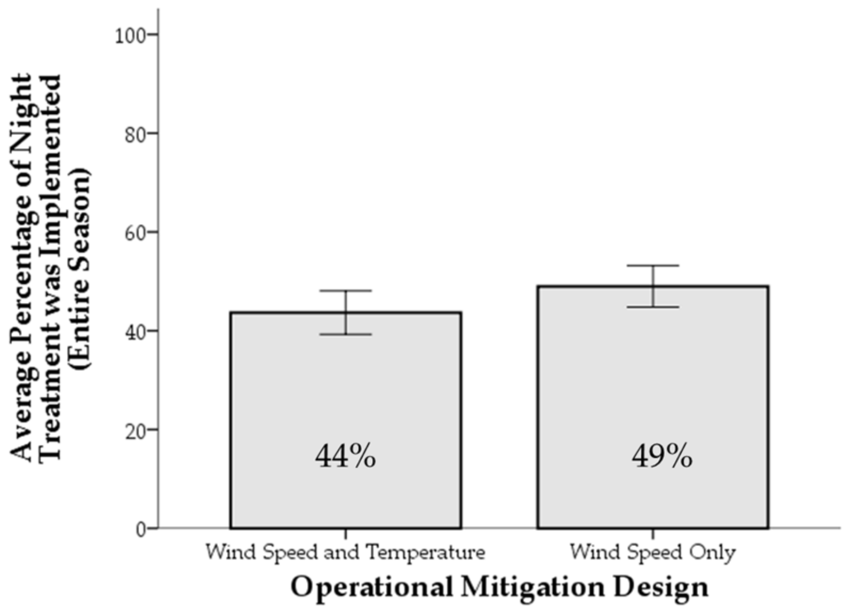


Figure 5. Hypothetical percentage of night treatment would have been implemented for a wind speed-temperature and wind speed-only design for the entire operational mitigation season based on weather data from the site. Sheffield Wind Facility, Caledonia County, Vermont; 3 June to 30 September 2012 and 2013.

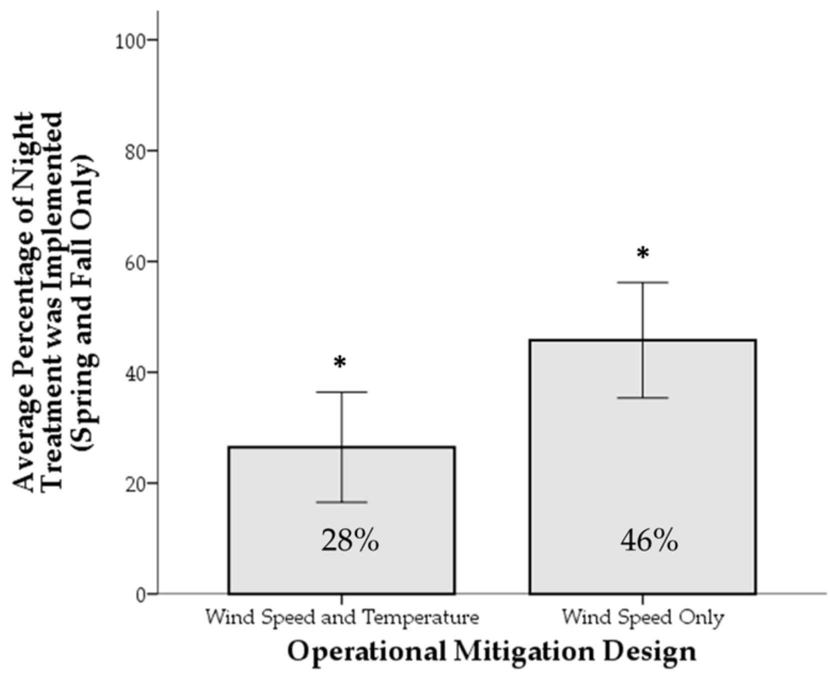


Figure 6. Hypothetical percentage of night treatments would have been implemented for a wind speed-temperature and wind speed-only design for the spring and fall seasons only based on weather data from the site. Sheffield Wind Facility, Caledonia County, Vermont; 3 June to 30 September 2012 and 2013. * = $p<0.05$.

APPENDIX A
EXAMPLE STUDY PLOT

Figure A.1. Example study plot, including total study area (126 m x 120 m), actual searched area, transect layout, and mapped visibility classes, for the post-construction and operational mitigation study at Sheffield Wind Facility, Caledonia County, Vermont. Refer to Appendix B for details of visibility classes.

Figure A.2. Transect (shown with red dash line) layout using spray paint, flagging, and wooden stakes for the post-construction and operational mitigation study at Sheffield Wind Facility, Caledonia County, Vermont.

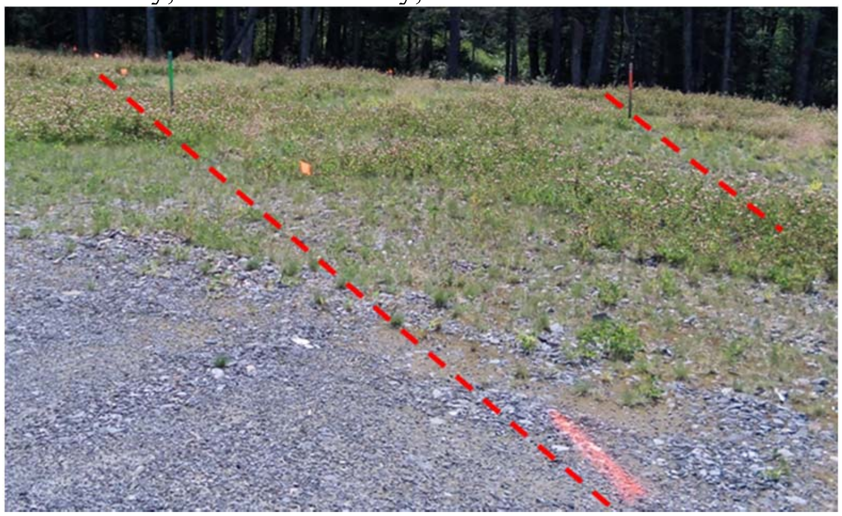


Figure A.3. Transect (shown with red dash line) layout using flagging and wooden stakes for the post-construction and operational mitigation study at Sheffield Wind Facility, Caledonia County, Vermont.

APPENDIX B
VISIBILITY CLASS DESIGNATIONS AND REPRESENTATIVE PHOTOS

	**Visibility Class:** Easy **Description:** >90% bare ground
	**Visibility Class:** Moderate **Description:** >25% bare ground

	**Visibility Class:** Difficult **Description:** <25% bare ground
	**Visibility Class:** Very difficult **Description:** 0% bare ground

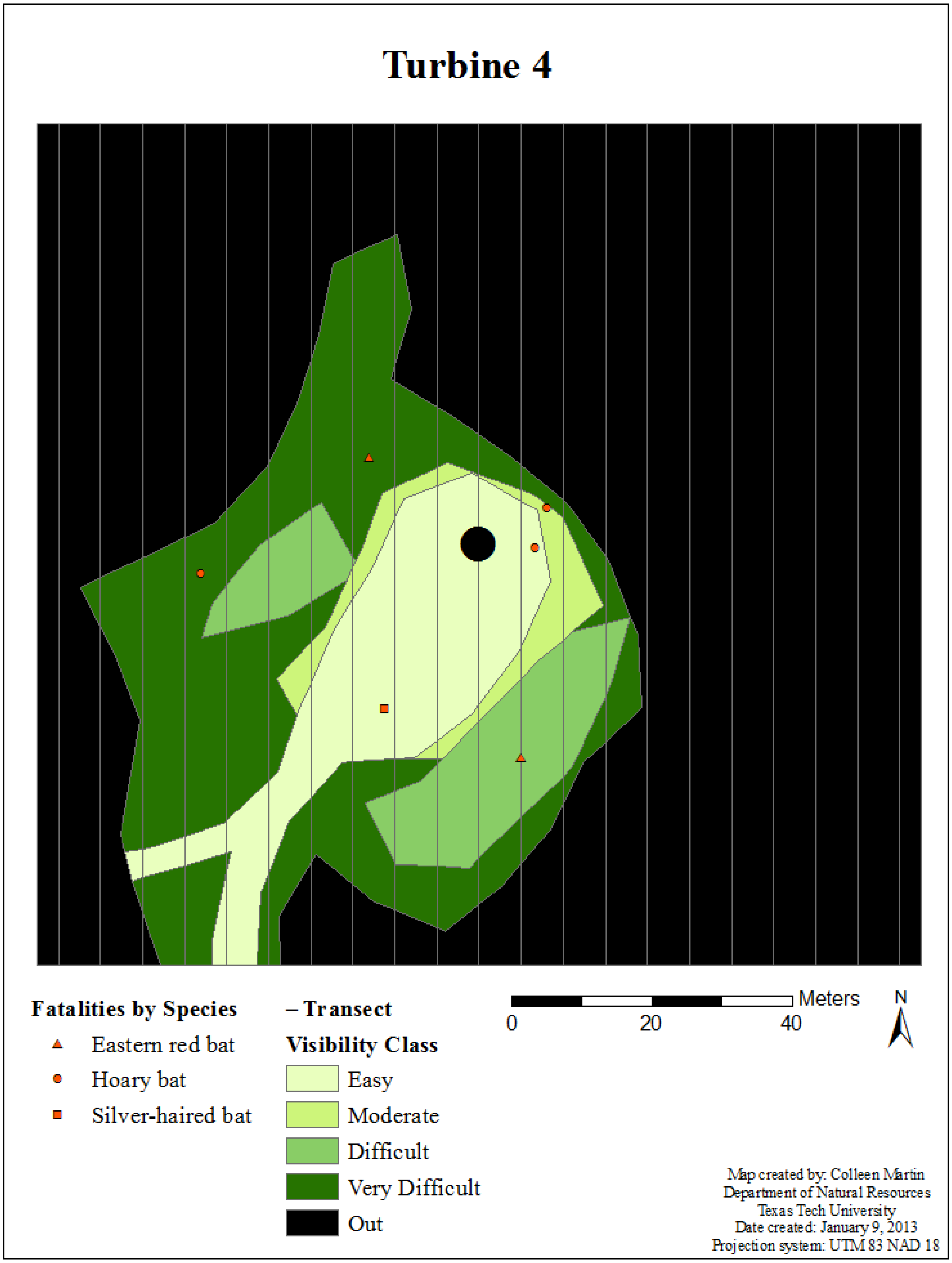
APPENDIX C
TURBINE MAPS – 2012

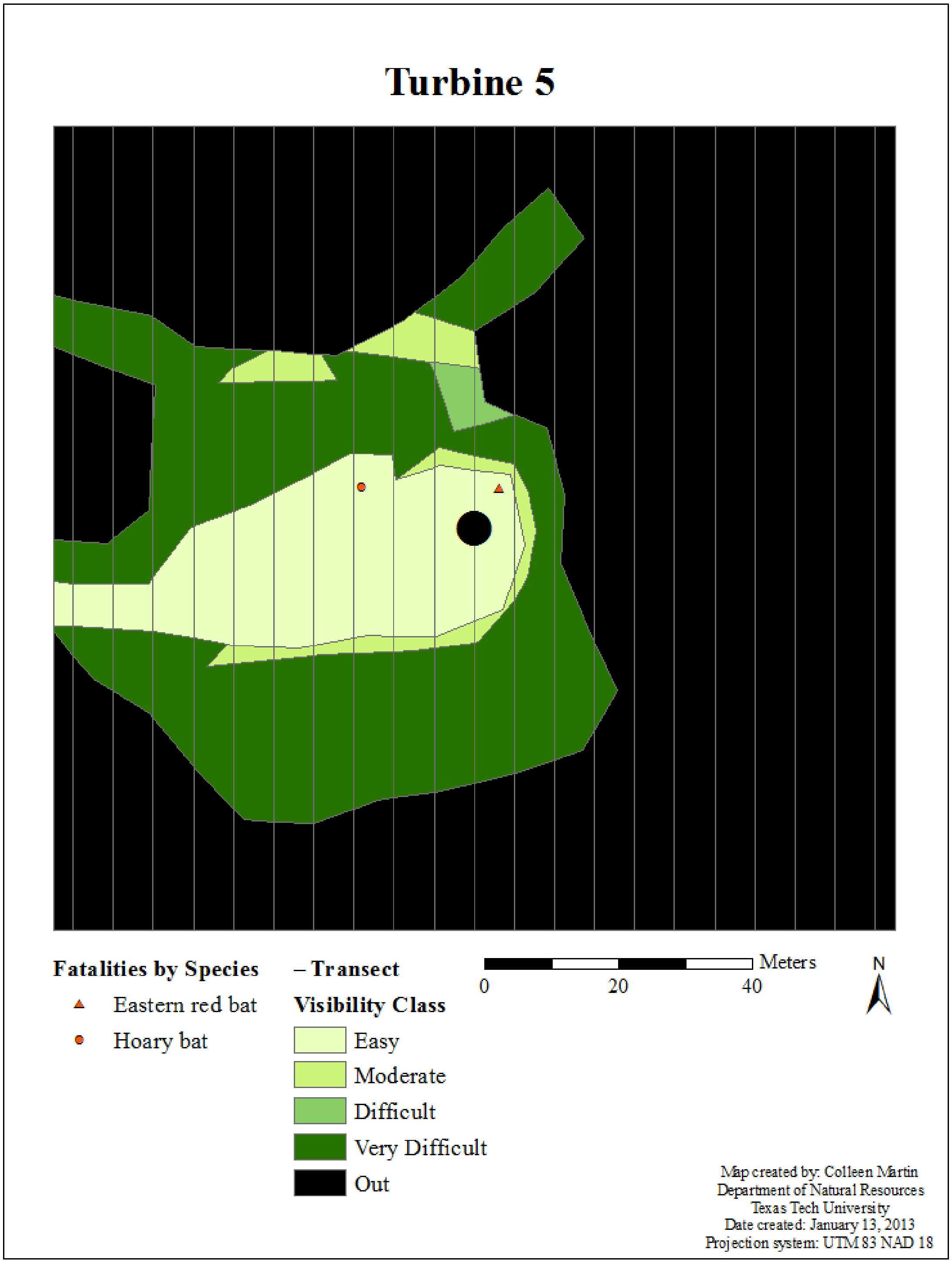

Turbine 1
Fatalities by Species
Hoary bat
Silver-haired bat
– Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
0
20
40
Meters
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 13, 2013
Projection system: UTM 83 NAD 18

