A Large-Scale Mitigation Experiment to Reduce Bat Fatalities at Wind Energy Facilities

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ABSTRACT Until large numbers of bat fatalities began to be reported at certain North American wind energy facilities, wildlife concerns regarding wind energy focused primarily on bird fatalities. Due in part to mitigation to reduce bird fatalities, bat fatalities now outnumber those of birds. To test one mitigation option aimed at reducing bat fatalities at wind energy facilities, we altered the operational parameters of 21 turbines at a site with high bat fatalities in southwestern Alberta, Canada, during the peak fatality period. By altering when turbine rotors begin turning in low winds, either by changing the wind-speed trigger at which the turbine rotors are allowed to begin turning or by altering blade angles to reduce rotor speed, blades were near motionless in low wind speeds, which resulted in a significant reduction in bat fatalities (by 60.0% or 57.5%, respectively). Although these are promising mitigation techniques, further experiments are needed to assess costs and benefits at other locations. (JOURNAL OF WILDLIFE MANAGEMENT 73(7):1077–1081; 2009)

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Renewable energy sources, such as wind energy, are seen as environmentally friendly alternatives to burning fossil fuels, and this has led to rapid growth of the wind energy industry. Worldwide, between 1997 and 2006, wind energy increased tenfold in installed capacity, the most dramatic increases occurring in 2005 (41%), 2006 (32%), and 2007 (31%; World Wind Energy Association [WWEA] 2008). Canada more than doubled its installed capacity in 2006 (Canadian Wind Energy Association 2008, WWEA 2008). In 2007, wind generation increased 45% in the United States and 26% in Canada (American Wind Energy Association 2008, Canadian Wind Energy Association 2008, WWEA 2008).

The growth of the wind energy industry has not been without concerns. Although many communities support renewable energy, some express concerns about noise, reduction of landscape beauty, and impacts on wildlife (e.g., Cross Timbers Landowners Conservancy 2008, Save Western NY 2008). Originally, wildlife concerns focused on bird fatalities, but because of many bat fatalities at some facilities, attention has shifted to potential impacts on bats (Kunz et al. 2007, Arnett et al. 2008). Bats are killed by some wind energy facilities in large numbers, especially at facilities with newer, taller turbines (Barclay et al. 2007). Bat fatalities now outnumber bird fatalities in some regions by as much as 10 to 1 (Barclay et al. 2007). The wind energy industry learned from the early incidents of bird collisions and has implemented successful mitigation strategies (but see Smallwood and Thelander 2008). Mitigation to reduce bird fatalities at wind turbines has been primarily by avoiding constructing facilities in environmentally sensitive areas, but other mitigation has included technology and physical changes, such as reducing perching opportunities (e.g., by switching to tubular towers from horizontal lattice towers), increasing turbine blade visibility, and reducing prey sources for raptors (Erickson et al. 2002, Drewitt and Langston 2006, Environment Canada 2007).

High rates of bat fatalities are troubling because bats have slow life-histories (Barclay and Harder 2003); they are relatively long-lived and reproduce slowly for mammals of their size, with most bats having only 1 or 2 young/year, and not every year (Barclay and Harder 2003). These life-history traits make bat populations slow to recover from population declines, thus making them sensitive to changes in mortality rates. Most bats killed at wind energy facilities across North America are migratory tree bats, such as hoary bats (*Lasiurus cinereus*), eastern red bats (*L. borealis*), and silver-haired bats (*Lasionycteris noctivagans*), which are killed during autumn migration (Arnett et al. 2008). These bats migrate from Canada and the northern United States to the southern United States or Mexico (Findley and Jones 1964, Cryan 2003, Cryan et al. 2004) and may encounter several wind-energy facilities along the way.

Previous studies have indicated that bat-fatality rates are not affected by inclement weather (Johnson et al. 2003*b*, Young et al. 2003*a*), aviation warning lights (Johnson et al. 2003*a*), or ultraviolet paint (Young et al. 2003*b*). Bat-fatality rates are affected by turbine height (Barclay et al. 2007), geographic location (Arnett et al. 2008), and wind speed, with more bats killed on low-wind nights (Fiedler 2004, von Hensen 2004, Arnett 2005, Arnett et al. 2008, Horn et al. 2008).

