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Bats and Wind Energy—A Literature Synthesis and Annotated Bibliography

Open-File Report 2012–1110

U.S. Department of the Interior
U.S. Geological Survey

Cover photograph: Hoary bat (*Lasiurus cinereus*), photo by Paul Cryan

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Executive Summary

Turbines have been used to harness energy from wind for hundreds of years (Gipe, 2004). However, with growing concerns about climate change, wind energy has only recently entered the mainstream of global electricity production. In 2010, the global installed capacity for wind energy reached 196,630 Megawatt (MW), which represents approximately 2.5 percent of the total global energy consumption (World Wind Energy Report, 2010). In the United States, the total utility-scale wind power capacity through the 3rd quarter of 2011 totaled 43,461 MW and this represents more than 20 percent of the world's installed wind power (American Wind Energy Association, 2012). In 2011, the electricity produced from wind energy in the United States amounted to 120 Terawatt-hours (thousand MW) or 2.9 percent of total global electricity demands (U.S. Energy Information Administration, 2012). Canada is the ninth largest producer of wind energy in the world with current installed capacity at 4,862 MW, representing about 2.1 percent of Canada's total electricity demand (Canadian Wind Energy Association, 2012).

Since early on in the development of wind-energy production, concerns have arisen about the potential impacts of turbines to wildlife; these concerns have especially focused on the mortality of birds. Early styles of turbines appeared to pose a greater risk to birds in terms of collision mortality than more modern turbines do (Erickson and others, 2002; Young and others, 2003). Early turbines were smaller, had a higher blade-rotation rate, and had a lower energy output. This resulted in more turbines being needed for significant electricity production, thereby increasing the chances of birds encountering turbines (Curry and Kerlinger, 2000; Erickson and others, 2002; Howell, 1995). The lattice towers of smaller turbines also provided birds with perching opportunities, which was thought to further increase mortality (Kerlinger, 2002; Orloff and Flannery, 1992; Osborn and others, 1998). Structural changes and improved turbine design have been instrumental in reducing mortality in birds (Johnson and others, 2002; Smallwood and Karas, 2009). For example, during a study at the Altamont Pass Wind Resource Area in California, it was found that when comparing the concurrently operating old-generation, smaller turbines during 2005–2007, adjusted fatality rates in the newer, larger, and taller turbines were 66 percent lower for all birds combined.

Despite the improvements to turbines that have resulted in reduced mortality of birds, there is clear evidence that bat mortality at wind turbines is of far greater conservation concern. Larger and taller turbines actually seem to be causing increased fatalities of bats (Barclay and others, 2007). Bats of certain species are dying by the thousands at turbines across North America, and the species consistently affected tend to be those that rely on trees as roosts and most migrate long distances (Cryan and Barclay, 2009). Bat mortality at wind-energy facilities was first documented in Australia, where 22 white-striped mastiff-bats (*Tadarida australis*) were found at the base of turbines over 4-year (yr) period (Hall and Richards, 1972). In 1999, 45 dead bats were found at a wind energy facility in Carbon County,

Wyoming; 10 dead bats were found at a wind energy facility in Umatilla County, Oregon; and 34 dead bats were found within a wind energy facility in Wisconsin (Keeley and others, 2001). Small numbers of dead bats have also been found at wind-energy facilities in California (Orloff and Flannery, 1992; Howell, 1997; Anderson and others, 2000; Thelander and Rugge, 2000). Turbine-related bat mortalities are now affecting nearly a quarter of all bat species occurring in the United States and Canada. Most documented bat mortality at wind-energy facilities has occurred in late summer and early fall and has involved tree bats, with hoary bats (*Lasiurus cinereus*) being the most prevalent among fatalities.