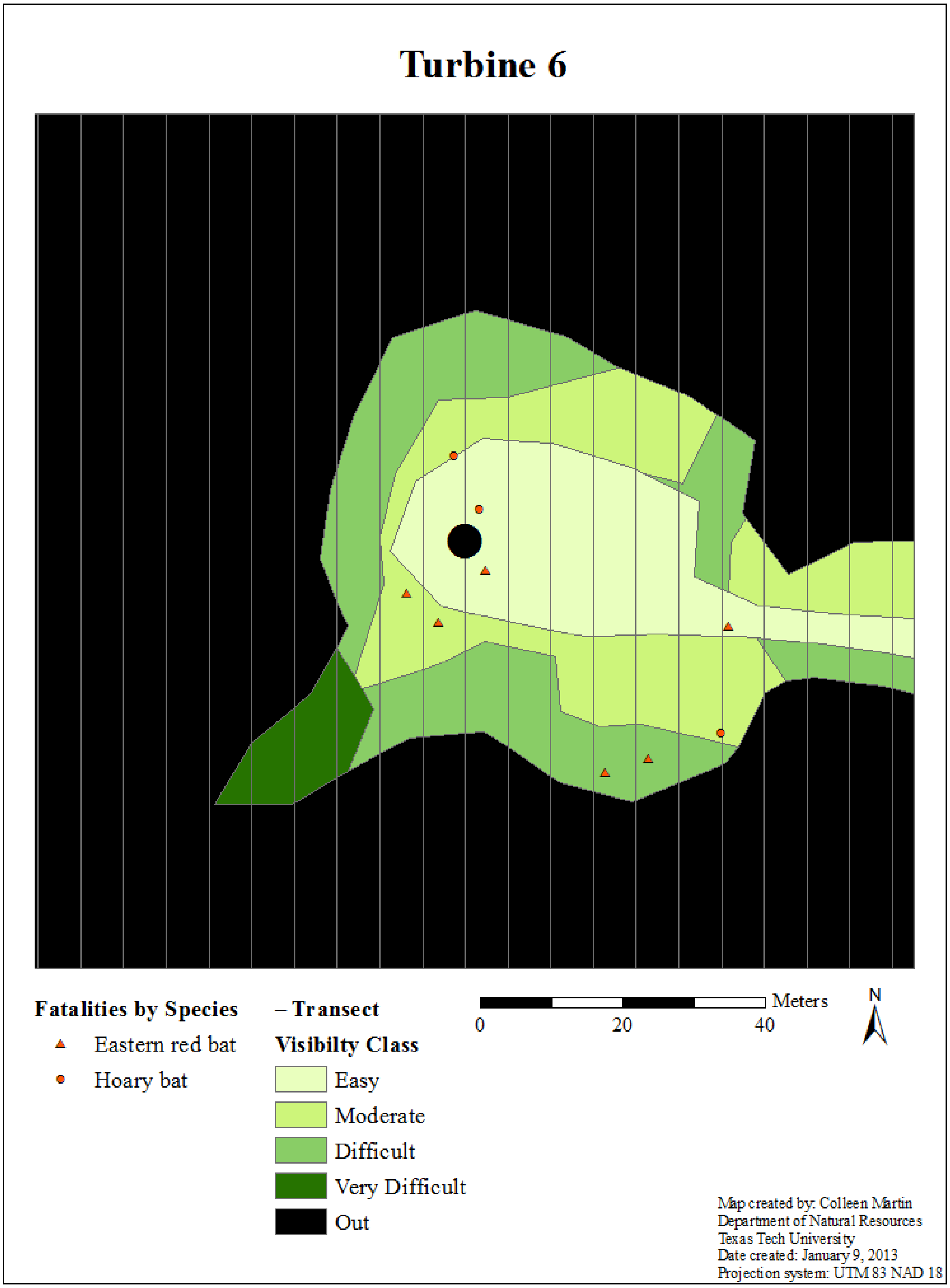
Turbine 2

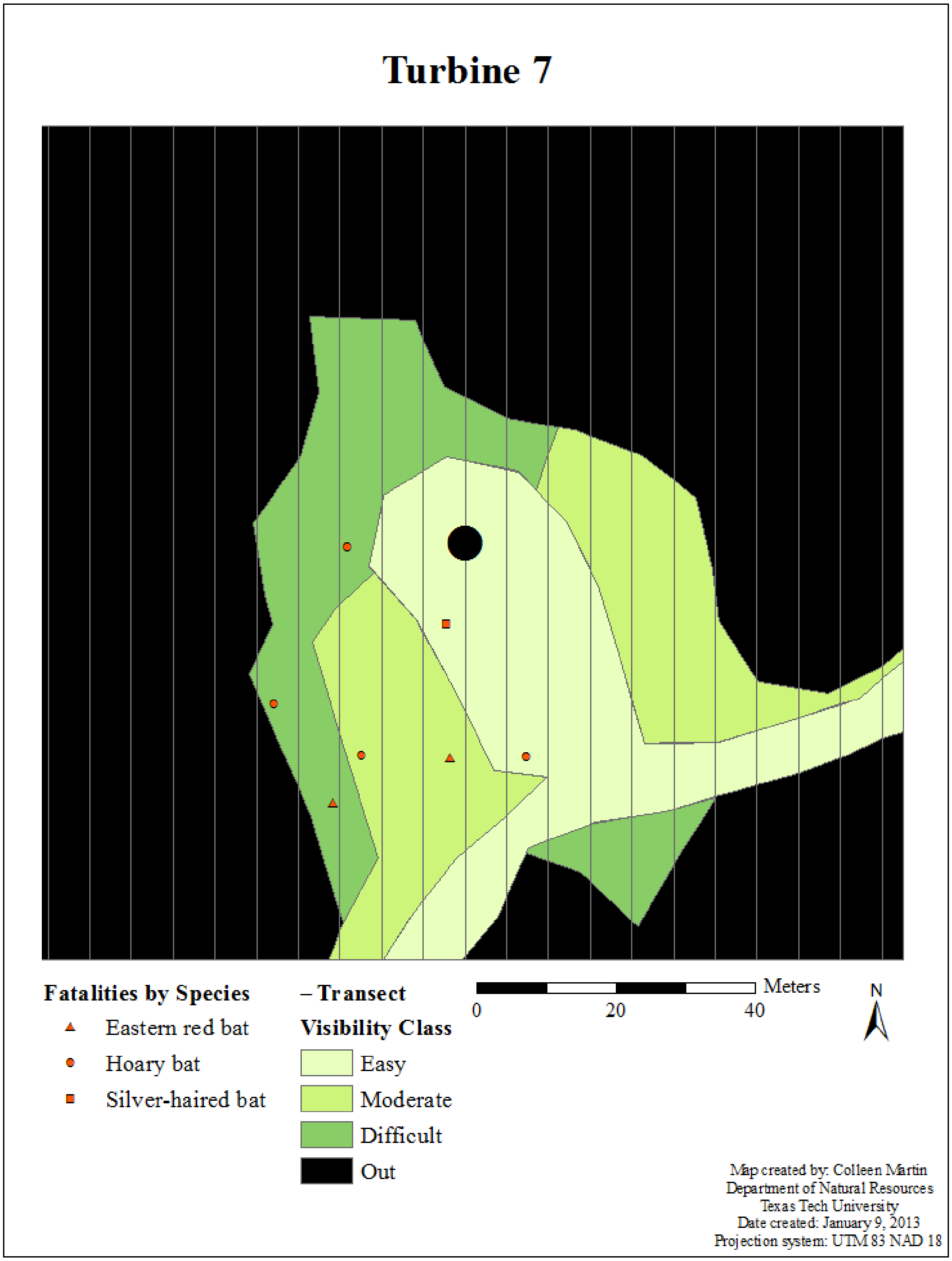

Fatalities by Species
Hoary bat
Silver-haired bat
Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
0
20
40
Meters
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 13, 2013
Projection system: UTM 83 NAD 18

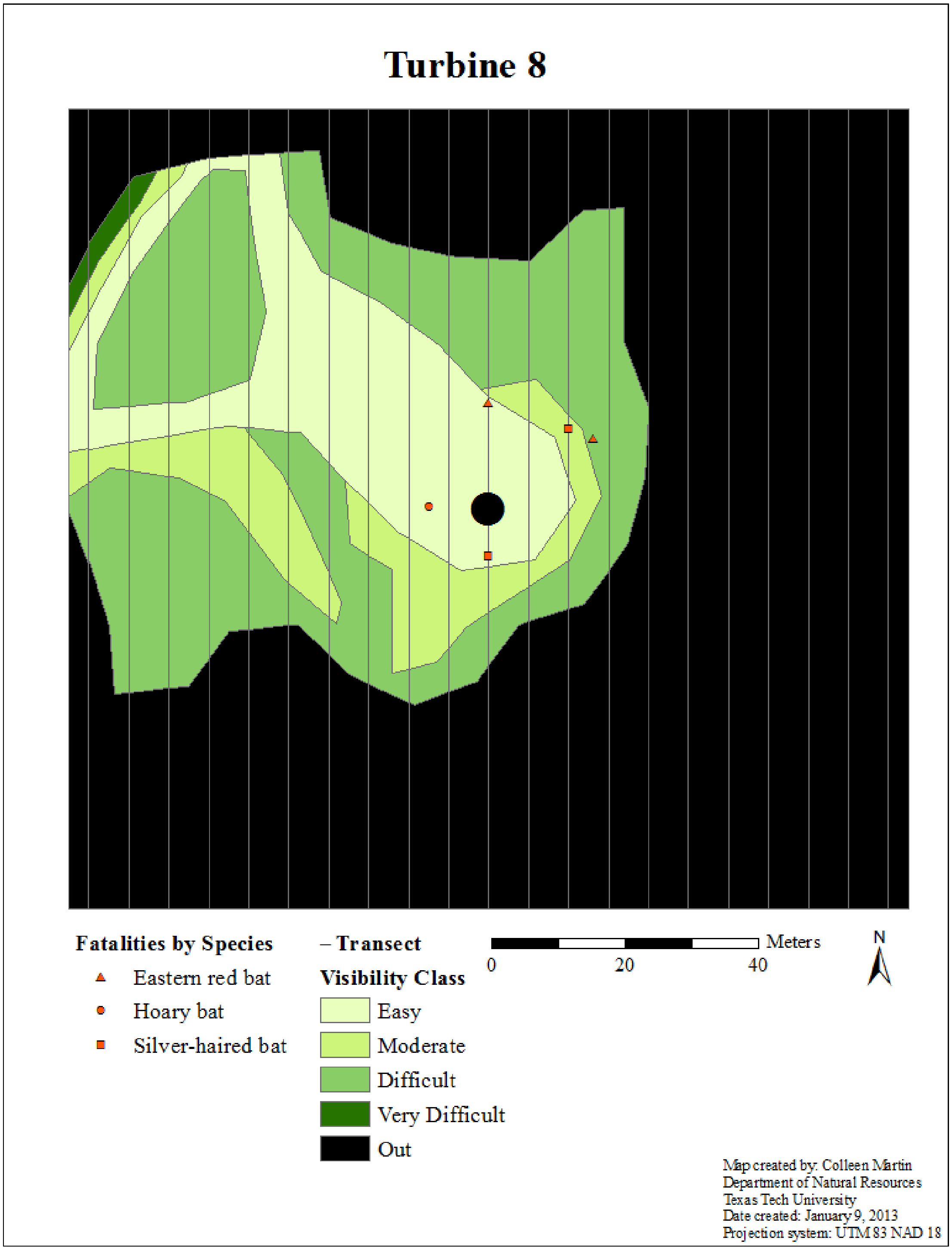
Turbine 3
Fatalities by Species
Hoary bat
Silver-haired bat
– Transect
Visibilty Class
Easy
Moderate
Difficult
Very Difficult
Out
Meters
0
20
40
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 9, 2013
Projection system: UTM 83 NAD 18

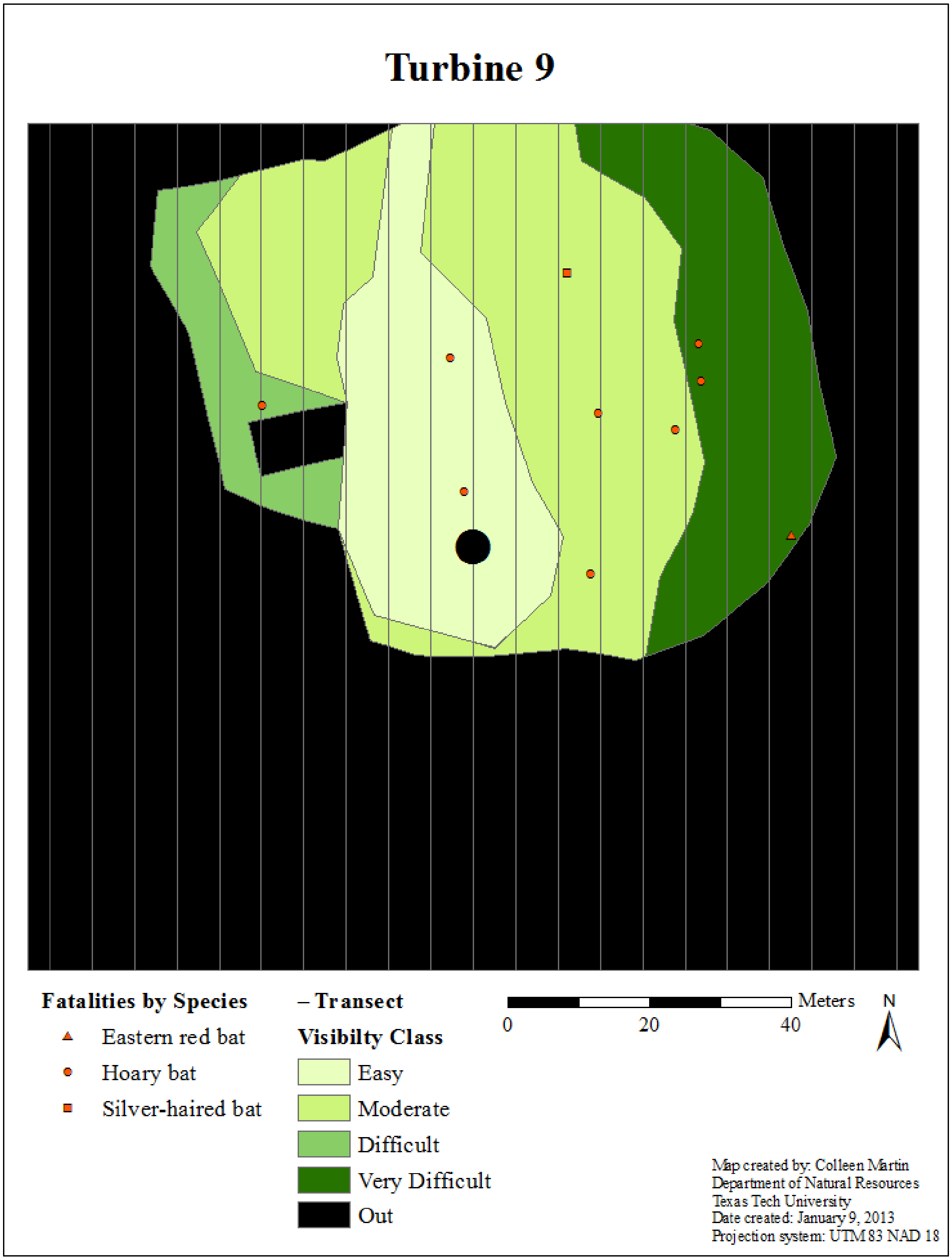

Turbine 4
Fatalities by Species
Eastern red bat
Hoary bat
Silver-haired bat
Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
0
20
40
Meters
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 9, 2013
Projection system: UTM 83 NAD 18


Turbine 5
Fatalities by Species
Eastern red bat
Hoary bat
– Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
Meters
0
20
40
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 13, 2013
Projection system: UTM 83 NAD 18


Turbine 6
Fatalities by Species
Eastern red bat
Hoary bat
Transect
Visibilty Class
Easy
Moderate
Difficult
Very Difficult
Out
Meters
0
20
40
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 9, 2013
Projection system: UTM 83 NAD 18


Turbine 7
Fatalities by Species
Eastern red bat
Hoary bat
Silver-haired bat
– Transect
Visibility Class
Easy
Moderate
Difficult
Out
0
20
40
Meters
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 9, 2013
Projection system: UTM 83 NAD 18

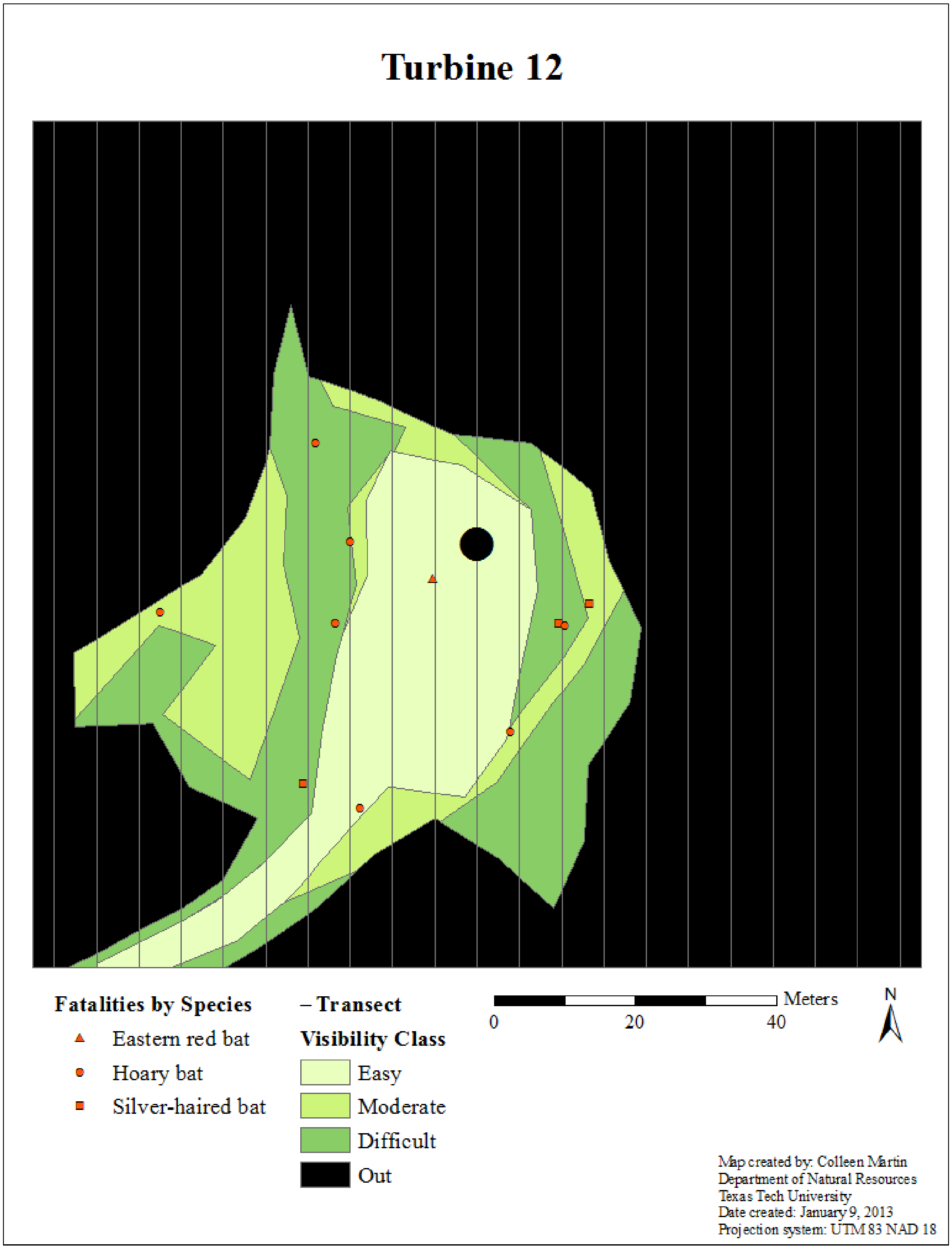

Turbine 8
Fatalities by Species
Eastern red bat
Hoary bat
Silver-haired bat
Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
0
20
40
Meters
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 9, 2013
Projection system: UTM 83 NAD 18