Given that more bat fatalities occur in low wind speeds, the relative ease of manipulating operation of turbines (e.g., compared to turbine location or ht), that turbines produce less electricity in low wind speeds, and that nonmoving turbine blades do not kill bats (Arnett 2005), we examined whether reducing the amount that turbine rotors turn in low wind speeds would reduce bat fatalities.

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STUDY AREA

We conducted a mitigation experiment at a wind energy installation in southwestern Alberta, Canada. The 2,023-ha facility was located approximately 40 km east of the Rocky Mountains (49°35′04″N, 113°47′48″W). The site contained 39 Vestas V80 turbines (Vestas Wind Systems A/S, Randers, Denmark), each with a rated capacity of 1.8 megawatts (MW). The 80-m-diameter rotors were on top of 65-m towers. Turbines were arranged in 8 rows running northwest to southeast. Thirty-one of the turbines were situated in cultivated, mixed agriculture and 8 turbines were in seeded pasture. Height of vegetation, percent ground cover, and time of crop harvest varied among turbines and years, but during the experimental period in 2007, vegetation height varied between 0 m and 0.5 m, percent ground cover varied from 0% to 65%, and all crops were harvested by 7 August.

Bat-fatality rates at this wind energy installation were relatively high, with a corrected fatality rate of 21.70 bats/turbine (12.06 bats/MW) in 2005 and 26.31 bats/turbine (14.62 bats/MW) in 2006 (Brown and Hamilton 2006, Baerwald 2008). Of these fatalities, 54.5% were hoary bats (2005, *n* = 244; 2006, *n* = 383) and 42.0% were silver-haired bats (2005, *n* = 272; 2006, *n* = 211; Brown and Hamilton 2006, Baerwald 2008).

METHODS

We conducted our study during the peak period of migration by hoary and silver-haired bats, from 15 July to 30 September, 2006 and 2007. Turbine operation was not altered in 2006. We searched 10 randomly chosen turbines every day as part of another study. For the mitigation experiment, we searched the remaining 29 turbines once per week. To locate bat carcasses, one searcher held the end of a 45-m rope attached to the base of a turbine, and another searcher held the end of a 7-m rope attached to the first searcher. Starting with the ropes fully extended (i.e., to 52 m from the turbine base) both searchers walked around the base of the turbine. The rope shortened by 14 m with each rotation thereby creating 2 spiral transects 7 m apart. Given the flat terrain and short vegetation, this proved to be the simplest and most effective search method, with the entire area between transect lines searched. For each carcass found, we recorded species, age, and sex (where possible).

The normal operation of the Vestas V80 turbines involves a cut-in speed of 4 m/second, which means that the turbine begins to generate electricity when wind speed reaches 4 m/second. Below that wind speed, the turbine rotor rotates at a slow rate that increases with wind speed until the rotor is turning at a rate required to trigger the generator rotation (Fig. 1), coinciding with a wind speed of 4 m/second. From 1 August to 7 September 2007, the period with the highest wind-turbine–related bat-fatality rates, the owner of the facility altered operation of 21 randomly chosen turbines in one of 2 ways. For 15 experimental rotor start-up speed turbines, the rotor start-up wind speed was increased to 5.5 m/second, meaning that turbines were idle and motionless during low wind speeds (Fig. 1). We chose the experimental rotor start-up speed based on previous studies relating bat activity or fatality to wind speed (Fiedler 2004, Arnett 2005, Arnett et al. 2008, Horn et al. 2008) and discussions with the wind facility owners and operators. At another 6 experimental idling turbines, using a low-speed idle strategy, operations of the turbines were manipulated to change the pitch angle of the blades and lower the generator speed required to start energy production, which caused turbines to be motionless in low wind speeds, similar to the other experimental treatment (Fig. 1), but with different implications for turbine operations. Both experimental protocols had the effect of reducing the time blades were rotating at low wind speeds.