Populations of bats are difficult to monitor (O'Shea and others, 2003). Because of this, there is insufficient information on the population status of the 45 species of bats in the United States, especially for migratory foliage- and tree-roosting bats (O'Shea and others, 2003). With this lack of understanding of total population sizes, demographics, and impacts of fatalities from wind turbines on the viability of affected bat populations, it is currently not possible to determine the influence of any single source of mortality or of any effects of mitigation strategies on these bat populations. In addition to the direct effects of wind-energy development on bat mortality, indirect effects may occur as well. Bats have low reproductive rates and generally give birth to a single individual once a year. This results in bat populations growing slowly and an inability to quickly rebound after rapid declines in population size. Bat populations therefore rely on high adult survival rates to compensate for low reproductive rates and prevent declines. Therefore, substantial cumulative impacts of wind-energy development on certain bat species, especially tree-roosting bats, are expected, and these populations would be slow to recover from any population declines (Barclay and Harder, 2003).

Numerous research opportunities exist that pertain to issues such as: (1) identifying the best and worst placement of sites for turbines and (2) mitigation strategies that would minimize impacts to wildlife (birds and bats). Unfortunately, to date, very little research of this type has appeared in the peer-reviewed scientific literature; much of the information exists in the form of unpublished reports and other forms of gray literature. This literature synthesis and annotated bibliography focuses on refereed journal publications and theses about bats and wind-energy development in North America (United States and Canada). Thirty-six publications and eight theses were found, and their key findings were summarized. These publications date from 1996 through 2011, with the bulk of publications appearing from 2007 to present, reflecting the relatively recent conservation concerns about bats and wind energy.

The idea for this Open-File Report formed while organizing a joint U.S. Fish and Wildlife Service/U.S. Geological Survey "Bats and Wind Energy Workshop," on January 25–26, 2012. The purposes of the workshop were to develop a list of research priorities to support decision making concerning bats with respect to siting and operations of wind-energy facilities across the United States. This document was intended to provide background information for the workshop participants on what has been published on bats and wind-energy issues in North America (United States and Canada).

Format of Report

This report is divided into three sections: (1) a literature synthesis; (2) an annotated bibliography; and, (3) additional references. The literature synthesis and annotated bibliography focus on North America and on refereed journal publications. Additional references include a selection of citations on bat ecology, international research on bats and wind energy, and unpublished reports.

Literature Review Methods

A detailed literature review was conducted using Internet resources and databases. The keywords chosen for these searches included "bats," "Chiroptera," "wind," and "wind energy."

Keywords were used alone or in combination with the other terms. Databases and search engines used included Google (*http://www.google.com*), Google Scholar (*http://scholar.google.com*), SciVerse Scopus (*http://www.scopus.com*), ISI Web of Knowledge (*http://apps.isiknowledge.com*), and the USGS Library's Digital Desktop (*http://library.usgs.gov*). The literature-cited sections of publications obtained from keyword searches were also cross-referenced to identify additional citations or gray literature that were missed by the Internet search engines.

Acknowledgments

The work on which this Open-File Report is based was conceived while organizing a joint U.S. Fish and Wildlife Service (FWS)/U.S. Geological Survey (USGS) "Bats and Wind Energy Workshop," on January 25–26, 2012. I thank the participants of the workshop for their suggestions and valuable input on the development of this document: From FWS, Paul Barrett (Southwest, R2), Gabriela Chavarria (Washington), Jeremy Coleman (Northeast, R5), Megan Cook (Washington), Craig Hanson (Mountain-Prairie, R6), David Kampwerth (Pacific, R1), TJ Miller (Midwest, R3), Scott Pruitt (R3), and Jennifer Szymanski (R3). From USGS, Laurie Allen (USGS Ecosystems Mission Area), Dan Manier [Fort Collins Science Center (FORT)], Nina Burkhardt (FORT), Paul Cryan (FORT), Robb Diehl (Northern Rocky Mountain Science Center), Jay Diffendorfer (Rocky Mountain Geographic Science Center), Marcos Gorresen (Pacific Islands Ecosystem Research Center), Manuela Huso [Forest and Rangeland Ecosystem Science Center (FRESC)], Doug Johnson (Northern Prairie Wildlife Research Center), Sue Phillips (FRESC), and Wayne Thogmartin (Upper Midwest Environmental Sciences Center). Ed Arnett (Bat Conservation International), Mark Hayes (FORT), and Patty Stevens (FORT) provided helpful peer review comments. Jenny Shoemaker (USGS, FORT) assisted with formatting the final report. Funding for this Open-File Report was provided by Laurie K. Allen and William A. Lellis (USGS Ecosystems Mission Area).