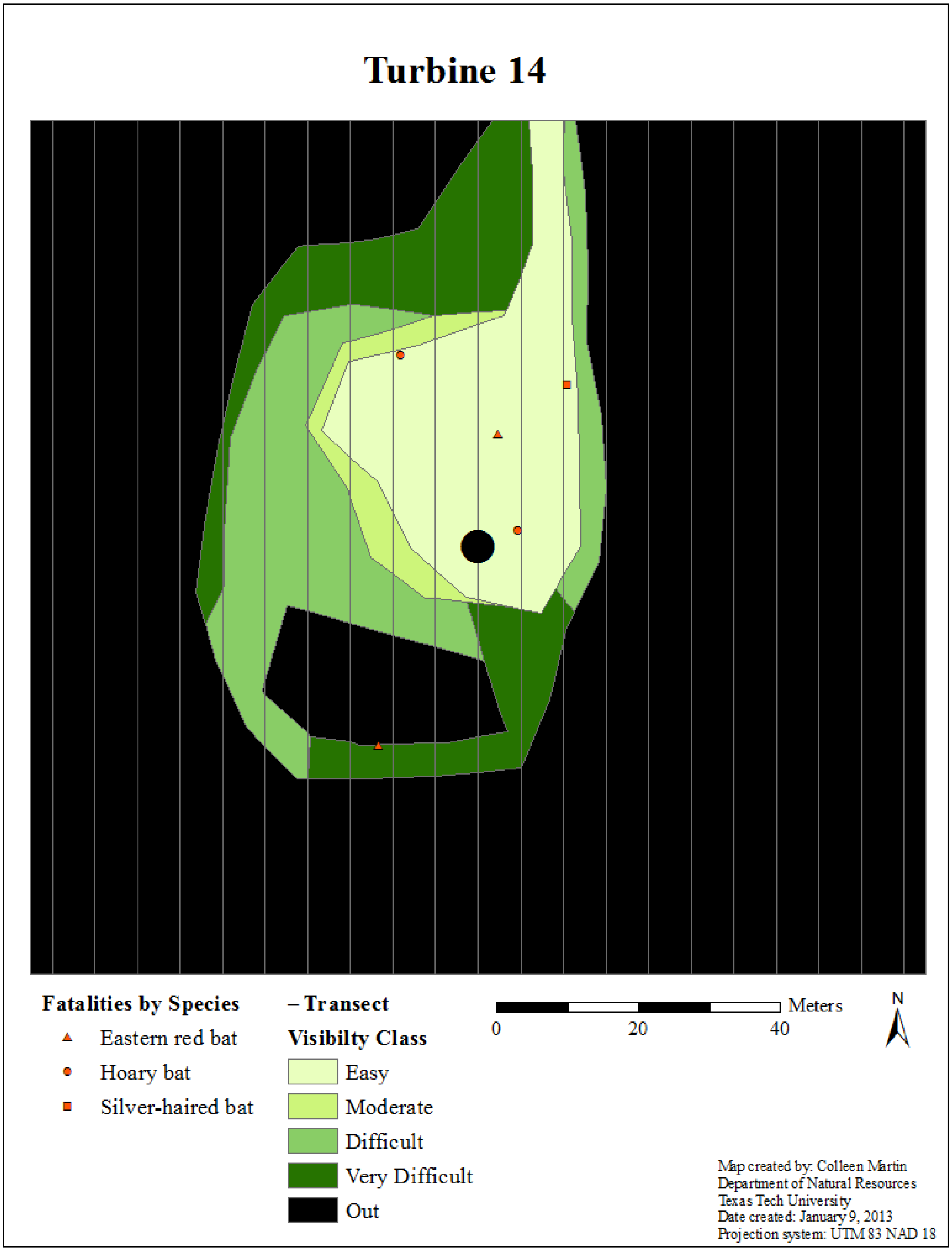
Turbine 9
Fatalities by Species
Eastern red bat
Hoary bat
Silver-haired bat
Transect
Visibilty Class
Easy
Moderate
Difficult
Very Difficult
Out
0
20
40
Meters
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 9, 2013
Projection system: UTM 83 NAD 18


Turbine 10
Fatalities by Species
Hoary bat
– Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
0
20
40
Meters
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 9, 2013
Projection system: UTM 83 NAD 18

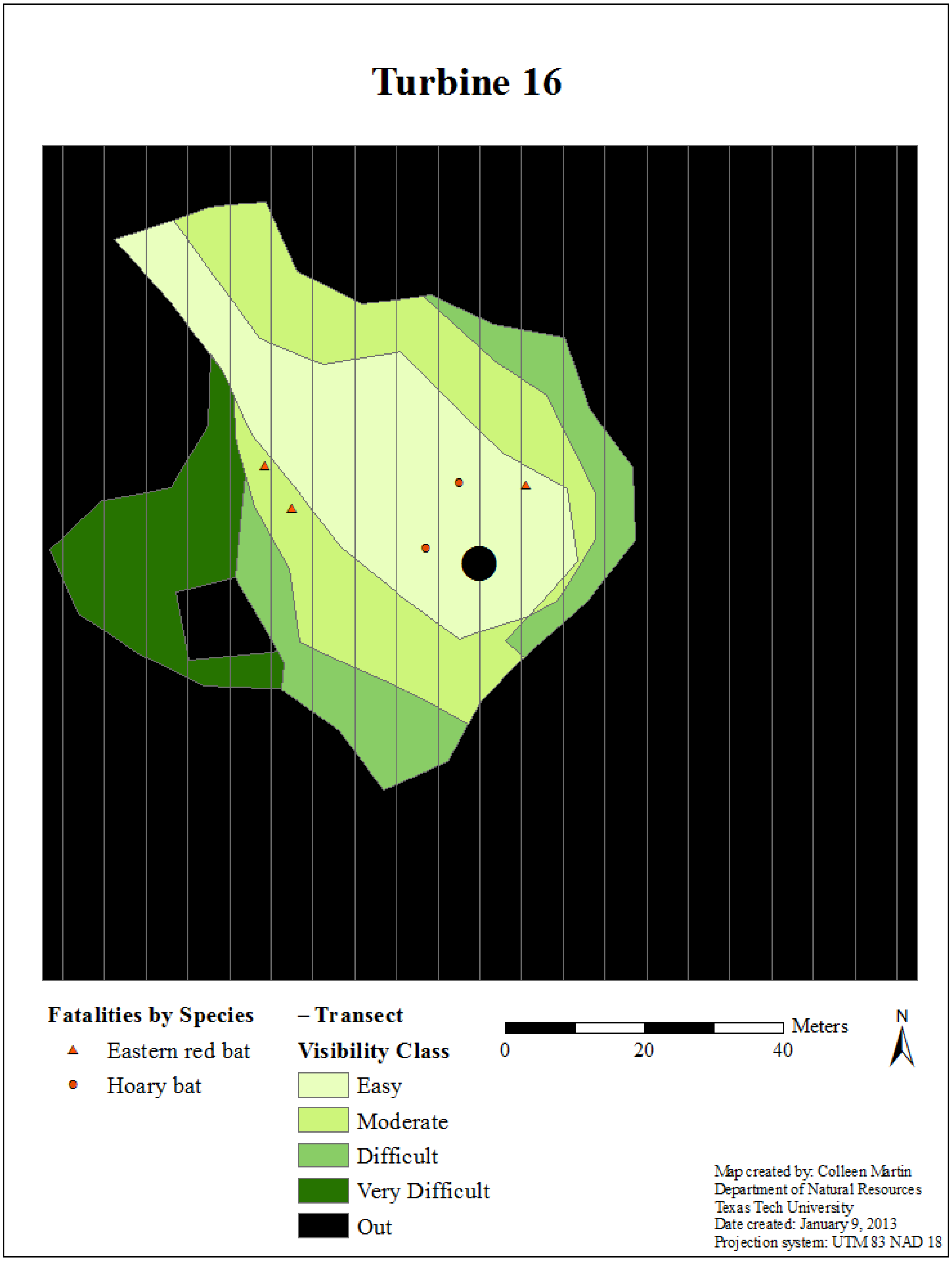

Turbine 11
Fatalities by Species
LACI
– Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
0
20
40
Meters
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 9, 2013
Projection system: UTM 83 NAD 18


Turbine 12
Fatalities by Species
Eastern red bat
Hoary bat
Silver-haired bat
Transect
Visibility Class
Easy
Moderate
Difficult
Out
Meters
0
20
40
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 9, 2013
Projection system: UTM 83 NAD 18

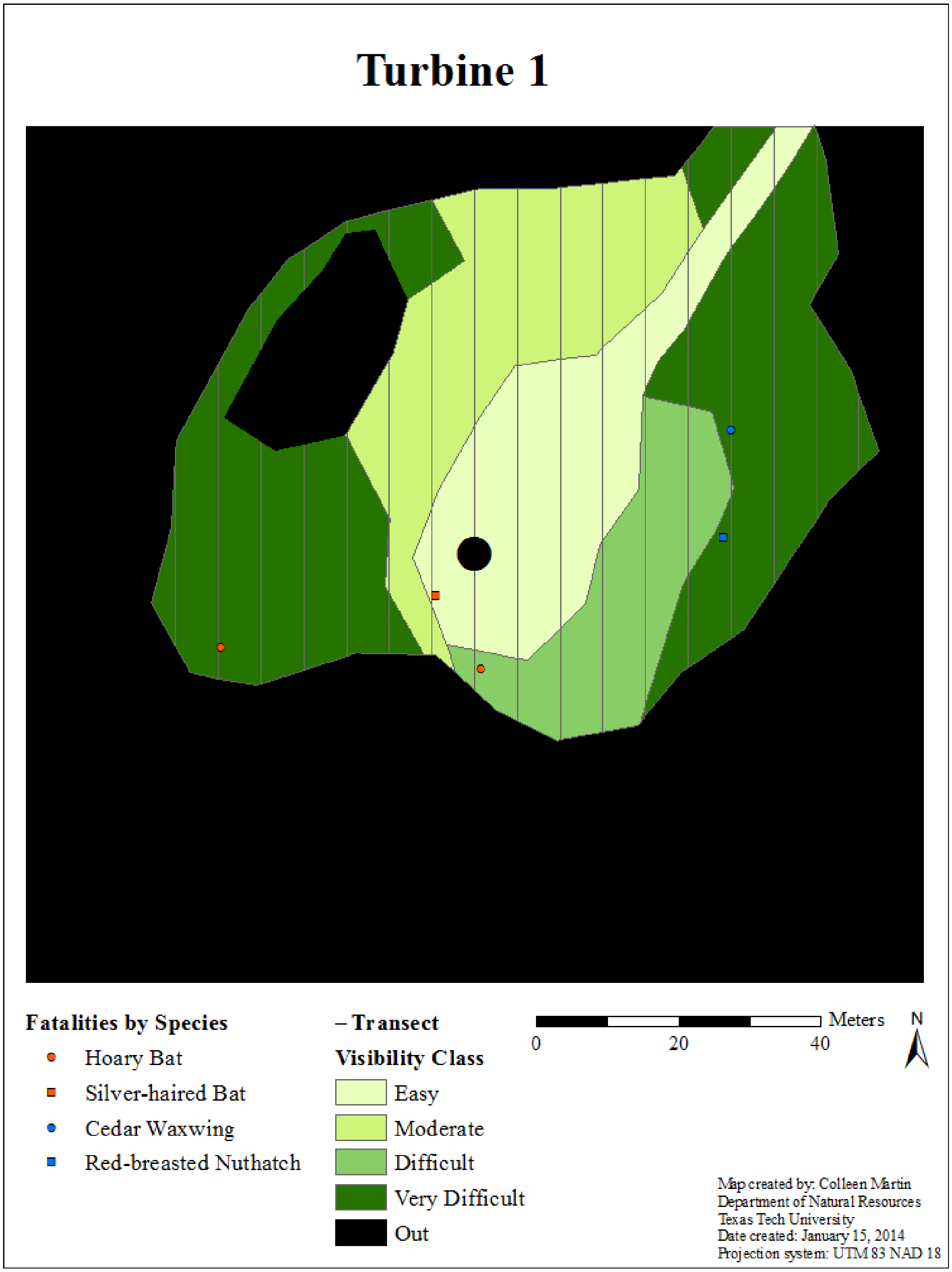

Turbine 13
Fatalities by Species
Eastern red bat
Hoary bat
Silver-haired bat
– Transect
Visibilty Class
Easy
Moderate
Difficult
Out
0
20
40
Meters
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 9, 2013
Projection system: UTM 83 NAD 18


Turbine 14
Fatalities by Species
Eastern red bat
Hoary bat
Silver-haired bat
– Transect
Visibilty Class
Easy
Moderate
Difficult
Very Difficult
Out
Meters
0
20
40
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 9, 2013
Projection system: UTM 83 NAD 18


Turbine 15
Fatalities by Species
Eastern red bat
Hoary bat
Silver-haired bat
– Transect
Visibilty Class
Easy
Moderate
Difficult
Very Difficult
Out
0
20
40
Meters
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 9, 2013
Projection system: UTM 83 NAD 18

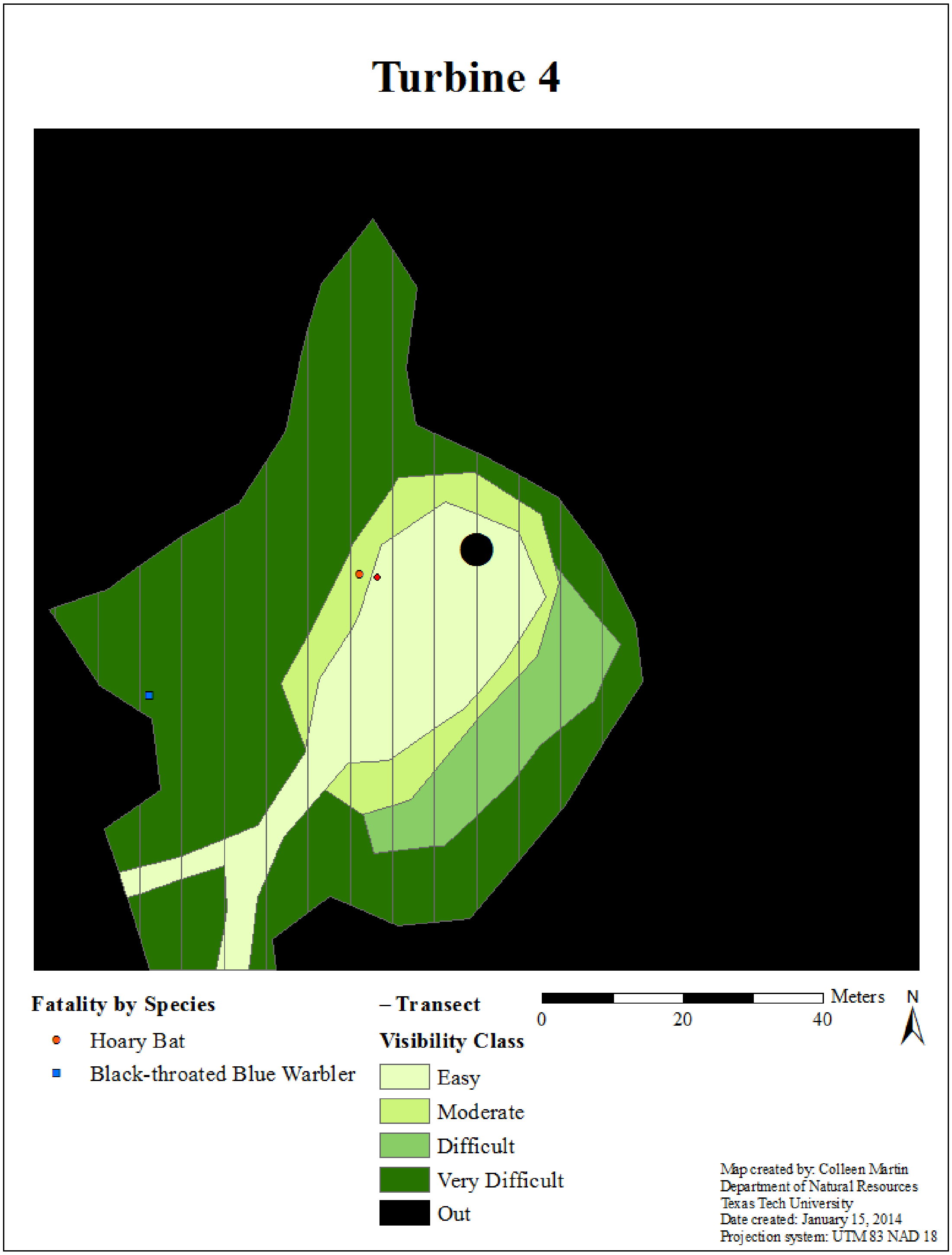

Turbine 16
Fatalities by Species
Eastern red bat
Hoary bat
Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
0
20
40
Meters
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 9, 2013
Projection system: UTM 83 NAD 18