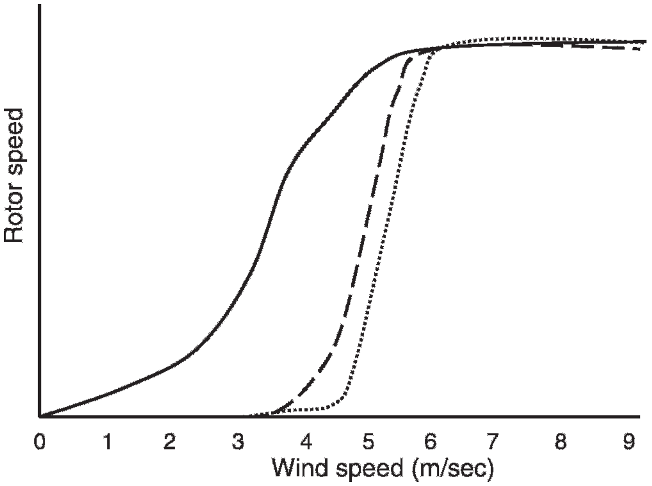

Figure 1. Schematic of the relationship between wind speed (m/sec) and turbine rotor-speed (revolutions/min) for the 3 turbine operations we used to examine whether reducing the amount that turbine rotors turn in low wind speeds would reduce bat fatalities in Alberta, Canada, 2006–2007. Solid line represents operation of control turbines with a 4 m/second cut-in speed and normal idle operation at low wind speeds. Dashed line indicates operation of turbines under the adjusted idle protocol in which blade angles were adjusted to reduce rotor speed in low wind speed. Dotted line indicates operation of turbines with increased rotor start-up speed of 5.5 m/second.

To select the experimental turbines, we stratified the wind farm into 4 quadrants (NE, NW, SE, and SW) and randomly selected a set number of turbines within each quadrant. We continued to search these turbines once per week and compared fatalities to those at 8 unaltered control turbines, also searched weekly. To ensure that there was no inherent difference in bat-fatality rates between the experimental and control turbines, we compared bat-fatality rates at control versus experimental turbines in 2006 (when no experiment was done) over the same time period as that used for the experiment in 2007.

To determine effectiveness of the mitigation, we compared bat-fatality rates during the experiment at the experimental and control turbines using a one-way analysis of variance (ANOVA) and a Tukey's test. We assessed effectiveness of the mitigation by species using Kruskal–Wallis and Wilcoxon tests because we could not normalize the data. To correct fatality rates per turbine for searcher efficiency and scavenger removal, we conducted searcher efficiency and scavenger removal experiments (details in Baerwald 2008) and corrected fatality rates using the following equation

(Baerwald 2008):

$$F_e = \left[\frac{(C/S_e)}{\left(\sum_I^{i=1} R_i\right)} \right] + \left\{ \left[\frac{C}{S_e} - C \right] - S_e \left[\left(\frac{C}{S_e} - C \right) R_i \right] \right\}$$

where F_e = estimated fatalities, C = number of carcasses found, S_e = searcher efficiency, R_i = percent of carcasses remaining by the *i*th day following initiation of a scavenger removal trial (Smallwood 2007), and I = search interval (in days). We performed all statistical analyses with JMP 7.0.1 (SAS Institute, Cary, NC) and present means ± standard error.

RESULTS

In 2006, during the same period that the experiment was run in 2007 (i.e., 1 Aug–7 Sep), there was no difference in corrected bat-fatality rates between turbines later selected as experimental or control (control = 24.1 ± 4.8 bats/turbine, experimental rotor start-up speed = 23.4 ± 3.5 bats/turbine, experimental idling = 19.6 ± 5.6 bats/turbine; ANOVA, $F_{2,\ 26} = 0.21$, $P = 0.81$). In 2007, during the experimental period, both sets of experimental turbines killed fewer bats than did control turbines (control = 19.0 ± 2.7, experimental rotor start-up speed = 7.6 ± 2.0 bats/turbine, experimental idling 8.1 ± 3.1; ANOVA, $F_{2,\ 26} = 6.34$, $P = 0.006$). There was no difference between the 2 experimental treatments (Tukey's test, $P > 0.05$).

Although corrected fatality rates for each species of migratory bat were reduced by between 50% and 70% at experimental turbines, these were not quite statistically significant when we analyzed the 3 treatments (hoary bat, control = 11.7 ± 2.8 bats/turbine, experimental rotor start-up speed = 4.6 ± 1.3 bats/turbine, experimental idling = 6.1 ± 1.7 bats/turbine; Kruskal–Wallis test, ${\chi^2}_2 = 5.07$, $P = 0.08$; silver-haired bat, control = 5.6 ± 1.7 bats/turbine, experimental rotor start-up speed = 2.3 ± 0.6 bats/turbine, experimental idling = 1.7 ± 1.0 bats/turbine; Kruskal–Wallis test, ${\chi^2}_2 = 4.56$, $P = 0.10$). However, when we combined the 2 experimental treatments and compared them to controls, experimental turbines had lower fatality rates for each species (hoary bat, control = 11.7 ± 2.8 bats/turbine, experimental = 5.0 ± 1.0 bats/turbine; Wilcoxon test, ${\chi^2}_1 = 4.4$, $P < 0.05$; silver-haired bat, control = 5.6 ± 1.7 bats/turbine, experimental = 2.1 ± 0.5 bats/turbine; ${\chi^2}_1 = 4.2$, $P < 0.05$).