I. Literature Synthesis

I found 36 refereed journal articles and eight theses during this literature search. The earliest article was published in 1996 (Osborn and others, 1996) and the number of publications per year increased until the present year. There was one publication in 1996, one in 2002, one in 2003, two in 2004, one in 2005, six in 2007, seven in 2008, four in 2009, six in 2010, nine in 2011, and finally, one in 2012. Five of the eight theses were annotated and included in this synthesis because they were intended for publication. Three of the theses were later published and annotated in this report. I identified five broad categories of topics: (1) Causes of mortality; (2) Fatalities and/or activity patterns; (3) Migration; (4) Mitigation and curtailment; and, (5) Review papers and syntheses. I summarize the literature for each of these topics in the following five subsections.

Causes of Mortality

Eight papers addressed the causes of bat mortality at wind-energy facilities. Kunz and others (2007a) and Cryan and Barclay (2009) provided overviews of the hypothesized causes of bat fatalities at turbines. These hypotheses fall into two categories: proximate and ultimate. Proximate causes explain the direct means by which bats die at turbines and include bats colliding with turbine towers, colliding with rotating blades, or barotrauma (that is, internal injuries suffered after being exposed to rapid pressure changes near the trailing edges and tips of the moving blades). Hypotheses of ultimate causes are numerous and include three general categories: random collisions, coincidental collisions, and collisions that occur because bats are attracted to turbines. Random collisions are those that occur due to chance alone or involve no assumptions of circumstance or attraction. Coincidental collisions involve bats being victims of unfortunate behavioral circumstances that put them at risk of colliding with turbines (for example, turbines are located along migratory pathways). Hypotheses of attraction propose that there is some attractor or combination of attractors drawing bats to wind turbines (Kunz and others, 2007).

The obvious prominent cause of bat deaths at wind turbines are direct collision (that is, blunt-force trauma) and barotrauma. Baerwald and others (2008) proposed that barotrauma was a significant cause of bat fatalities at wind turbines in southwestern Alberta, Canada. They found that 46 percent of bats killed at turbines had no discernible external injuries that would have been fatal, and 92 percent of bats necropsied had hemorrhaging in the thoracic and/or abdominal cavities. In a follow-up study at this same location, a small percentage (2.5 percent) of bats found while conducting fatality searches were alive and only 30 percent of those live bats had visible signs of skeletal damage or considerable soft tissue damage. However, Grodsky and others (2011) used veterinary diagnostic procedures to investigate bat fatalities in southeastern Wisconsin and found that the exact cause of death (that is, barotrauma or direct collision) could not be determined in most bats due to the variability of injuries and a lack of exclusively attributable lesions. They concluded that the cause of death for bats killed at turbines was not exclusively or predominantly barotrauma or direct collision but rather an indiscernible combination of both. Simply using a visual inspection of a bat carcass is not adequate for conclusively diagnosing fatal injuries, including broken bones. Rollins and others (2012) examined the causes of lung damage from salvaged bats and found that results could be confounded by common postmortem artifacts (for example, decomposition, temperature differences) as well as the competing hypothesized causes of traumatic injury (for example, blunt force trauma, barotrauma, laceration). Because these competing factors could not be confidently excluded during a pathological examination, pulmonary barotrauma should not be diagnosed from salvaged bat carcasses unless assessments are also made for ruptured ear drums. The authors conclude that their results point to a need for improvements in the current monitoring procedures at wind-energy facilities and in the experimental approaches used to determine whether barotrauma or other causes contribute to bat mortality.

Horn and others (2008) used thermal infrared (TIR) cameras to monitor the activity of bats at Mountaineer Wind Energy Center in West Virginia. They found clear evidence of bats avoiding turbine blades and of bats being directly struck by blades. One of the most important observations from this study was that bats were observed actively investigating both moving and motionless turbine blades; this suggests that they may be attracted to the turbines as potential roosting trees.