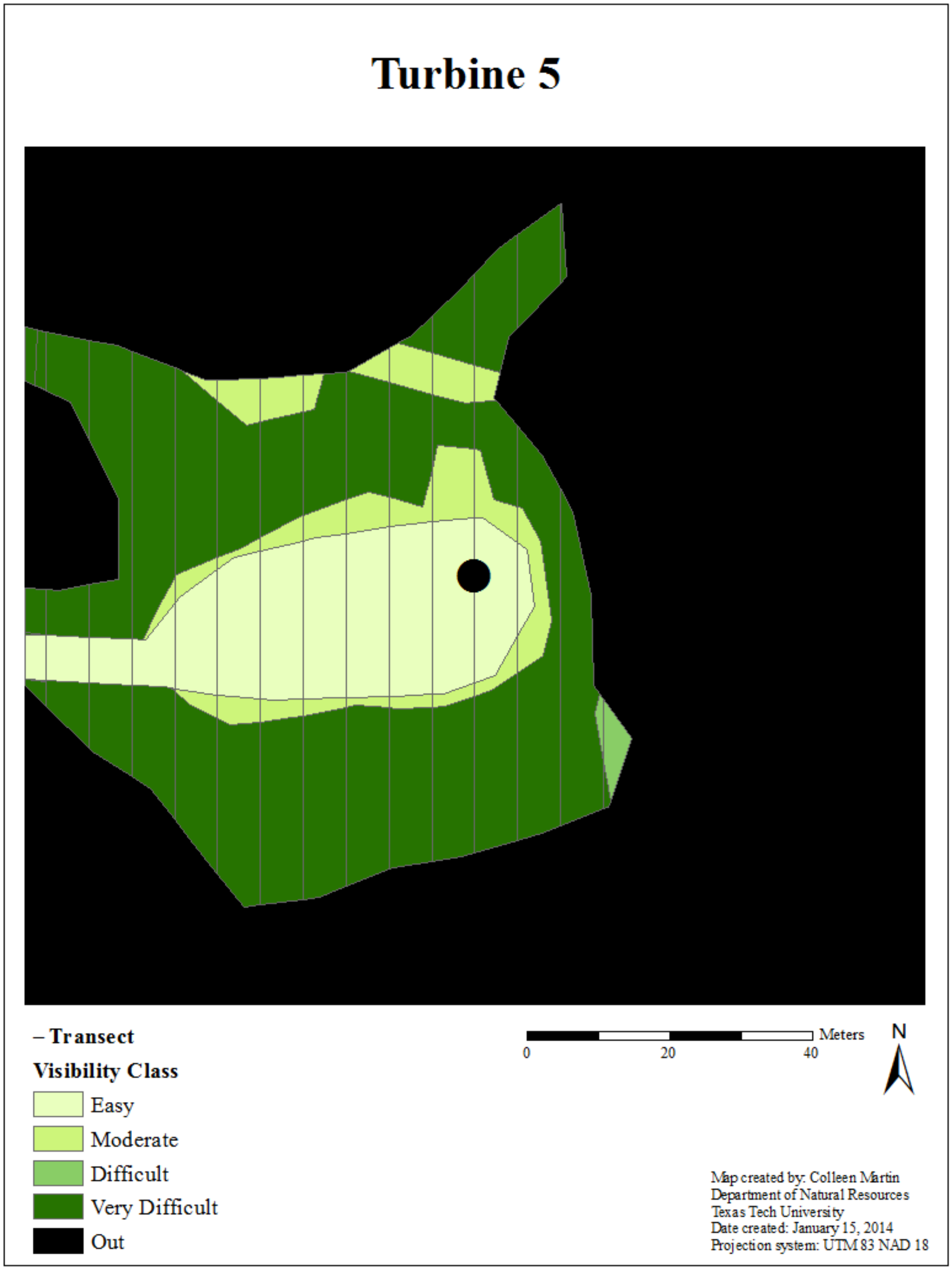
APPENDIX D
TURBINE MAPS – 2013

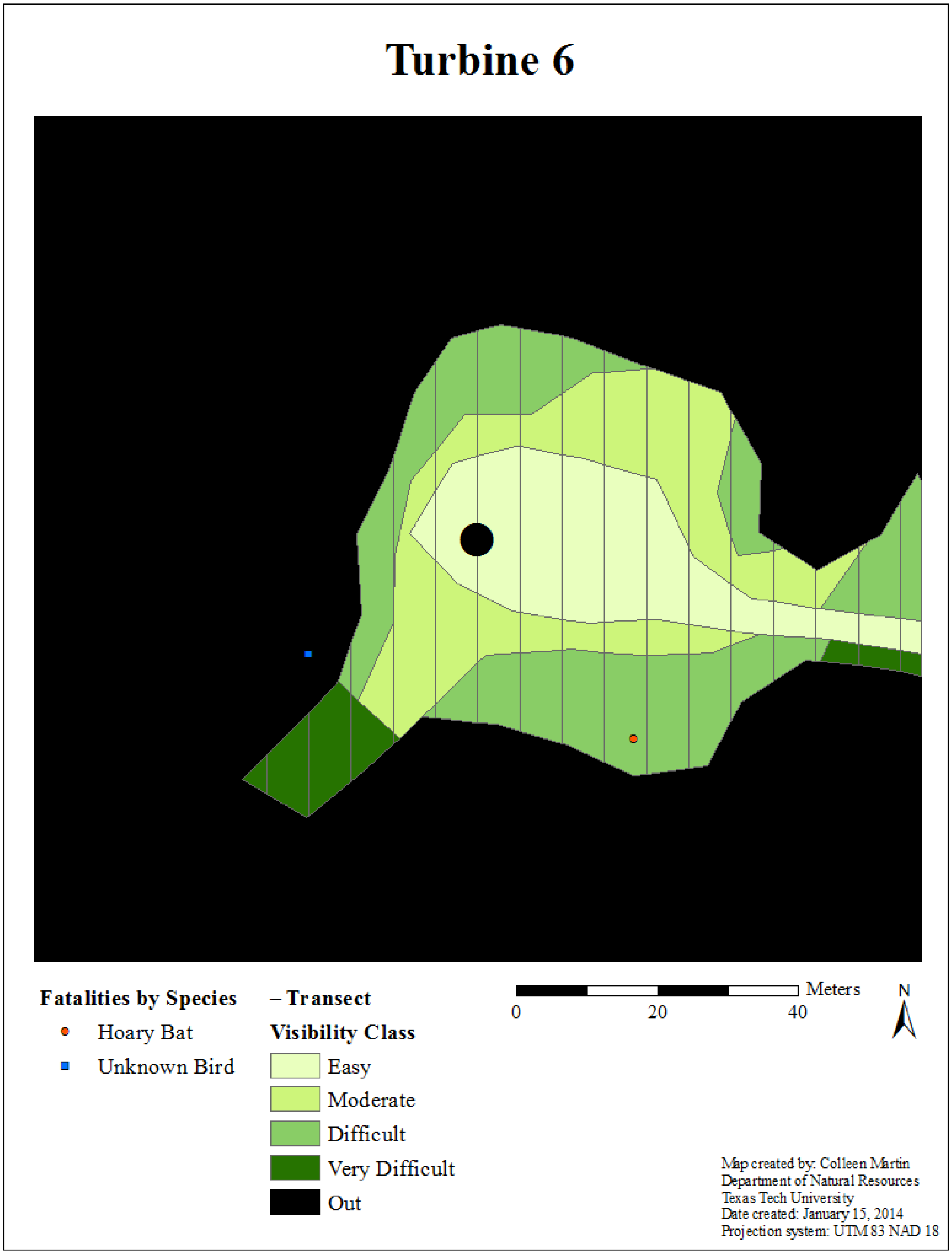

Turbine 1
Fatalities by Species
Hoary Bat
Silver-haired Bat
Cedar Waxwing
Red-breasted Nuthatch
– Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
0
20
40
Meters
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 15, 2014
Projection system: UTM 83 NAD 18

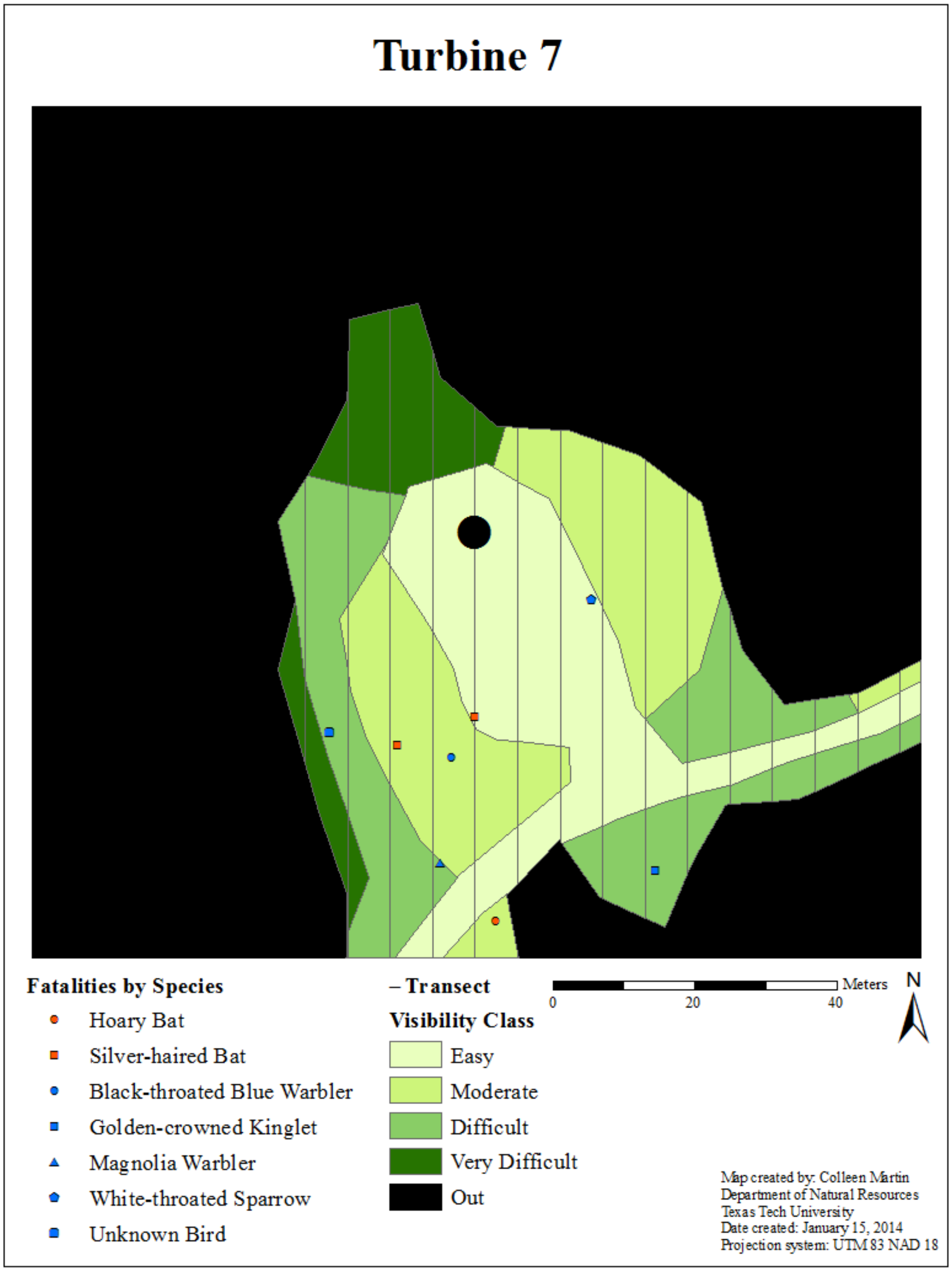

Turbine 2
Fatalities by Species
Red-eyed Vireo
– Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
Meters
0
20
40
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 15, 2014
Projection system: UTM 83 NAD 18

Turbine 3
Fatalities by Species
Hoary Bat
Golden-crowned Kinglet
Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
Meters
0
20
40
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 15, 2014
Projection system: UTM 83 NAD 18


Turbine 4
Fatality by Species
Hoary Bat
Black-throated Blue Warbler
Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
0
20
40
Meters
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 15, 2014
Projection system: UTM 83 NAD 18


Turbine 5
– Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
0
20
40
Meters
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 15, 2014
Projection system: UTM 83 NAD 18


Turbine 6
Fatalities by Species
Hoary Bat
Unknown Bird
– Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
Meters
0
20
40
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 15, 2014
Projection system: UTM 83 NAD 18


Turbine 7
Fatalities by Species
Hoary Bat
Silver-haired Bat
Black-throated Blue Warbler
Golden-crowned Kinglet
Magnolia Warbler
White-throated Sparrow
Unknown Bird
– Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
0
20
40
Meters
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 15, 2014
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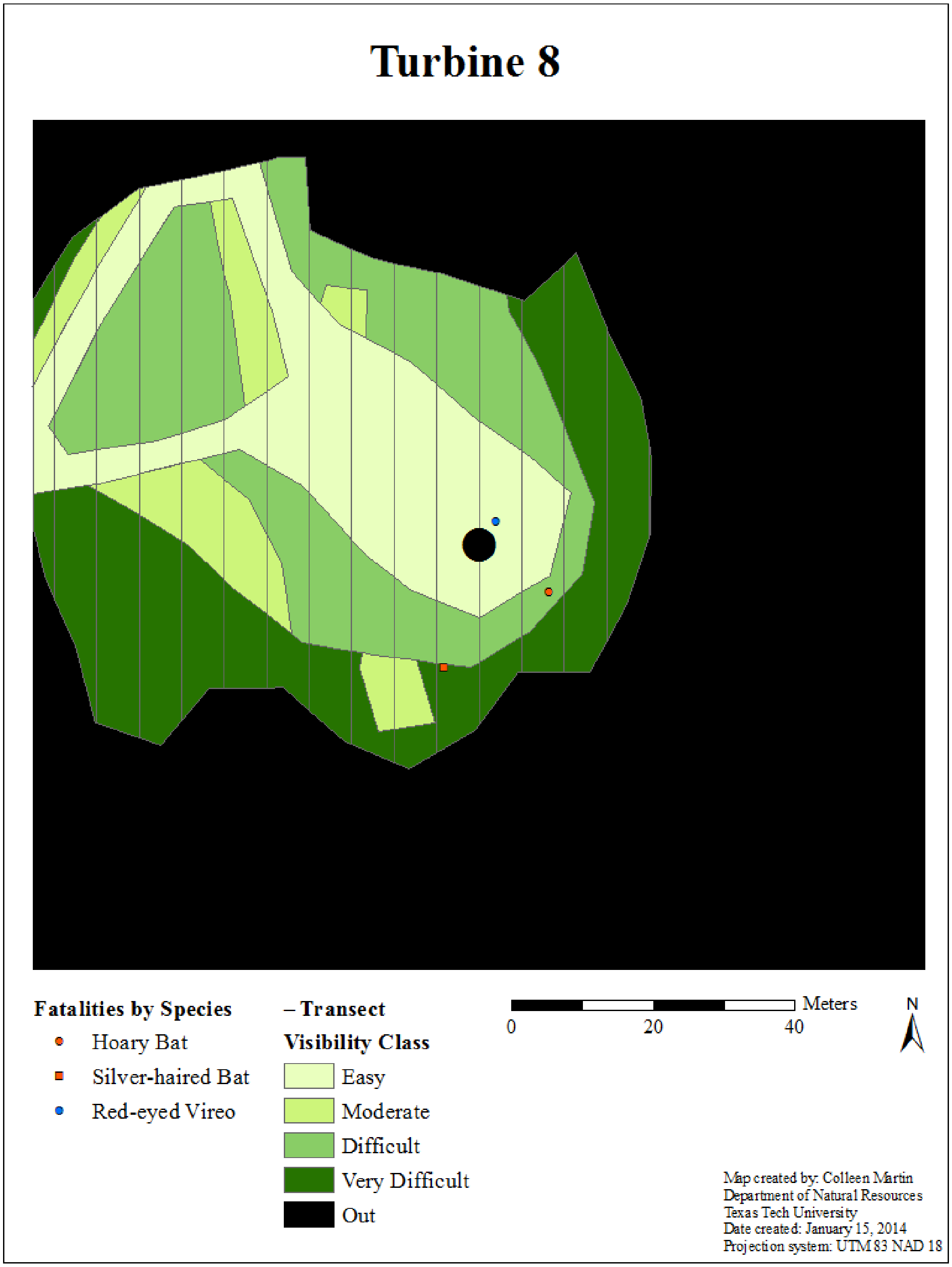
Turbine 8
Fatalities by Species
Hoary Bat
Silver-haired Bat
Red-eyed Vireo
– Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
Meters
0
20
40
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 15, 2014
Projection system: UTM 83 NAD 18