From sunset to sunrise during the experiment, if the operational parameters of the experimental rotor start-up turbines had been unaltered, they would not have produced electricity an average of 29% of the time, based on wind speeds measured at each turbine. However, by changing the rotor start-up speed, these experimental turbines did not produce electricity an average of 59% of the experimental period at night, based on recorded wind speeds, which represents a decrease in operational hours of 42.3% during the experiment. The change in operation of the low-speed idle experimental turbines did not influence the proportion of time they generated electricity.

DISCUSSION

The 2 experimental changes we instituted to the operation of wind turbines had a similar effect on their operation at low wind speeds and, thus, as we predicted, on bat fatalities. However, the effect of changes in operation was different in terms of costs.

By increasing the rotor start-up wind speed at some turbines, we reduced the amount of time these turbines likely produced electricity by an average of 42.3%. However, the cost of this change in terms of electricity and revenue generation was not as great as originally anticipated, due to a combination of market prices at the time and the fact that electricity is generated especially at higher winds speeds, above the experimental rotor start-up speed of 5.5 m/second. It is estimated that over the 1-month experiment, total revenue lost from the 15 turbines with increased rotor start-up speed was between $3,000 and $4,000 (Canadian currency). Due to technology limitations of the V80 turbines, rotor start-up speed had to be altered for the entire duration of the study, 24 hours a day, not just at night when bats fly. If operational parameters could have been changed only when bats were active at night, then costs would have been even less. Costs could be further reduced if there are correlations between weather variables (other than wind speed) and fatality risk, and operation can be altered only during high-risk conditions. Conversely, if the market or contract prices were higher during this time, if the wind regime was more influenced by lower wind speeds, or if reduced electricity production violated contract terms, then costs would have been greater.

Typically, wind speeds in southwestern Alberta are lowest in the late summer and early autumn (ABB Electric Systems Consulting 2004), which coincides with the timing of autumn migration of hoary and silver-haired bats and high fatality rates in our study area. Bat migration may not coincide with periods of low wind speeds and electrical generation at sites with high bat-fatality rates in other areas of North America. Thus, altering turbine operation at low wind speeds may be more costly or less beneficial. Additional studies at sites encompassing an array of landscapes, environmental variables, and species need to be performed to determine general effectiveness of this mitigation technique.

The change in wind turbine operation to change the pitch angle of the blades and lower the required generator speed for electricity production had the same effect on bat fatalities as did increasing rotor start-up wind speed. However, there was only a small reduction in electricity and revenue generation compared to normal operation. This change in operation was instituted as a means of reducing wear and tear on the rotor and generator and may, thus, have the dual benefit of reducing bat fatalities and maintenance costs while only marginally affecting electricity and revenue generation.

It is not clear why bat activity and fatalities at wind turbines are lower in high wind speeds. It may be that migration is less efficient in high wind speeds and, thus, migratory movement by these species is reduced. It is also possible that migration continues, but individuals fly at higher altitudes and are thus not detectable and not within the blade-swept area of wind turbines. In either case, if the pattern is consistent across different landscapes and geographic locations, mitigation through the low-speed idle strategy or changing rotor start-up speed may be generally effective.

Management Implications

Although we reduced bat fatalities at a high-fatality site, it was an initial experiment. Further experiments should be performed at other rotor start-up speeds and low-wind idling strategies to determine how these parameter changes influence fatality rate and cost-effectiveness of this form of mitigation. Our experiment reduced hoary and silver-haired bat fatalities, but studies need to be performed at sites where there are high fatality rates of other species, such as eastern red bats, eastern pipistrelles (*Perimyotis subflavus*; Arnett 2005) and Mexican free-tailed bats (*Tadarida brasiliensis*; Piorkowski 2006). Because different makes and models of wind turbines operate differently in terms of rotor start-up speed and idling in low winds, experiments should also be performed using sites with different types of turbines. Compared to relocating turbines with high bat-fatality rates or replacing tall turbines with shorter ones, altering the operational parameters of wind turbines has the potential to be an effective way to reduce bat fatalities. Additional studies at sites encompassing a range of environmental variables, relationships between weather and fatalities, bat species composition, and size and make of turbines, need to be performed to determine the general effectiveness of this mitigation technique.