Kunz and others (2007) first proposed the hypothesis that tree bats are attracted to turbines. Cryan (2008) further elaborated on this hypothesis by proposing that tree bats collide with turbines while engaging in mating behaviors that center on the tallest trees in the landscape. Tree bats may use the highest trees in a landscape as rendezvous points during the mating season and this behavior places them at risk of collision with the blades of wind turbines. Jameson's (2010) thesis called this the "Reproductive Landmarks Hypothesis" and found evidence that tree bats were attracted to tall structures during the fall migration, the same time of year of most documented mortality at wind-energy facilities. Direct evidence of mating at communication towers and turbines was not observed during this study; however, high levels of bat activity were recorded at communication towers during migration.

Fatalities and/or Activity Patterns

Eleven papers and five theses investigated patterns of fatality and/or activity of bats at wind-energy facilities. Four papers and one thesis looked at fatalities alone, while the remaining studies examined both bat activity at and near turbines and bat mortalities. Patterns that emerged from these fatality and activity studies were the following: (1) fatality rates for bats at wind turbines and the species most affected differed by geographical region; (2) there was a tendency for more males to be killed than females (with a few exceptions); (3) most mortality occurred during fall migration; (4) the majority of fatalities were tree bats (hoary, silver-haired, and eastern red bats); (5) searcher detection and scavenger rates for bat carcasses are highly variable and depend on the region, vegetation, and methodology used; (6) there was no consistency in how mortality rates were presented; (7) bat-activity (acoustical) patterns around turbines and in nearby habitats varied by geographical region; and, (8) there was a tendency for bat fatalities to increase in low wind speeds.

Prior to Osborn and others (1996), most studies on the biological impacts of wind energy were designed to assess the impacts to birds. Bat collisions with turbines were infrequent and had not received attention by natural resource agencies or the scientific community. While conducting a study to assess impacts to birds from wind turbines at the Buffalo Ridge Wind Resource Area in southwestern Minnesota in 1994–1995, Osborn and others (1996) found 13 bat carcasses of 5 different species, 11 of which were tree bats (hoary, silver-haired, and red bats). A high percentage of these fatalities (85 percent) occurred during the summer. Johnson and others (2003) continued to document mortality of bats at this same location from 1996 to 1999 and found 163 fatalities: 89 percent of the fatalities were hoary and eastern red bats, and 97 percent occurred from July 15 to September 15. In 2001 and 2002, Johnson and others (2004) continued to conduct fatality searches as in the previous two studies, but included acoustic and mist-netting surveys to investigate bat activity and composition in relation to the wind facility. They found more bat activity at foraging and roosting areas than at turbines. Mortality of bats at wind turbines did not appear to involve foraging bats, but instead corresponded with post-breeding southward migration of hoary (*Lasiurus cinereus*), eastern red (*L. borealis*), and silver-haired bats (*Lasionycteris noctivagans*).

At about the same time as the work being done at Buffalo Ridge, Minnesota, Gruver (2002) conducted a study examining bat community structure and bat fatalities at the Foote Creek Rim Wind Power Facility in south-central Wyoming from 2000 to 2001. He found that although bats in the genus *Myotis* represented approximately 81 percent of all bats captured using mist nets, bat fatalities consisted of 22 hoary bats and 1 big brown bat over the course of this study. (Hoary bats and big brown bats are in different genera than *Myotis*.)

Previous to 2003 or 2004, mortalities were reported as numbers of carcasses found and were summarized by species. Around 2004, fatality surveys began to address the sampling and statistical issues of estimating mortality using carcass surveys. Studies began to incorporate searcher efficiency and scavenger removal trials into their methodology. However, there was still a lot of variability in how mortality statistics were presented. For example, some studies lumped tree bats and reported an adjusted mortality rate for the year and for the entire location (Fiedler, 2004), some reported a rate of bats killed for the sampling period of the study [(for example, from April to December 2003; Jain and others (2011)], and some reported the number of bats killed per turbine per day and/or per MW per day (Grodsky, 2010).