Turbine 9
Fatalities by Species
Silver-haired Bat
American Redstart
Dark-eyed Junco
Golden-crowned Kinglet
Magnolia Warbler
Red-breasted Nuthatch
Unknown Bird
Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
Meters
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20
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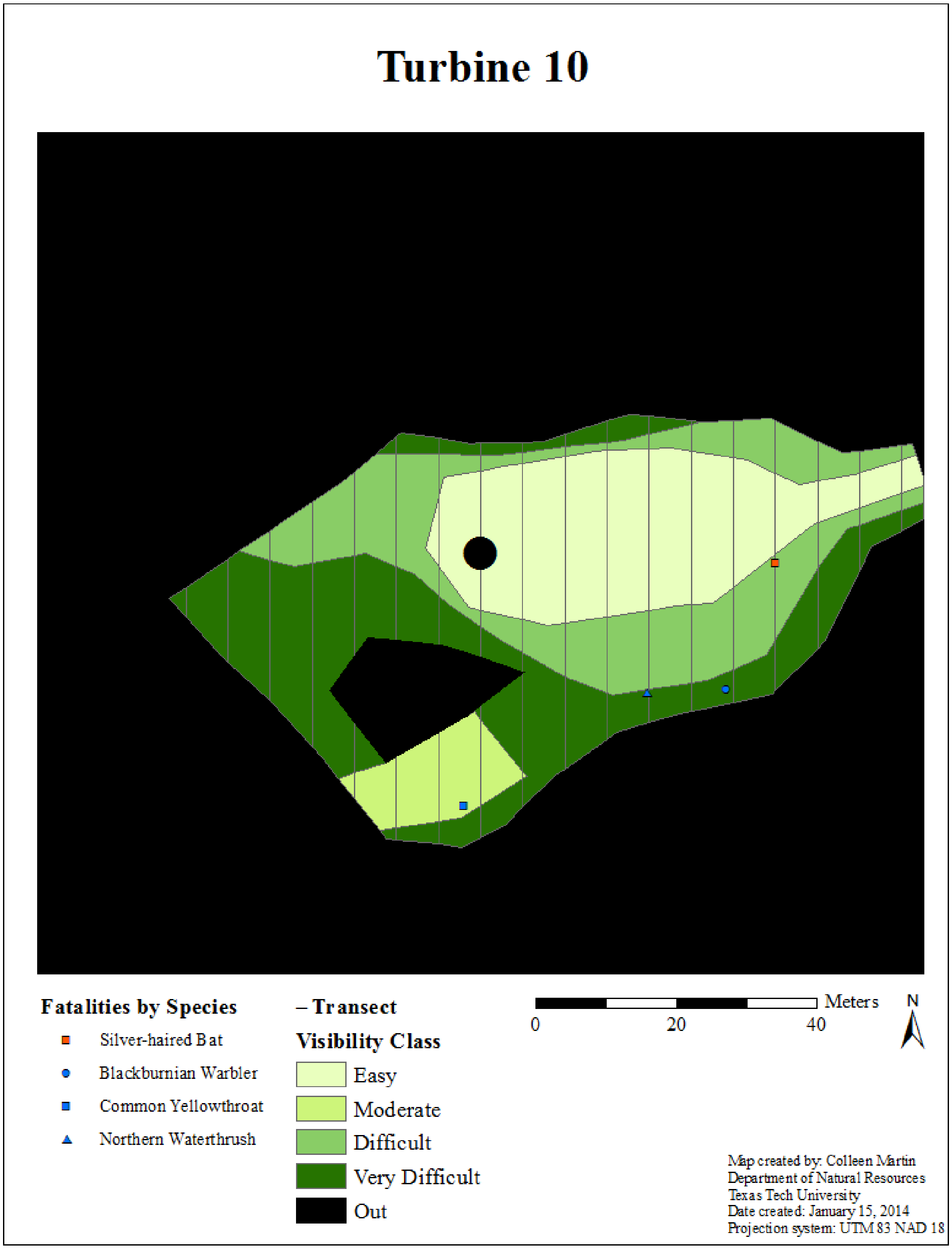
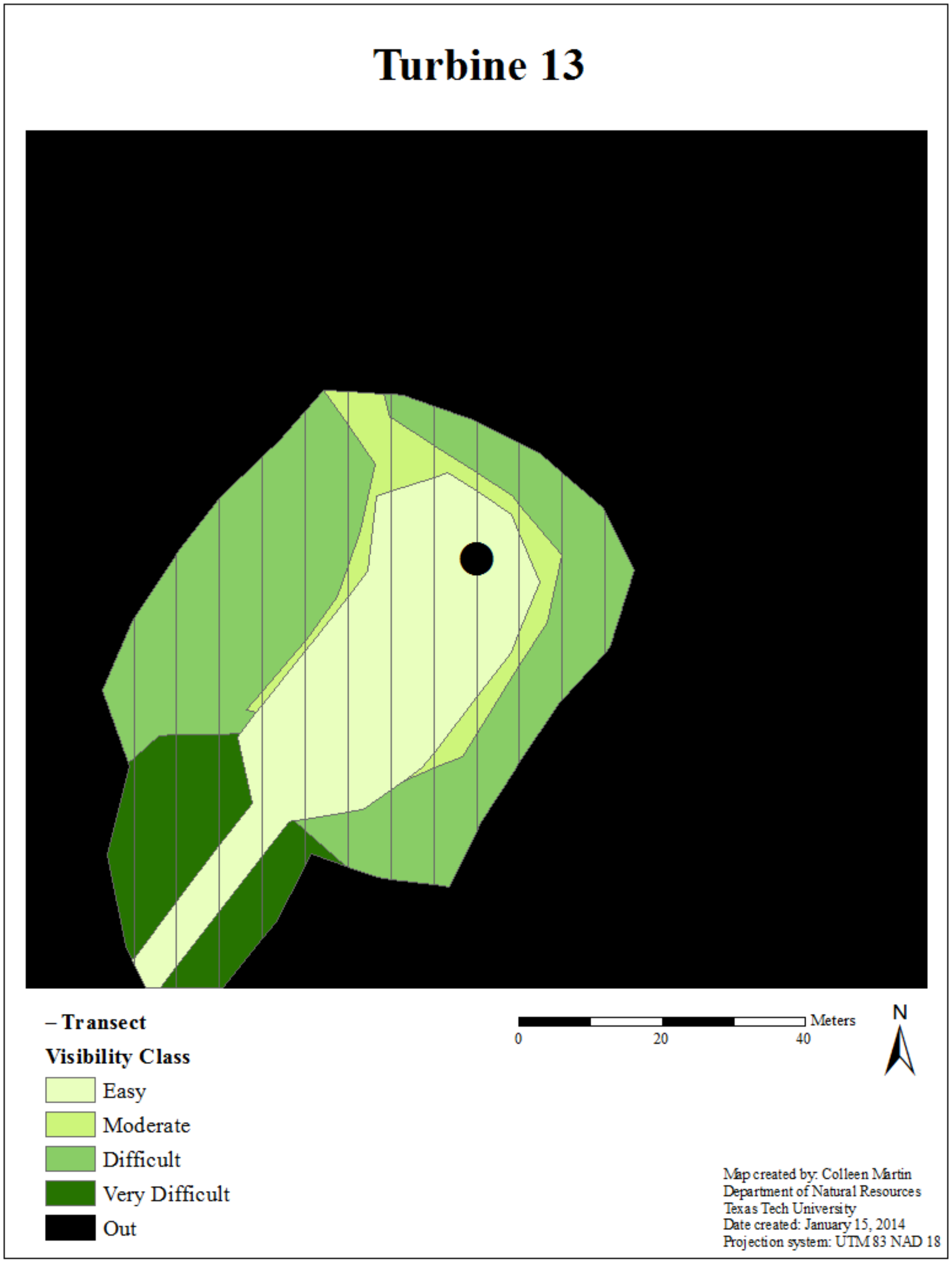
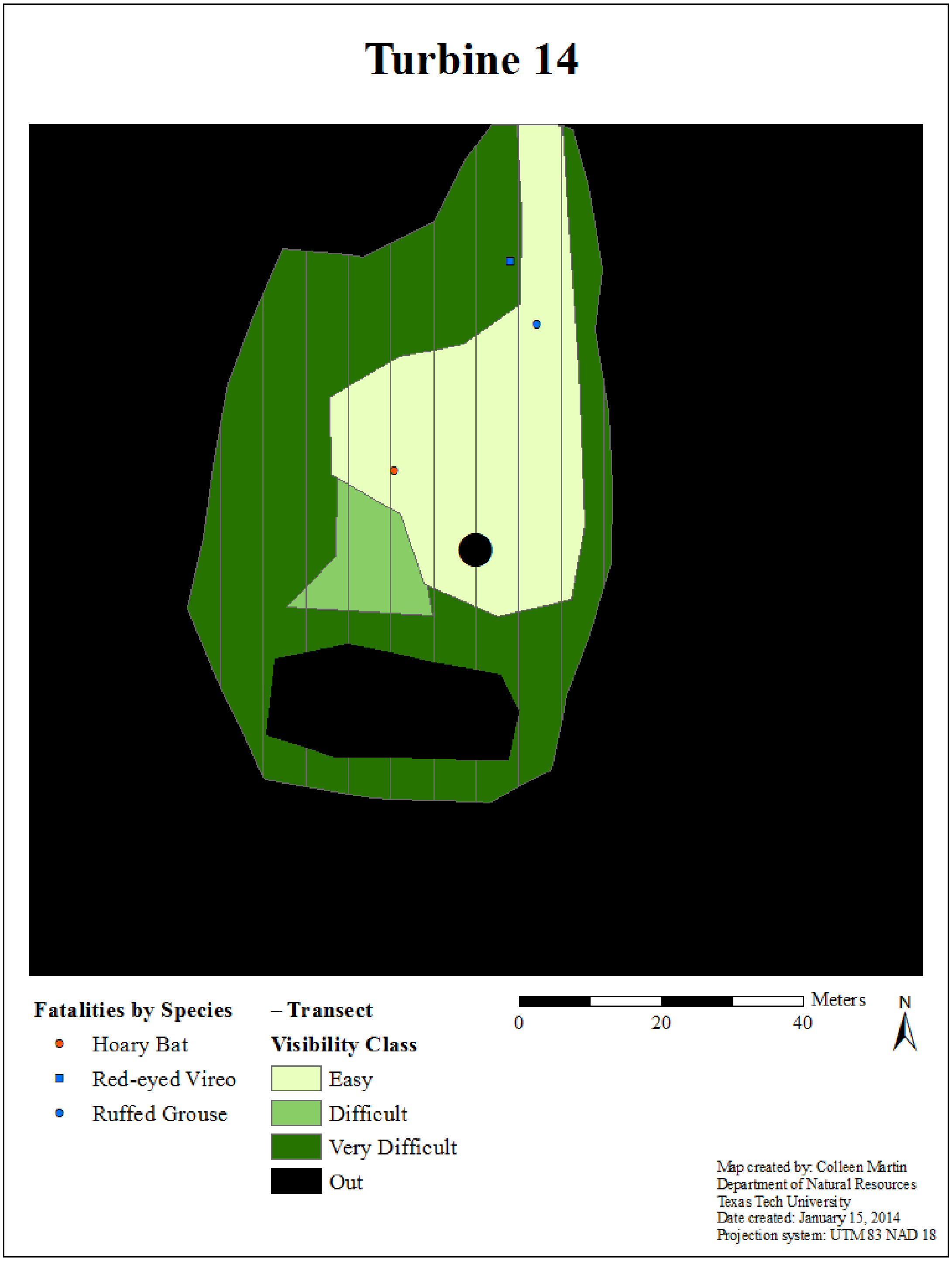
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 15, 2014
Projection system: UTM 83 NAD 18

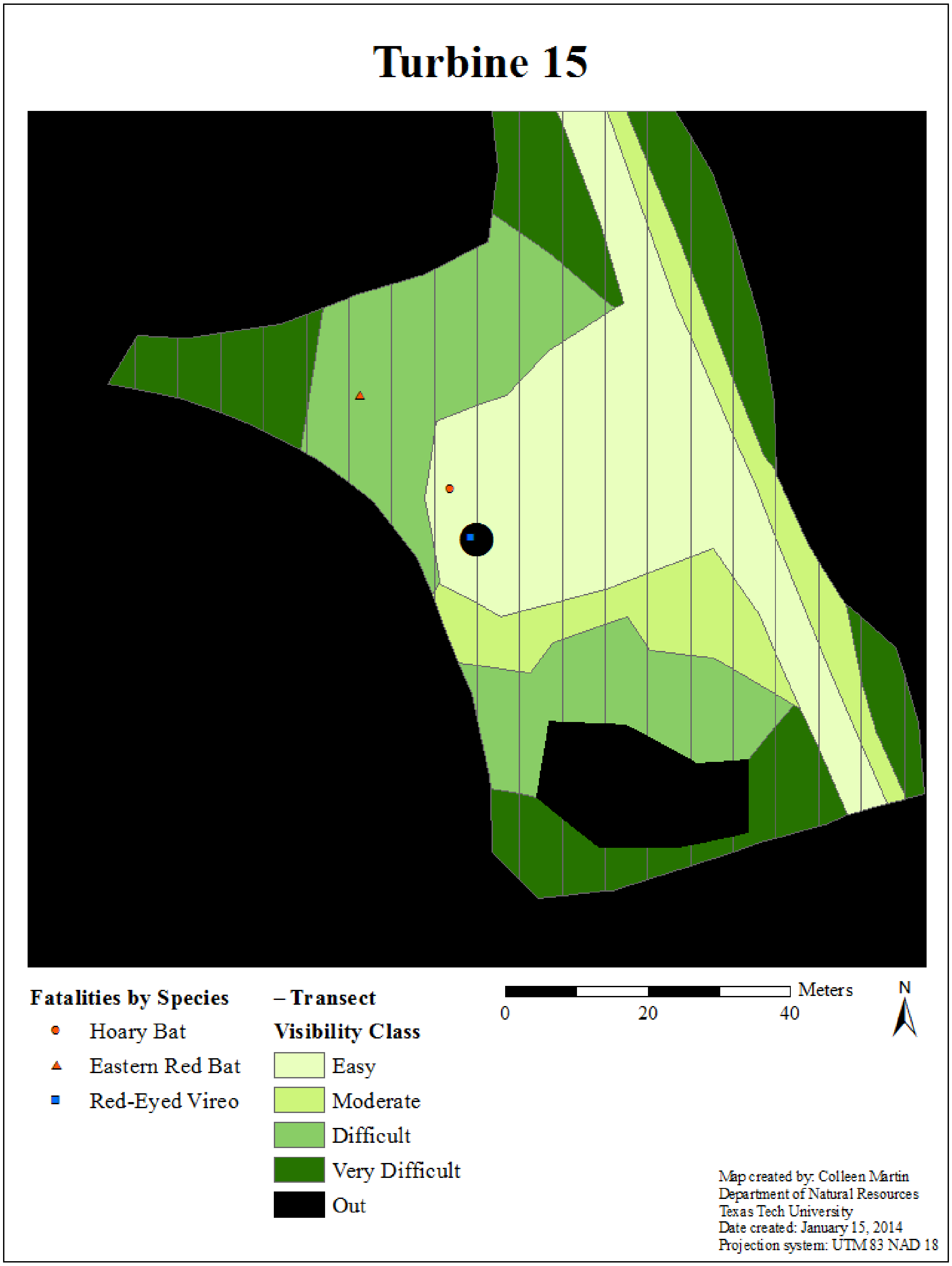

Turbine 10
Fatalities by Species
Silver-haired Bat
Blackburnian Warbler
Common Yellowthroat
Northern Waterthrush
– Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
Meters
0
20
40
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 15, 2014
Projection system: UTM 83 NAD 18


Turbine 11
Fatalities by Species
Silver-haired Bat
Golden-crowned Kinglet
Yellow-rumped Warbler
Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
Meters
0
20
40
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 15, 2014
Projection system: UTM 83 NAD 18


Turbine 12
Fatalities by Species
American Redstart
– Transect
Visibilty Class
Easy
Moderate
Difficult
Very Difficult
Out
0
20
40
Meters
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 15, 2014
Projection system: UTM 83 NAD 18


Turbine 13
– Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
Meters
0
20
40
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 15, 2014
Projection system: UTM 83 NAD 18


Turbine 14
Fatalities by Species
Hoary Bat
Red-eyed Vireo
Ruffed Grouse
– Transect
Visibility Class
Easy
Difficult
Very Difficult
Out
Meters
0
20
40
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 15, 2014
Projection system: UTM 83 NAD 18


Turbine 15
Fatalities by Species
Hoary Bat
Eastern Red Bat
Red-Eyed Vireo
– Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
Meters
0
20
40
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 15, 2014
Projection system: UTM 83 NAD 18


Turbine 16
Fatalities by Species
Yellow-bellied Sapsucker
Transect
Visibility Class
Easy
Moderate
Difficult
Very Difficult
Out
Meters
0
20
40
N
Map created by: Colleen Martin
Department of Natural Resources
Texas Tech University
Date created: January 15, 2014
Projection system: UTM 83 NAD 18

APPENDIX E
TURBINES SURVEYED FOR POST-CONSTRUCTION STUDY

Figure E.1. Turbines surveyed for the post-construction study (shown in red) and operational mitigation study (all turbines) during the 2012 field season at Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012.

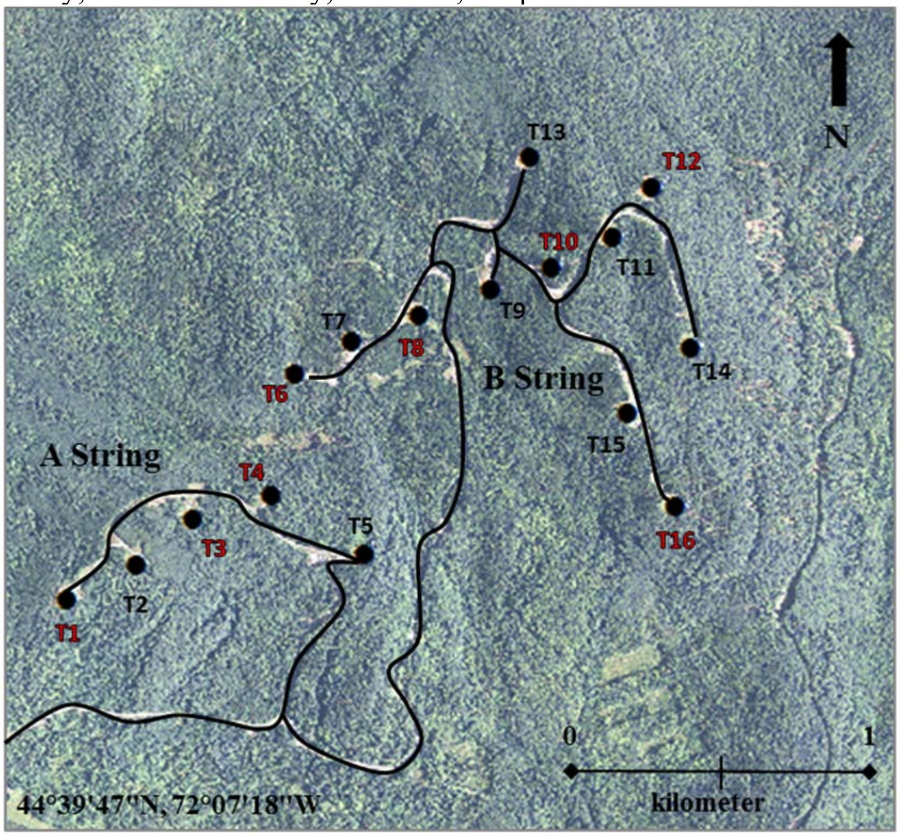
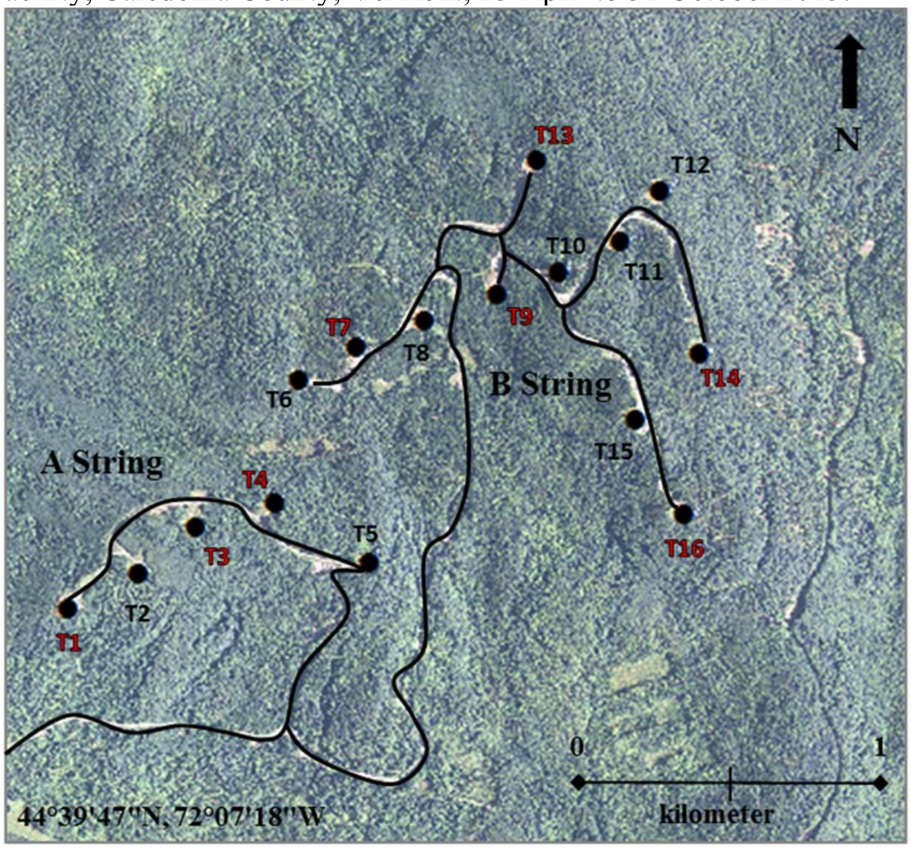


Figure E.2. Turbines surveyed for the post-construction study (shown in red) and operational mitigation study (all turbines) during the 2013 field season at Sheffield Wind Facility, Caledonia County, Vermont; 23 April to 31 October 2013.