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LITERATURE CITED

ABB Electric Systems Consulting. 2004. Integration of wind energy into the Alberta electric system – stage 4: operations impact. Report no. 2003-10803-2.R03.4. Alberta Electric Systems Operator, Raleigh, North Carolina, USA.

American Wind Energy Association. 2008. GWEC global market release. <http://www.awea.org/newsroom/pdf/GWEC_Global_Market_Release_0208.pdf>. Accessed 21 Apr 2008.

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

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

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

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

Barclay, R. M. R., and L. D. Harder. 2003. Life histories of bats: life in the slow lane. Pages 209–253 *in* T. H. Kunz and M. B. Fenton, editors. Bat ecology. University of Chicago Press, Chicago, Illinois, USA.

Brown, W. K., and B. L. Hamilton. 2006. Monitoring of bird and bat collisions with wind turbines at the Summerview Wind Power Project, Alberta, 2005–2006. Vision Quest Windelectric, Calgary, Alberta, Canada.

Canadian Wind Energy Association. 2008. Wind energy sets global growth record in 2007. <http://www.canwea.ca/media/release/release_e.php?newsId=4>. Accessed 21 Apr 2008.

Cross Timbers Landowners Conservancy. 2008. CTLC home page. <http://www.stopwindturbines.com/>. Accessed 21 Apr 2008.

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

Cryan, P. M., M. A. Bogan, R. O. Rye, G. P. Landis, and C. L. Kester. 2004. Stable hydrogen isotope analysis of bat hair as evidence for seasonal molt and long-distance migration. Journal of Mammalogy 85:995–1001.

Drewitt, A. L., and R. H. W. Langston. 2006. Assessing the impacts of wind farms on birds. Ibis 148:29–42.

Environment Canada. 2007. Wind turbines and birds: a guidance document for environmental assessment. Environment Canada and Canadian Wildlife Service, Gatineau, Quebec, Canada.

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

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

Findley, J. S., and C. Jones. 1964. Seasonal distribution of the hoary bat. Journal of Mammalogy 45:461–470.

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

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

Johnson, G. D., W. Erickson, J. White, and R. McKinney. 2003*b*. Avian and bat mortality during the first year of operation at the Klondike Phase I Wind Project, Sherman County, Oregon. Northwestern Wind Power, Goldendale, Washington, USA.

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

Piorkowski, M. D. 2006. Breeding bird habitat use and turbine collisions of birds and bats located at a wind farm in Oklahoma mixed-grass prairie. Thesis, Oklahoma State University, Stillwater, USA.

Save Western NY. 2008. Save Western New York. <http://www.savewesternny.org/index.html>. Accessed 21 Apr 2008.

Smallwood, K. S. 2007. Estimating wind turbine–caused bird mortality. Journal of Wildlife Management 71:2781–2791.

Smallwood, K. S., and C. Thelander. 2008. Bird mortality in the Altamont Pass Wind Resource Area, California. Journal of Wildlife Management 72:215–223.

von Hensen, F. 2004. Gedanken und arbeitshypothesen zur fledermausvertr glichkeit von windenergieanlagen. Nyctalus 9:427–435.

World Wind Energy Association [WWEA]. 2008. World Wind Energy Association statistics. <http://www.wwindea.org/home/index.php?option=com_content&task=view&id=198&Itemid=43>. Accessed 21 Apr 2008.

Young, D. P., Jr., W. P. Erickson, R. E. Good, M. D. Strickland, and G. D. Johnson. 2003*a*. Final report avian and bat mortality associated with the initial phase of the Foote Creek Rim windpower project, Carbon County, Wyoming: November 1998–June 2002. Pacificorp, Portland, Oregon, USA, and SeaWest Windpower, San Diego, California, USA, and Bureau of Land Management, Rawlins District Office, Rawlins, Wyoming, USA.

Young, D. P., Jr., W. P. Erickson, M. D. Strickland, R. E. Good, and K. J. Sernka. 2003*b*. Comparison of avian responses to UV-light-reflective paint on wind turbines. National Renewable Energy Laboratory, Golden, Colorado, USA.

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