Bat mortality was investigated at Buffalo Mountain Windfarm in eastern Tennessee from 2000 to 2003 (Fiedler, 2004). At this location, eastern red bats made up the majority of bat fatalities (61.3 percent), followed by tricolored bats (22.4 percent), and hoary bats (10.1 percent). An adjusted mortality rate for this study and location was estimated to be 20.82 bats/turbine/year. On nights where fresh fatalities occurred at turbines, bat activity levels, determined by acoustic monitoring, were greater than on nights where no fatalities occurred. However, turbine collisions of red and hoary bats were disproportionately greater than the acoustical monitoring would have indicated if acoustic activity was directly proportional to fatality risk.

Jain and others (2011) examined bat mortality and activity at Top of Iowa Wind Resource Area in north-central Iowa during 2003–2004. They calculated an adjusted mortality rate for the entire wind-resource area for each year of the study. In 2003, mortality was estimated to be 396.05 plus or minus 71.71 (95 percent CI) bats (4.45 bats/turbine, 4.94 bats/MW) and in 2004, that estimate increased to 635.83 plus or minus 111.89 (95 percent CI) bats (7.14 bats/turbine, 7.94 bats/MW). There was no difference between bat activity at turbine sites and adjacent crop fields without turbines during both years.

Another Midwestern study took place in Wisconsin. Grodsky (2010) studied bird and bat mortality at the Forward Energy Center in southeastern Wisconsin. Daily fatality rates were calculated for migratory tree bats as 0.158 bats/turbine/day and 0.105 bats/MW/day. In addition to daily fatality rates, the author also corrected estimates for tree bat mortality to the number of bats per turbine and bats per MW over the entire study in order match the standards from other studies (Jain and others, 2007; Kerlinger and others, 2007; Gruver and others, 2009). These estimates were 47.865 bats/turbine/entire study and 31.875 bats/MW/entire study. By his estimation, approximately 4,454 total bats, 3,019 migratory bats, and 912 non-migratory bats were killed during the 2 springs and 2 falls of the study.

Piorkowski and O'Connell (2010) studied the spatial patterns of summer bat mortality from collisions with wind turbines at the Oklahoma Wind Energy Center in the southern Great Plains, Oklahoma. This study provided the first evidence of a steady rate of collision mortality of Brazilian free-tailed bats (*Tadarida brasiliensis*). Eighty-five percent of all bat fatalities were Brazilian free-tailed bats and rates of mortality adjusted for probability of detection and incorporating published removal estimates yielded an estimate of 74–92 individuals (0.73–0.90/MW) in 2004 and 67–85 (0.66–0.83/MW) in 2005.

Until Miller's (2008) thesis, no studies of bat mortality at wind-energy facilities had been completed in Texas, despite Texas leading the United States in installed wind-energy capacity. Miller (2008) looked at patterns of avian and bat mortality at the Red Canyon Wind Energy Center in the southern portion of the Texas Panhandle from September 2006 to September 2007. As with Piorkowski and O'Connell's (2010) Oklahoma study, the Brazilian free-tailed bat represented the majority of all bat fatalities (94 percent), followed by hoary bats (4 percent), and eastern red bats (2 percent). The author classified turbines into three categories: low, medium, and high mortality. Turbines were assigned these three mortality categories based on elevation, aspect, and percent of the turbine site that was a part of the Caprock Escarpment edge, a distinct palisade-like escarpment. High mortality turbines were southwest-facing, less than 853 meters (m) in elevation with greater than 38 percent Caprock Escarpment edge within the turbine site boundary. Medium mortality turbines were south-facing, between 853 and 865 m in elevation, and with between 34 and 38 percent of the site boundary as Caprock edge. Low mortality turbines were southeast-facing, greater than 865 m in elevation, and less than 34 percent of the site boundary as Caprock edge. Low mortality turbines were estimated to kill 15.29 bats/MW, medium mortality turbines were estimated to kill 45.00 bats/MW, and high mortality turbines were estimated to kill 106.67 bats/MW. Total mortality was estimated for the entire wind energy development to be 36.87 bats/MW.