APPENDIX F
FATALITY DATA SHEET

Sheffield Wind Farm
Fatality Report 2013

Incidental Yes No

ID #: ______________________ **Searcher:** ______________________

(Date_species code_turbine_# found that day, i.e. 1/1/01_LABO_T1_1)

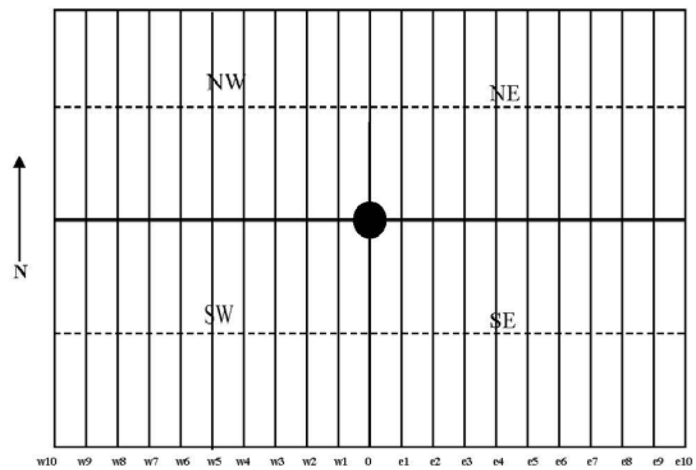
Recovery Date: ______________ **Time Found:** ____________________

THE TURBINE

Turbine #: __________________

Quadrant: NE SE NW SW **Degree from turbine:** _______ **Distance (m):** ___________

Note: Degrees should match quadrant. NE: 0 –90 SE: 90 – 180 SW: 181 – 270 NW: 271 – 359



Dominant Cover (choose only one):

______ Bare Ground (e.g., road, gravel, dirt)
______ Vegetation (clover, grass, blackberry)
  _____ Short (below ankle)
  _____ Medium (ankle to knee)
  _____ Tall (above knee)
______ Large Rock/Boulders
______ Brush Pile

Other: ______________________

% Veg: <10 11-25 26-50 50-75 75-99 100

THE TRANSECT

Transect # :_______________

Perp. Distance to Transect (m):________________

Found Outside of plot? Yes No

Visibility Index

______ Easy (e.g. ≥ 90% bare ground)
______ Moderate (e.g., ≥ 25% bare ground with ≤ 15 cm ground cover height)
______ Difficult (e.g., ≤ 25% bare ground with ≥ 30 cm ground cover height)
______ Very Difficult (e.g., little or no bare ground, 25% of ground cover ≥ 30 cm)

Veg. Height (cm): Max____ Dom. Avg.____

Slope >25%: Yes No

Notes: ____________________________________

- 1 -

**modified from E.B. Arnett (Ed.). Relationships between bats and wind turbines in Pennsylvania and West Virginia: An assessment of bat fatality search protocols, patterns of fatality, and behavioral interactions with wind turbines. Final Report. Bat Conservation International, Austin, TX. 187 pp.*

THE CARCASS

Bird / Bat **Band/tag:**______________ **Live / Fatality** **If Live:** Euthanized Released

Camera:____________ **Photo Numbers if taken**: __________

Species: ______________________ **(i.e.** ***Myotis lucifugus*** **= MYLU)** (If unknown keep carcass and contact lead)

Age: A J U **Sex:** M F U

Repro: Preg Lact Post Lact Scrotal Non repro Unknown

Position: Face Up Face Down

Physical Condition at time of find: Complete Partial Feather Spot

Injury Type (circle one): No visible injuries Visible injuries (explain below) Unknown

Describe injuries: ____

____

Carcass Condition:

_____ Fresh

_____ Decomposing – early

_____ Decomposing – late

_____ Desiccated

Infestation:

______ None ____Maggot eggs _____ Maggots

______ Ants ______ Flies _____ Bees/Wasps

______ Beetles _____ Grasshoppers

_____ Other ______________________________

Eyes:

_____ Round/fluid filled

_____ Dehydrated

_____ Sunken

_____ Empty

Estimated time of death:

______ Last night

______ 2 – 3 days

______ 4 – 7 days

______ 7 – 14 days

______ > 2 weeks

______ > month

______ Unknown

Hair: Yes No **Wing Punch:** Yes No **Toe Clip:** Yes No

Hair/Wing Punch/Toe Clipping ID:________________ **TK Number**:____________________

Wing score: 0 (fewer than 5 scar spots) 1 (< 50% wing depigmented) 2 (> 50% wing with scar tissue) 3 (Deteriorated wing membrane and necrotic tissue. Isolated holes > 0.5 cm) Unknown

Additional Notes:

____

____

____

____

____

- 2 -

APPENDIX G
DENSITY-WEIGHT PROPORTION AREAS

Figure G.1. Example study plot with 1 m^2 rasterized units used to calculate density-weighted proportion areas for adjusting fatality estimates at Sheffield Wind Facility, Caledonia County, Vermont.

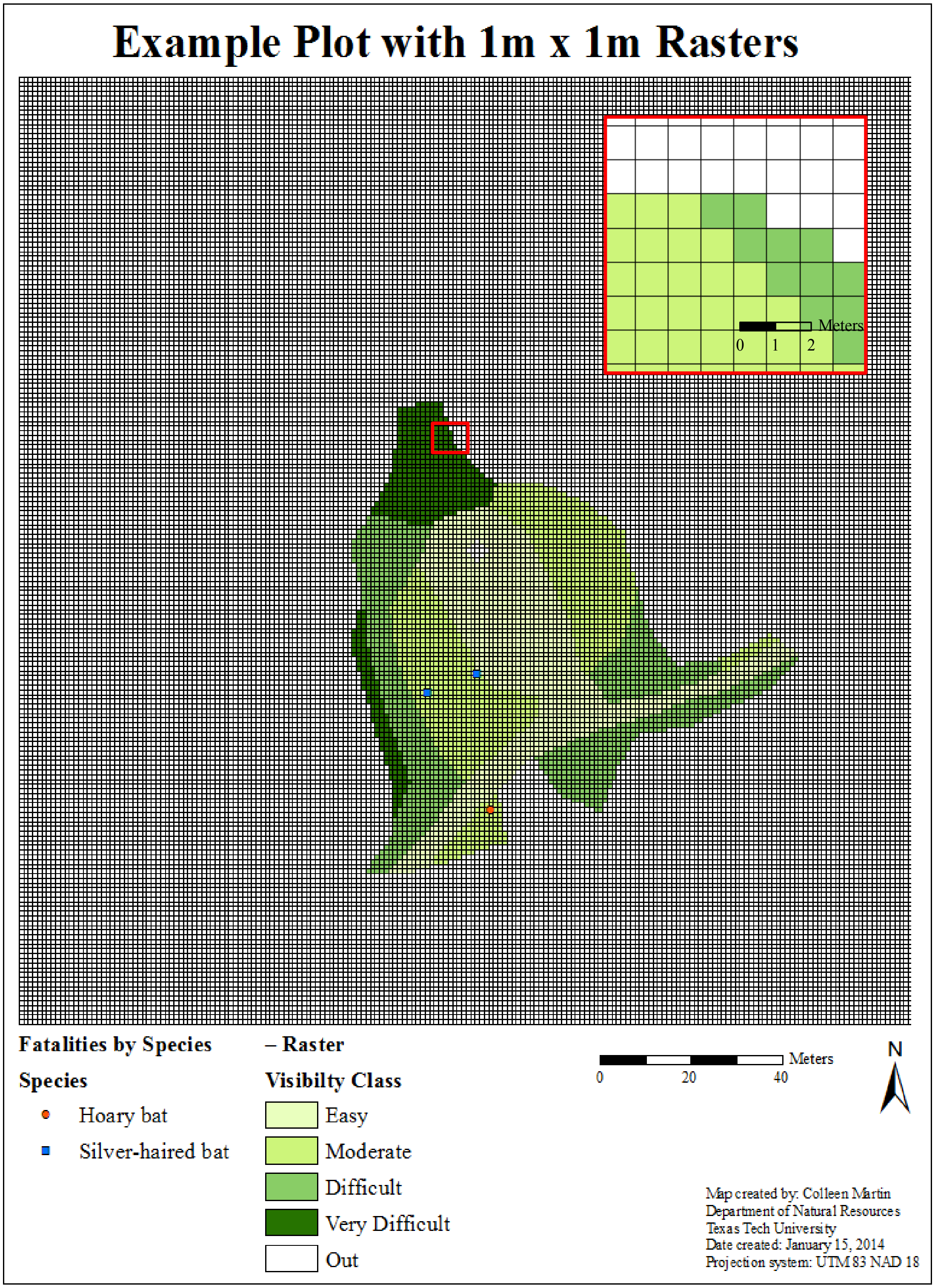
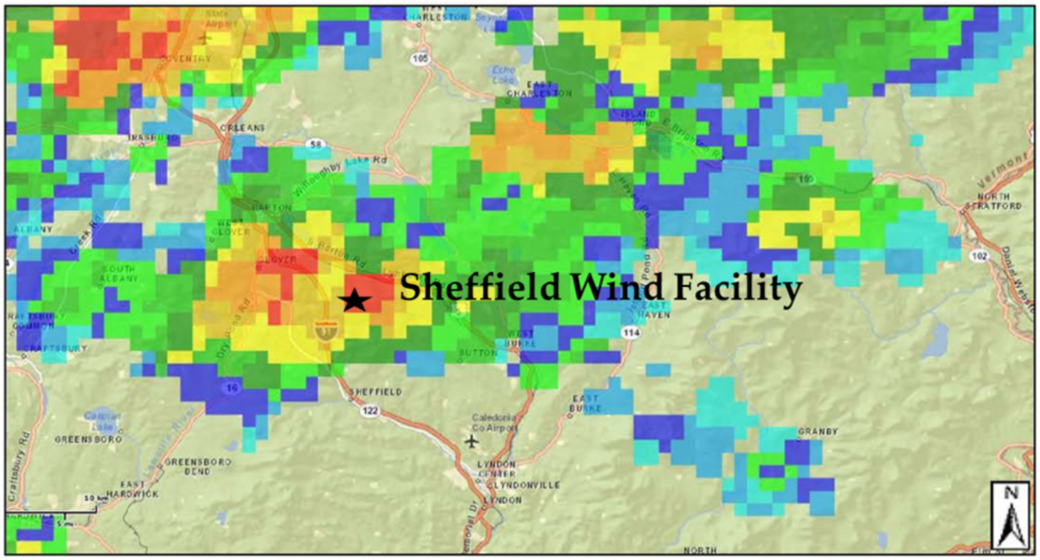


Table G.1. Estimated density-weighted proportion areas used to adjust for areas within survey plots that were not searchable, as well as to extrapolate estimates to the entire study plot, for each turbine at Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012 and 23 April to 31 October 2013. Density-weight was calculated using bat carcasses only, but was used for estimating both bat and bird fatalities.

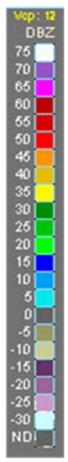
	2012	**2013**
Turbine	**Density-weight proportion area**	
1	0.60	0.57
2	0.43	0.42
3	0.58	0.54
4	0.50	0.48
5	0.53	0.53
6	0.50	0.43
7	0.56	0.50
8	0.56	0.55
9	0.56	0.52
10	0.45	0.44
11	0.58	0.56
12	0.47	0.43
13	0.49	0.43
14	0.45	0.46
15	0.55	0.55
16	0.47	0.45

APPENDIX H
POST HOC ANALYSIS

Figure H.1. Example of NEXRAD historical reflectivity map used to determine nightly storm events at Sheffield Wind Facility, Caledonia County, Vermont.



Legend:



Reflectivity Category	dBZ	Rainrate (in/hr)	Intensity
Purple	65	16.6	Extreme / Large Hail
Red 3	60	8	Extreme / Moderate Hail
Red 2	55	4	Very Heavy / Small Hail
Red 1	50	1.9	Heavy
Yellow 3	45	0.92	Moderate to Heavy
Yellow 2	40	0.45	Moderate Rain
Yellow 1	35	0.22	Moderate Rain
Green 3	30	0.1	Light to Moderate
Green 2	25	0.05	Light
Green 1	20	0.02	Very Light
Blue 3	15	0.01	Mist
Blue 2	10	< 0.01	Light Mist
Blue 1	5	< 0.01	Hardly Noticeable

National Oceanic and Atmospheric Administration

Table H.1. Example of the table used to record nightly storm events based on NEXRAD historical reflectivity maps at Sheffield Wind Facility, Caledonia County, Vermont.

Date/time	**Precipitation (0 = No, 1 = Yes)**	**Year (2012 = 0, 2013 = 1)**	**Reflectivity Category**
8/27/12 22:50	1	0	Green 1
8/27/12 23:00	0	0	.
8/27/12 23:10	0	0	.
8/27/12 23:20	0	0	.
8/27/12 23:50	1	0	Green 1
8/28/12 0:00	1	0	Green 2
8/28/12 0:10	1	0	Green 2
8/28/12 0:20	1	0	Green 3
8/28/12 0:30	1	0	Green 3
8/28/12 0:40	1	0	Green 2
8/28/12 0:50	1	0	Green 2
8/28/12 1:00	1	0	Green 3
8/28/12 1:20	0	0	.

. = No radar present.

APPENDIX I
BAT FATALITY DATA

Table I.1. Bat carcasses found in 2012 field season during official surveys at Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012.

Date	Species	Turbine	Distance to turbine (m)	Azimuth (°)	Age	Sex	Estimated time of death
6/18/2012	Silver-haired bat	9	41	21	Unknown	Unknown	Unknown
6/29/2012	Hoary bat	4	11	64	Adult	Male	Previous night
7/2/2012	Silver-haired bat	8	7	182	Adult	Male	Previous night
7/7/2012	Silver-haired bat	12	16	136	Adult	Male	Previous night
7/12/2012	Eastern red bat	16	28	302	Adult	Male	Previous night
7/14/2012	Hoary bat	12	17	135	Adult	Male	Previous night
7/19/2012	Hoary bat	9	17	105	Adult	Female	Previous night
7/20/2012	Hoary bat	12	23	243	Adult	Female	Previous night
7/21/2012	Eastern red bat	16	22	294	Adult	Female	Live - released
7/23/2012	Hoary bat	1	12	28	Adult	Female	Previous night
7/28/2012	Hoary bat	4	8	96	Adult	Male	Previous night
7/28/2012	Hoary bat	7	32	166	Adult	Male	Previous night
7/28/2012	Hoary bat	9	36	306	Adult	Female	Previous night
7/28/2012	Hoary bat	12	27	172	Adult	Male	Live - died during rehab
7/28/2012	Hoary bat	12	18	273	Adult	Male	Previous night
7/28/2012	Hoary bat	12	46	260	Adult	Male	Previous night
7/28/2012	Hoary bat	13	37	293	Adult	Male	Previous night
7/28/2012	Hoary bat	13	28	258	Adult	Male	Previous night
7/29/2012	Eastern red bat	4	20	310	Adult	Female	2-3 days
7/31/2012	Hoary bat	1	56	79	Adult	Female	Previous night
7/31/2012	Hoary bat	2	14	325	Adult	Female	Previous night
7/31/2012	Hoary bat	7	17	270	Unknown	Unknown	4-7 days

Date	Species	Turbine	Distance to turbine (m)	Azimuth (°)	Age	Sex	Estimated time of death
7/31/2012	Eastern red bat	9	45	90	Adult	Female	Previous night
8/2/2012	Hoary bat	3	27	259	Adult	Male	2-3 days
8/2/2012	Eastern red bat	5	7	34	Adult	Female	Previous night
8/3/2012	Eastern red bat	8	19	58	Adult	Female	Previous night
8/3/2012	Eastern red bat	8	23	0	Adult	Male	2-3 days
8/3/2012	Hoary bat	9	27	355	Adult	Male	Previous night
8/4/2012	Hoary bat	8	9	274	Adult	Male	Previous night
8/5/2012	Hoary bat	12	41	206	Adult	Female	2-3 days
8/7/2012	Hoary bat	3	11	188	Adult	Female	Previous night
8/7/2012	Eastern red bat	12	8	235	Adult	Female	Previous night
8/8/2012	Hoary bat	1	33	4	Adult	Male	Previous night
8/8/2012	Eastern red bat	15	52	138	Adult	Female	Previous night
8/8/2012	Eastern red bat	16	13	33	Adult	Female	Previous night
8/9/2012	Hoary bat	6	4.85	26	Adult	Female	Previous night
8/9/2012	Hoary bat	11	30	306	Adult	Male	Previous night
8/9/2012	Hoary bat	14	6	70	Adult	Male	Previous night
8/9/2012	Hoary bat	16	12	348	Adult	Male	Previous night
8/10/2012	Hoary bat	3	33	321	Adult	Female	2-3 days
8/11/2012	Hoary bat	5	18	292	Adult	Male	Previous night
8/13/2012	Hoary bat	7	1.6	40	Adult	Male	Previous night
8/13/2012	Silver-haired bat	7	12	195	Adult	Female	Previous night
8/14/2012	Eastern red bat	7	42	209	Adult	Male	2-3 days
8/14/2012	Hoary bat	9	8	353	Adult	Male	Previous night
8/14/2012	Hoary bat	16	8	288	Adult	Male	Previous night

Date	**Species**	**Turbine**	**Distance to turbine (m)**	**Azimuth (°)**	**Age**	**Sex**	**Estimated time of death**
8/15/2012	Hoary bat	9	33	62	Adult	Male	Previous night
8/15/2012	Hoary bat	9	43	50	Adult	Male	2-3 days
8/16/2012	Silver-haired bat	12	42	218	Adult	Male	Previous night
8/17/2012	Silver-haired bat	3	6	46	Adult	Male	Previous night
8/17/2012	Hoary bat	9	40	56	Adult	Male	2-3 days
8/18/2012	Hoary bat	1	17	50	Adult	Male	Previous night
8/19/2012	Silver-haired bat	4	27	212	Adult	Female	Previous night
8/19/2012	Hoary bat	9	26	45	Unknown	Female	2-3 days
8/20/2012	Hoary bat	7	34	208	Adult	Male	2-3 days
8/24/2012	Hoary bat	15	28	48	Adult	Female	Previous night
8/25/2012	Hoary bat	6	12	354	Adult	Male	Previous night
8/25/2012	Eastern red bat	14	16	12	Juvenile	Female	Previous night
8/26/2012	Hoary bat	1	36	266	Adult	Male	2-3 days
8/26/2012	Hoary bat	1	46	352	Adult	Male	2-3 days
8/26/2012	Eastern red bat	14	31	231	Unknown	Unknown	Unknown
8/27/2012	Hoary bat	14	29	340	Adult	Male	Previous night
8/30/2012	Hoary bat	7	36	232	Unknown	Unknown	4-7 days
8/31/2012	Eastern red bat	6	40	142	Unknown	Unknown	Unknown
9/2/2012	Eastern red bat	6	11	230	Adult	Male	Previous night
9/2/2012	Eastern red bat	15	12	162	Adult	Male	Previous night
9/3/2012	Silver-haired bat	1	10	38	Adult	Male	Previous night
9/3/2012	Eastern red bat	6	44	125	Adult	Male	Previous night
9/4/2012	Silver-haired bat	15	30	143	Adult	Male	2-3 days
9/5/2012	Silver-haired bat	2	5	216	Adult	Male	2-3 days

Date	Species	Turbine	Distance to turbine (m)	Azimuth (°)	Age	Sex	Estimated time of death
9/7/2012	Eastern red bat	13	24	260	Adult	Male	2-3 days
9/8/2012	Hoary bat	12	27	304	Adult	Male	Previous night
9/10/2012	Eastern red bat	15	21	105	Adult	Male	Live - died during rehab
9/12/2012	Silver-haired bat	8	17	47	Adult	Male	Live - released
9/15/2012	Silver-haired bat	14	26	31	Adult	Male	Previous night
9/17/2012	Silver-haired bat	12	18	120	Unknown	Unknown	7-14 days
9/18/2012	Silver-haired bat	13	25	309	Adult	Male	Previous night
9/24/2012	Eastern red bat	6	5	148	Adult	Male	Previous night
9/24/2012	Eastern red bat	10	17	56	Adult	Female	Previous night
9/25/2012	Eastern red bat	4	31	171	Adult	Male	Previous night
9/27/2012	Eastern red bat	7	31	186	Adult	Male	Previous night
9/30/2012	Hoary bat	1	27	356	Adult	Male	Previous night
10/3/2012	Eastern red bat	10	9	286	Adult	Unknown	2-3 days
10/16/2012	Hoary bat	6	45	129	Adult	Male	Previous night
10/21/2012	Eastern red bat	6	12	200	Adult	Male	Previous night
10/22/2012	Eastern red bat	6	38	151	Adult	Unknown	Previous night

Table I.2. Incidental bat carcasses found in 2012 field season at Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012.

Date	Species	Turbine	Distance to turbine (m)	Azimuth (°)	Age	Sex	Estimated time of death
7/28/2012	Hoary bat	4	40	266	Adult	Male	Previous night

Table I.3. Bat carcasses found in 2013 field season during official surveys at Sheffield Wind Facility, Caledonia County, Vermont; 23 April to 31 October 2013.

Date	Species	Turbine	Distance to turbine (m)	Azimuth (°)	Age	Sex	Estimated time of death
5/19/2013	Silver-haired bat	9	16	44	Adult	Female	Previous night
6/4/2013	Hoary bat	3	32	16	Adult	Male	2-3 days
6/4/2013	Silver-haired bat	10	42	94	Adult	Male	Previous night
6/20/2013	Hoary bat	1	16	179	Adult	Male	Previous night
6/22/2013	Hoary bat	15	8	334	Adult	Male	Previous night
6/24/2013	Hoary bat	14	16	316	Adult	Male	Previous night
7/27/2013	Silver-haired bat	8	18	198	Adult	Female	Previous night
8/24/2013	Silver-haired bat	6	36	144	Adult	Male	2-3 days
8/25/2013	Silver-haired bat	7	32	202	Adult	Female	2-3 days
9/5/2013	Hoary bat	4	17	260	Adult	Male	Previous night
9/5/2013	Silver-haired bat	7	26	182	Adult	Male	Previous night
9/5/2013	Hoary bat	8	12	126	Adult	Male	Previous night
9/7/2013	Silver-haired bat	11	30	275	Adult	Male	2-3 days
9/10/2013	Eastern red bat	15	26	323	Adult	Male	Previous night
9/20/2013	Hoary bat	7	55	179	Adult	Female	2-3 days
10/4/2013	Silver-haired bat	1	8	226	Adult	Male	Previous night
10/31/2013	Hoary bat	1	38	252	Adult	Female	2-3 days

Table I.4. Incidental bat carcasses found in 2013 field season at Sheffield Wind Facility, Caledonia County, Vermont; 23 April to 31 October 2013.

Date	Species	Turbine	Distance to turbine (m)	Azimuth (°)	Age	Sex	Estimated time of death
7/19/2013	Hoary bat	12	112	224	Adult	Unknown	2-3 days
9/9/2013	Silver-haired bat	10	97	146	Adult	Unknown	Previous night

Figure I.1. Total number of bat carcasses found per day during 2012 field season at Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012. All species and decay conditions combined.

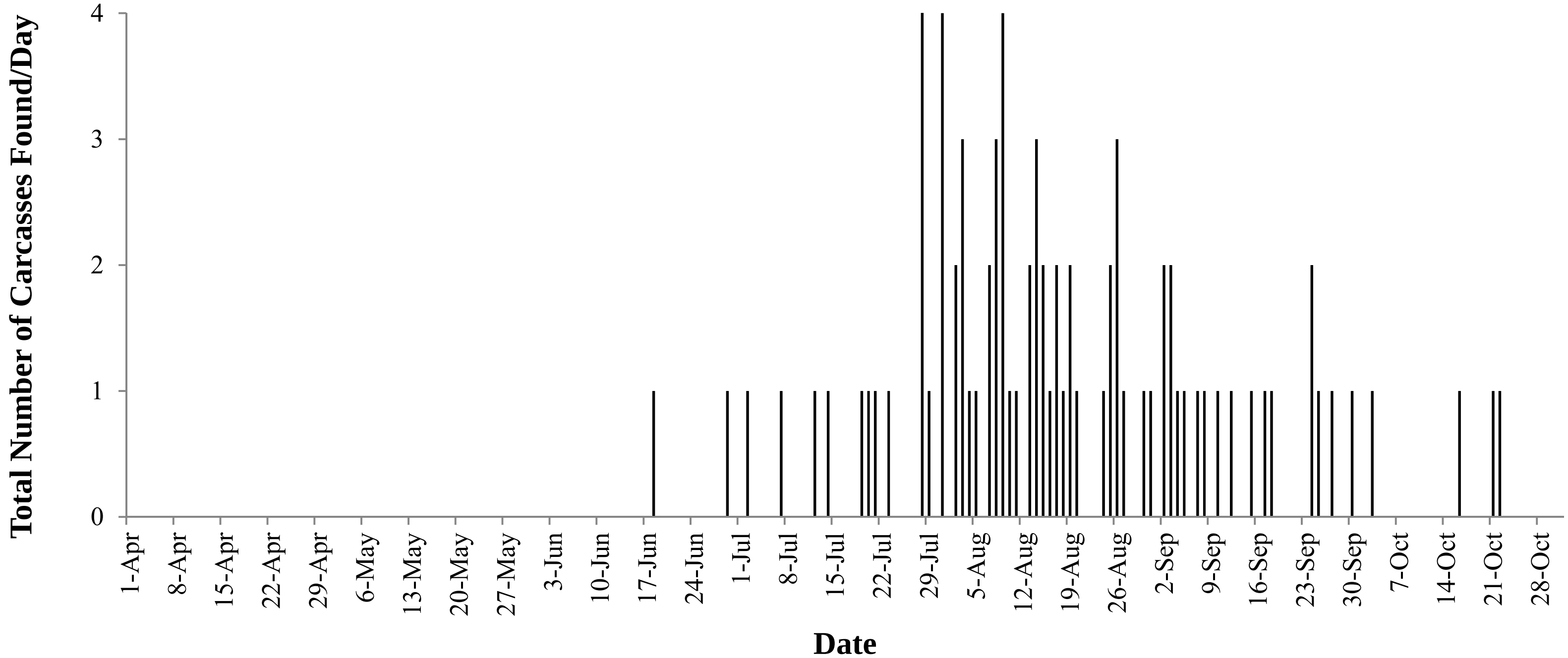


Figure I.2. Total number of bat carcasses found per day during 2013 field season at Sheffield Wind Facility, Caledonia County, Vermont; 23 April to 31 October 2013. All species and decay conditions combined.

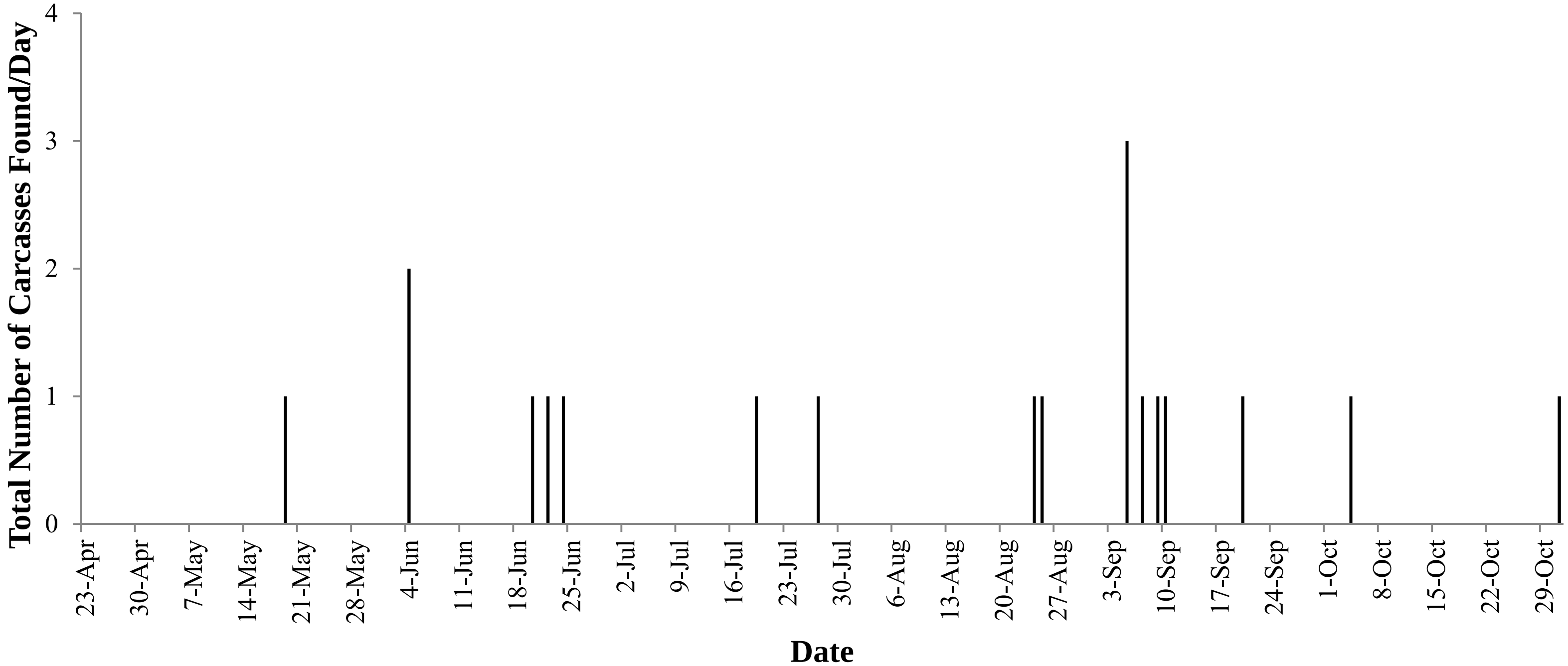


Table I.5. Intercardinal directions and azimuths of bat carcasses found from the base of the turbine at the Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012 and 23 April to 31 October 2013. Carcasses found both incidentally and during official surveys are included.

Intercardinal direction	Azimuth (°)	Total # found	Percent
NNE	0–45	14	13%
ENE	46–90	13	12%
ESE	91–135	9	8%
SSE	136–180	14	13%
SSW	181–225	15	14%
WSW	226–270	15	14%
WNW	271–315	14	13%
NNW	316–359	12	11%

Table I.6. Estimated bat fatalities, per turbine, per megawatt, and entire site for the 2012 field season. Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012. Eight of the 16 turbines had a raised cut-in speed as part of the operational mitigation study during Period 2. As such, estimates during that time period may be lower than would have been observed if the facility was fully operational.

		Per turbine			**Per megawatt**			**Entire site**		
Study period	**Number fresh carcasses found**	**Fatality estimates**	**Lower 95% CI**	**Upper 95% CI**	**Fatality estimates**	**Lower 95% CI**	**Upper 95% CI**	**Fatality estimates**	**Lower 95% CI**	**Upper 95% CI**
Period 1*										
Hoary bat	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
Eastern red bat	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
Silver-haired bat	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
All bats	*0*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0*	*0*	*0*
Period 2**										
Hoary bat	33	7.01	4.01	12.15	2.80	1.60	4.86	113	65	195
Eastern red bat	16	3.18	1.70	5.43	1.27	0.68	2.17	51	28	87
Silver-haired bat	10	2.15	0.84	4.25	0.86	0.34	1.70	35	14	69
All bats	*59*	*12.34*	*8.18*	*19.84*	*4.94*	*3.27*	*7.94*	*198*	*131*	*318*
Period 3***										
Hoary bat	2	1.10	0.76	1.91	0.44	0.30	0.76	18	13	31
Eastern red bat	2	1.20	0.85	3.58	0.48	0.34	1.43	20	14	58
Silver-haired bat	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
All bats	*4*	*2.31*	*0.80*	*4.92*	*0.92*	*0.32*	*1.97*	*37*	*13*	*79*
Total season										
Hoary bat	35	8.11	5.16	13.38	3.24	2.06	5.35	130	82	215
Eastern red bat	18	4.38	2.18	7.48	1.75	0.87	2.99	71	34	120
Silver-haired bat	10	2.15	0.84	4.25	0.86	0.34	1.70	35	13	68
All bats	**63**	**14.65**	**10.06**	**22.56**	**5.86**	**4.02**	**9.02**	**235**	**160**	**361**

** 1 April–2 June; ** 3 June–30 September; *** 1 October–31 October.* [+] *Only fresh carcasses found during official surveys were used to estimate fatality.*

Table I.7. Estimated bat fatalities, per turbine, per megawatt, and entire site for the 2013 field season at Sheffield Wind Facility, Caledonia County, Vermont; 23 April to 31 October 2013. Eight of the 16 turbines had a raised cut-in speed as part of the operational mitigation study during Period 2. As such, estimates during that time period may be lower than would have been observed if the facility was fully operational.