At the Altamont Pass Wind Resource Area (APWRA) in California, Smallwood and Karas (2008) examined avian and bat mortality rates at older-generation turbines compared to repowered (larger and taller) turbines over several years (1998–2003 and 2005–2007). Adjusted fatality rates for bats increased from zero at the old vertical-axis turbines to 16.4/year at the new, repowered turbines. This was nearly 800 percent greater bat mortality at the new, larger turbines when compared to the older-generation turbines. However, the newer turbines were found to reduce bird fatality rates a great deal. The authors extrapolated the average adjusted bat fatality rate from the repowered turbines to a completely repowered APWRA and estimated about 454 bat fatalities/year might result.

Weller and Baldwin (2011) combined the results of continuous echolocation and meteorological monitoring at multiple stations to model the conditions that explain the presence of migratory bats at a wind energy facility in southern California. Despite low overall bat-activity levels, the authors were able to build models that successfully predicted conditions when migratory bats were present. Using acoustic detectors and occupancy modeling, they found that occupancy of bats was associated with lower nightly wind speeds and higher nightly temperatures, mirroring results from other wind-energy facilities in other regions and habitats. The results also highlight the importance of modeling conditions that explain bat activity on a seasonal basis. There were marked differences in activity levels seasonally; the relative importance of explanatory variables also differed seasonally. The authors conclude that using this model-based approach could improve the effectiveness and efficiency of mitigations for bat fatalities at wind-energy facilities. If properly conducted, echolocation monitoring and meteorological monitoring may provide a reliable index to expected bat fatality levels at wind-energy facilities.

Canadian bat mortality studies report relatively high fatalities at wind-energy facilities (Baerwald and Barclay, 2009; 2011; Jameson, 2010; Klug and others, 2011). Baerwald and Barclay (2009; 2011) examined the geographical variation in activity levels and fatality rates of bats at one proposed and eight existing wind-energy facilities across southern Alberta, Canada, from 2006 to 2007. Corrected fatality rates varied among the 9 sites sampled, from 31.41 plus or minus 3.04 bats/turbine/year to 1.26 plus or minus 0.18 bats/turbine/year, with higher rates at western wind-energy facilities and lower rates at eastern facilities. Fatality rates did not appear to be influenced by migratory bat activity at ground level or at 30 m. Jameson (2010) examined the factors influencing bat mortality at the St. Leon Wind Energy Project in south-central Manitoba, Canada, in 2008 and 2009. In 2008, adjusted mortality rates reported for this study were 11.5 plus or minus 4.9 bats/turbine (7.2 plus or minus 3.1 bats/MW) for silver-haired bats, 15.7 plus or minus 5.5 bats/turbine (9.9 plus or minus 3.4 bats/MW) for hoary bats, and 2.0 plus or minus 1.0 bats/turbine (1.2 plus or minus 0.6 bats/MW) for eastern red bats. In 2009, adjusted mortality estimates were 7.7 plus or minus 2.1 bats/turbine (4.6 plus or minus 1.3 bats/MW) for silver-haired bats, 5.8 plus or minus 2.1 bats/turbine (3.5 plus or minus 1.3 bats/MW) for hoary bats, and 1.1 plus or minus 0.8 bats/turbine (0.7 plus or minus 0.5 bats/MW) for eastern red bats.

Fatality Search and Estimation Techniques

Arnett (2006) conducted a baseline effort to assess the efficiency of dog-handler teams to recover bat fatalities at two wind-energy facilities in West Virginia and Pennsylvania. Overall dog-handler efficiency (percent of trial bats found) for all trials and bats combined, and using combined findings from both dogs, was 71 percent at Mountaineer (W. Va.) and 81 percent at Meyersdale (Pa.), compared to 42 percent and 14 percent for humans, respectively. Significant variability was found in searcher efficiency (both dog-handler and humans) based on vegetative cover, terrain, and amount of high-visibility habitat found at the two sites. Although the findings from this pilot study were promising, the author suggested that more research was needed to better understand patterns and to account for limitations and biases influencing the efficiency of dog-handler teams as a tool to improve fatality estimates for bats at wind-energy facilities.