		Per turbine			Per megawatt			Entire site		
Study period	**Number fresh carcasses found[+]**	**Fatality estimates**	**Lower 95% CI**	**Upper 95% CI**	**Fatality estimates**	**Lower 95% CI**	**Upper 95% CI**	**Fatality estimates**	**Lower 95% CI**	**Upper 95% CI**
Periods 1* and 3**										
Hoary bat	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
Eastern red bat	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
Silver-haired bat	2	0.70	0.48	1.19	0.28	0.19	0.48	12	8	19
All bats	*2*	*0.70*	*0.48*	*1.19*	*0.28*	*0.19*	*0.48*	*12*	*8*	*19*
Period 2***										
Hoary bat	5	0.96	0.39	1.73	0.38	0.16	0.69	16	7	28
Eastern red bat	1	0.24	0.18	0.86	0.10	0.07	0.34	4	3	14
Silver-haired bat	3	0.90	0.13	2.14	0.36	0.05	0.86	15	3	35
All bats	*9*	*2.10*	*1.20*	*3.69*	*0.84*	*0.48*	*1.48*	*34*	*20*	*60*
Total season										
Hoary bat	5	0.96	0.39	1.73	0.38	0.16	0.69	16	7	28
Eastern red bat	1	0.24	0.18	0.86	0.10	0.07	0.34	4	3	14
Silver-haired bat	5	1.60	0.90	4.30	0.64	0.36	1.72	27	15	63
All bats	**11**	**2.80**	**1.90**	**4.40**	**1.12**	**0.76**	**1.76**	**46**	**31**	**71**

** 23 April–2 June; ** 1 October–31 October; ***3 June–30 September. [+] Only fresh carcasses found during official surveys were used to estimate fatality.*

APPENDIX J
BIRD FATALITY DATA

Table J.1. Bird carcasses found in 2012 field season during official searches at Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012.

Date	Species	Turbine	Distance to turbine (m)	Azimuth (°)	Age	Sex	Estimated time of death
4/14/2012	Golden-crowned Kinglet	1	39	94	Adult	Male	Previous night
4/15/2012	Golden-crowned Kinglet	6	39	127	Adult	Female	Previous night
4/16/2012	Golden-crowned Kinglet	10	49	105	Adult	Male	Previous night
4/17/2012	Golden-crowned Kinglet	1	63	60	Adult	Female	Previous night
4/19/2012	Golden-crowned Kinglet	6	32	144	Adult	Female	Previous night
4/19/2012	Unknown bird	16	35	260	Unknown	Unknown	Unknown
5/4/2012	White-throated Sparrow	3	2.15	261	Adult	Unknown	Previous night
5/23/2012	Red-eyed Vireo	6	44	131	Adult	Unknown	Previous night
5/23/2012	Red-eyed Vireo	8	17	259	Adult	Unknown	Previous night
5/25/2012	Red-eyed Vireo	6	32	134	Adult	Unknown	Previous night
5/25/2012	Red-eyed Vireo	8	55	341	Adult	Unknown	Previous night
5/26/2012	Red-eyed Vireo	1	32	0	Adult	Unknown	Previous night
6/1/2012	Red-eyed Vireo	10	26	63	Adult	Unknown	Previous night
6/5/2012	Red-eyed Vireo	8	31	32	Adult	Unknown	4-7 days
6/5/2012	Unknown bird	14	51	17	Unknown	Unknown	Unknown
7/29/2012	Sharp-shinned Hawk	4	37	294	Juvenile	Unknown	Previous night
7/29/2012	Unknown bird	6	26	237	Juvenile	Unknown	2-3 days
8/2/2012	Red-eyed Vireo	4	1.6	46	Adult	Female	Previous night
8/13/2012	Red-breasted Nuthatch	12	31	192	Adult	Male	Previous night
8/26/2012	Red-breasted Nuthatch	12	36	18	Juvenile	Female	Previous night
8/27/2012	Red-breasted Nuthatch	3	31	10	Juvenile	Female	2-3 days
9/3/2012	Red-eyed Vireo	4	3.45	299	Unknown	Unknown	Previous night
9/8/2012	Blackpoll Warbler	9	47	11	Juvenile	Unknown	Previous night

Date	**Species**	**Turbine**	**Distance to turbine (m)**	**Azimuth (°)**	**Age**	**Sex**	**Estimated time of death**
9/14/2012	Tennessee Warbler	10	48	115	Juvenile	Unknown	2-3 days
9/17/2012	Magnolia Warbler	15	69	39	Juvenile	Unknown	Previous night
9/18/2012	Unknown bird	16	40	350	Unknown	Unknown	Previous night
9/23/2012	Ruby-crowned kinglet	7	51	144	Juvenile	Male	Previous night
9/28/2012	Ruffed Grouse	16	31	246	Unknown	Unknown	Previous night
9/30/2012	Magnolia Warbler	6	45	230	Juvenile	Unknown	Previous night
9/30/2012	Unknown bird	8	32	265	Unknown	Unknown	4-7 days
10/15/2012	Black-capped Chickadee	16	45	343	Unknown	Unknown	Previous night
10/16/2012	Golden-crowned Kinglet	1	49	84	Adult	Male	Previous night
10/17/2012	Yellow-rumped Warbler	6	51	125	Juvenile	Male	Previous night
10/26/2012	Golden-crowned Kinglet	10	36	142	Adult	Male	Previous night

Table J.2. Incidental bird carcasses found in 2012 field season at Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012.

Date	**Species**	**Turbine**	**Distance to turbine (m)**	**Azimuth (°)**	**Age**	**Sex**	**Estimated time of death**
5/23/2012	Red-eyed Vireo	5	6.6	351	Adult	Unknown	Previous night

Table J.3. Bird carcasses found in 2013 field season during official surveys at Sheffield Wind Facility, Caledonia County, Vermont; 23 April to 31 October 2013.

Date	Species	Turbine	Distance to turbine (m)	Azimuth (°)	Age	Sex	Estimated time of death
4/23/2013	Golden-crowned Kinglet	9	46	358	Adult	Female	2-3 days
4/23/2013	Ruffed Grouse	14	33	17	Unknown	Unknown	Unknown
5/7/2013	Red-breasted Nuthatch	9	67	22	Adult	Unknown	Previous night
5/10/2013	Unknown bird	7	35	218	Unknown	Unknown	> month
5/23/2013	Magnolia Warbler	9	33	15	Adult	Male	Previous night
5/31/2013	Unknown bird	9	45	14	Unknown	Unknown	>2 weeks
6/6/2013	Red-breasted Nuthatch	1	35	88	Adult	Unknown	Previous night
6/9/2013	Red-eyed Vireo	8	3.5	38	Unknown	Unknown	Previous night
6/10/2013	Golden-crowned Kinglet	11	55	11	Unknown	Unknown	7-14 days
6/12/2013	Unknown bird	6	29	238	Unknown	Unknown	>2 weeks
8/1/2013	Red-eyed Vireo	15	0.6	293	Juvenile	Unknown	Previous night
8/16/2013	Dark-eyed Junco	9	55	68	Unknown	Unknown	Unknown
8/18/2013	Cedar Waxwing	1	40	66	Juvenile	Unknown	Previous night
8/23/2013	Northern Waterthrush	10	31	132	Adult	Unknown	Previous night
9/2/2013	Red-eyed Vireo	14	41	9	Unknown	Unknown	Previous night
9/5/2013	Magnolia Warbler	7	47	188	Juvenile	Unknown	Previous night
9/5/2013	Blackburnian Warbler	10	40	121	Juvenile	Unknown	Previous night
9/5/2013	American Redstart	12	22	188	Juvenile	Unknown	Previous night
9/6/2013	Black-throated Blue Warbler	7	32	188	Juvenile	Unknown	Previous night
9/10/2013	American Redstart	9	40	76	Juvenile	Unknown	2-3 days
9/25/2013	Common Yellowthroat	10	36	186	Adult	Female	Previous night
9/27/2013	Red-eyed Vireo	2	1.4	82	Adult	Unknown	Previous night
9/27/2013	Black-throated Blue Warbler	4	51	248	Adult	Male	Previous night

Date	**Species**	**Turbine**	**Distance to turbine (m)**	**Azimuth (°)**	**Age**	**Sex**	**Estimated time of death**
10/5/2013	White-throated Sparrow	7	19	122	Unknown	Unknown	Previous night
10/7/2013	Golden-crowned Kinglet	9	60	20	Adult	Unknown	Previous night
10/15/2013	Golden-crowned Kinglet	7	54	154	Unknown	Unknown	4-7 days
10/31/2013	Golden-crowned Kinglet	3	24	40	Adult	Male	2-3 days

Table J.4. Incidental bird carcasses found in 2013 field season at Sheffield Wind Facility, Caledonia County, Vermont; 23 April to 31 October 2013.

Date	**Species**	**Turbine**	**Distance to turbine (m)**	**Azimuth (°)**	**Age**	**Sex**	**Estimated time of death**
4/17/2013	Ruffed Grouse*	1	28	102	Unknown	Unknown	Unknown
4/22/2013	Ruffed Grouse*	3	20	99	Unknown	Unknown	Unknown
4/24/2013	Yellow-bellied Sapsucker	16	1.8	16	Adult	Female	2-3 days
6/1/2013	Yellow-rumped Warbler	11	46	311	Adult	Male	7-14 days

** Found prior to the start of official surveys while clearing study plots.*

Figure J.1. Total number of bird carcasses found per day during 2012 field season at Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012. All species and decay conditions combined.

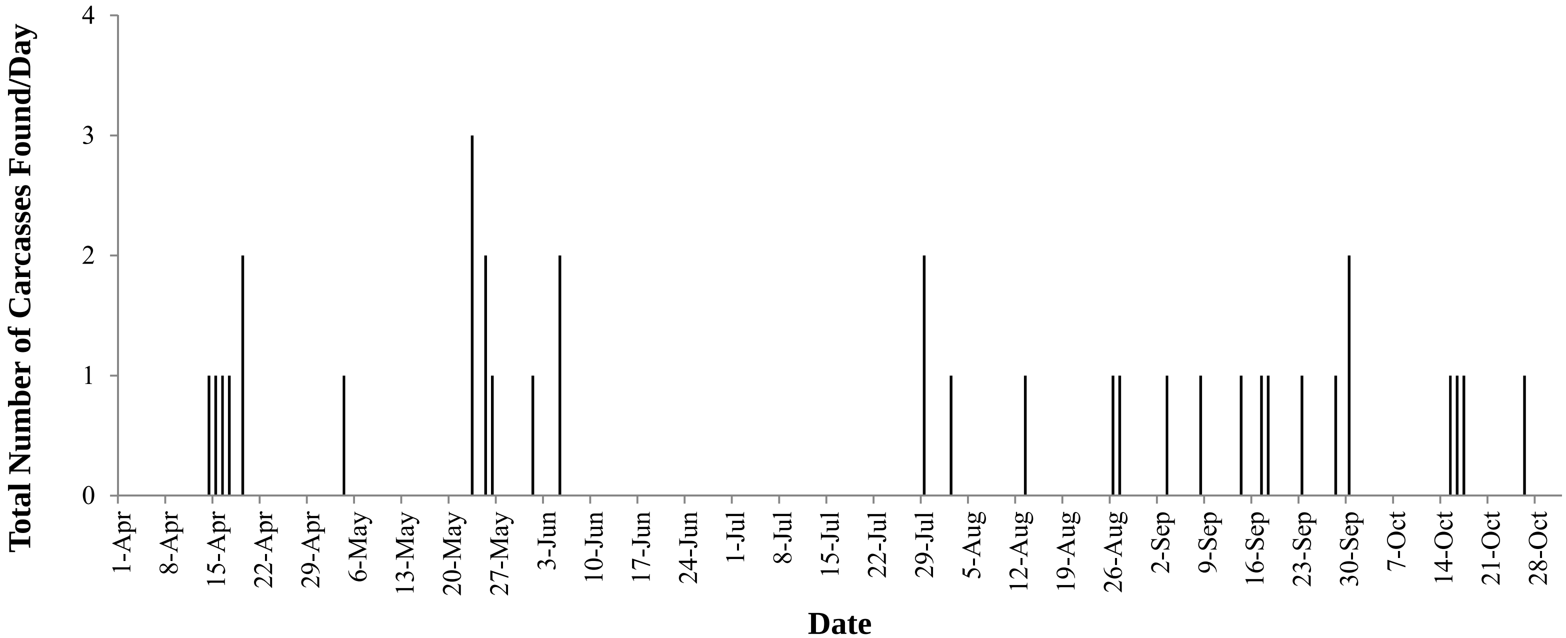


Figure J.2. Total number of bird carcasses found per day during 2013 field season at Sheffield Wind Facility, Caledonia County, Vermont; 23 April to 31 October 2013. All species and decay conditions combined.

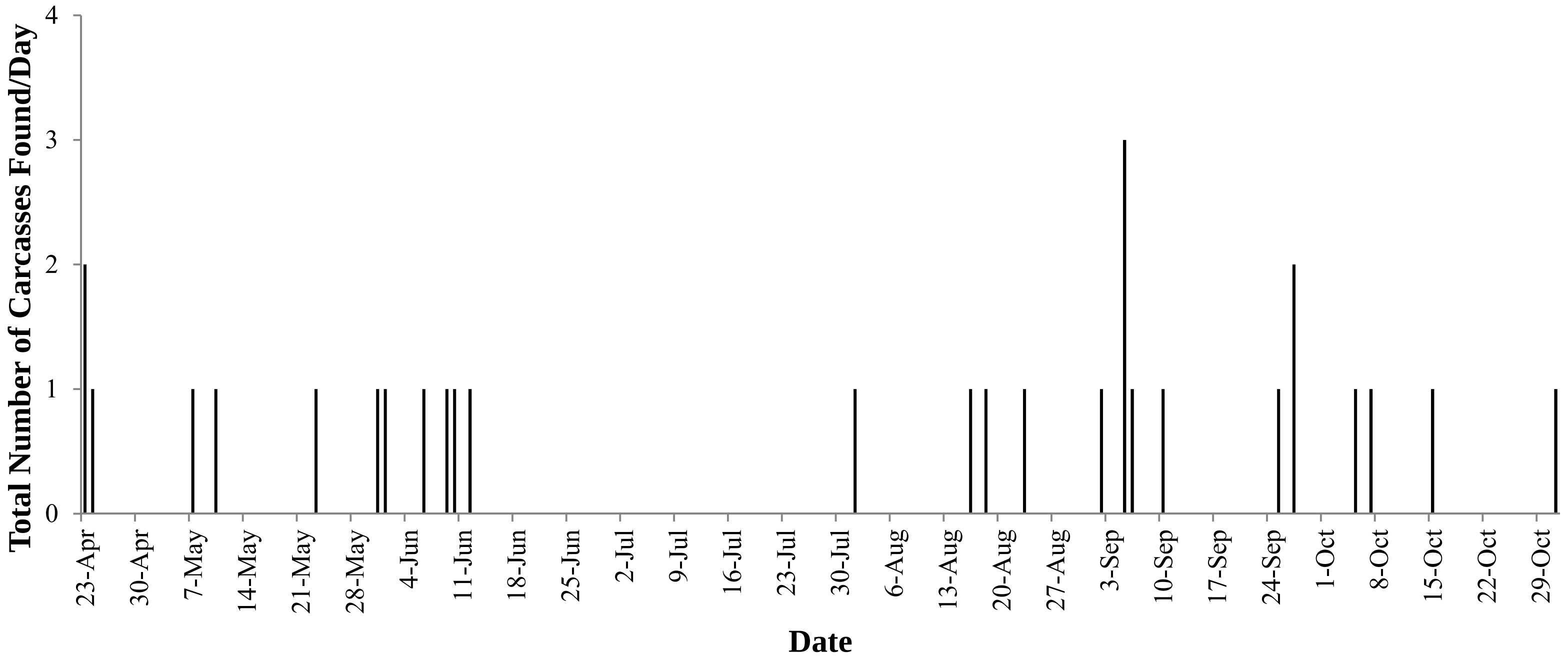


Table J.5. Intercardinal directions and azimuths of bird carcasses found from the base of the turbine at the Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012 and 23 April to 31 October 2013. Carcasses found both incidentally and during official surveys are included.

Intercardinal direction	Azimuth (°)	Total # found	Percent
NNE	0–45	17	27%
ENE	46–90	9	14%
ESE	91–135	10	16%
SSE	136–180	4	6%
SSW	181–225	6	9%
WSW	226–270	9	14%
WNW	271–315	4	6%
NNW	316–359	5	8%

Table J.6. Estimated bird fatalities, per turbine, per megawatt, and entire site for the 2012 field season at Sheffield Wind Facility, Caledonia County, Vermont; 1 April to 31 October 2012.

Study period	**Number of carcasses found**	**Fatality estimate**	**Lower 95% CI**	**Upper 95% CI**
Period 1*				
Per turbine	N/A	6.32	3.08	12.00
Per megawatt	N/A	2.53	1.23	4.80
Site total	11	102	50	192
Period 2 **				
Per turbine	N/A	3.87	2.12	6.93
Per megawatt	N/A	1.55	0.85	2.77
Site total	12	62	34	111
Period 3***				
Per turbine	N/A	2.97	1.71	5.25
Per megawatt	N/A	1.19	0.68	2.10
Site total	4	48	28	84
Total season				
Per turbine	N/A	13.17	9.20	20.05
Per megawatt	N/A	5.27	3.68	8.02
Site total	**27**	**211**	**147**	**321**

** 1 April–2 June; ** 3 June–30 September; *** 1 October–31 October. + Only fresh carcasses found during official surveys were used to estimate fatality.*

Table J.7. Estimated bird fatalities, per turbine, per megawatt, and entire site for the 2013 field season at Sheffield Wind Facility, Caledonia County, Vermont; 23 April to 31 October 2013.

Study period	Number of carcasses found	Fatality estimate	Lower 95% CI	Upper 95% CI
Periods 1* and 3**				
Per turbine	N/A	2.72	0.51	11.04
Per megawatt	N/A	1.09	0.20	4.42
Site total	4	44	9	177
Period 2 ***				
Per turbine	N/A	5.29	2.43	17.52
Per megawatt	N/A	2.12	0.97	7.01
Site total	12	85	39	281
Total season				
Per turbine	N/A	8.01	3.78	22.16
Per megawatt	N/A	3.20	1.51	8.86
Site total	**16**	**129**	**60**	**355**

** 23 April–2 June; ** 1 October–31 October; *** 3 June–30 September. + Only fresh carcasses found during official surveys were used to estimate fatality.*