Huso (2010) addressed the problem of estimating numbers of wildlife fatalities from observed carcasses. She proposed a fatality estimator that accounts for searcher efficiency, scavenger removal, search interval, density-weighted area searched, and visibility within search transects. The proposed estimator's bias and precision were compared to two other estimators in common use during bat-carcass surveys. Bias is the difference between a population mean of the estimator and an accepted reference or true value (Bainbridge, 1985). Precision is the measure of the statistical variance of an estimation procedure (West, 1999). None of the three estimators compared were unbiased under all conditions. However, bias in the proposed estimator never exceeded plus or minus 27 percent, whereas bias in the other two estimators was always negative and exceeded that of the proposed estimator in 98 percent and 93 percent of the simulated conditions, respectively. The proposed estimator was relatively robust to variation in sources and magnitudes of imperfect detectability, but was sensitive to distributional assumptions regarding carcass-removal rates and searcher efficiency. The proposed estimator offers significant improvement over two current estimators and provides relatively unbiased estimates of fatality that can be applied under a variety of conditions and survey protocols.

Migration

Four publications examined migration patterns of bats in relation to wind-energy facilities. A fifth paper provided a short review of how certain aspects of bird migration could be useful for designing research on bat migration and wind-energy interactions (Larkin, 2006). Reynolds (2006) sampled spring migration at the Maple Ridge Wind Project in the Tug Hill Plateau ecoregion of western New York in 2005. He sampled migratory activity using acoustic monitoring at two sites and found that most of the migratory bat activity occurred at minimum wind speeds below 1.3 meters per second (m/s). He also found that days with high bat-migration activity had a mean maximum temperature of 23.9 plus or minus 4.4°C and lower bat-migration activity at temperatures of 9.8 plus or minus 4.8°C. Acoustic-monitoring results from this study strongly suggested that the Tug Hill Plateau region did not support a large bat population in terms of either species diversity or total bat abundance. Most of the migratory bat activity occurred at wind speeds below the cut-in speeds of a typical commercial wind turbine. However, this study did not sample fall migration: the period in which most bat fatalities occur at wind-energy facilities, including the high fatality rates observed at the Maple Ridge Wind Farm where Reynolds monitored.

Cryan and Brown (2007) investigated migration of bats at the Southeast Farallon Island off the coast of California west of the Bay Area. They analyzed a 38-year (yr) data set of observations of hoary bats arriving and departing on this island. They also investigated whether moonlight and weather conditions influenced the occurrence of bats on the island. They found that hoary bats were observed more frequently in September than any other month. Bats were more likely to arrive and depart from the island on evenings when wind speeds were relatively low, during darker phases of the moon, and during overcast nights. These results are relevant to the problem of bat fatalities at wind turbines because (1) arrivals of migrating tree bats at particular sites may be predictable events, (2) there was conclusive evidence that tree bats migrate over offshore water where future construction of wind turbines has been proposed, (3) migratory hoary bats use vision to navigate during migration and are drawn toward visual stimuli, (4) there was a clear relationship between the timing of autumn migration by hoary bats and collisions with anthropogenic structures, and (5) there was a possible behavioral explanation for bat collisions with wind turbines.

Johnson and others (2011a) examined the seasonal bat activity on Assateague Island National Seashore off the coast of Maryland, in 2005 and 2006. They used acoustic monitoring stations at three locations on the island to sample bat activity. More than half the total bat passes were from eastern red bats (59.33 percent), followed by big brown bats (3.05 percent), hoary bats (0.10 percent), tricolored bats (0.10 percent), and silver-haired bats (0.07 percent). They found that bat activity generally increased in April, peaked in August, and declined gradually until December. Bats were less active during periods of low temperatures and high wind speeds, possibly above thresholds for wind turbine cut-in speed. The results from this study provided evidence that bats migrate along the Atlantic coastline and use barrier islands, possibly for navigation or as stopover sites, and this has implications for proposed offshore wind-energy facilities.

Johnson and others (2011b) examined seasonal and geographic trends in acoustic detection of migrating tree-roosting bats at one existing and thirteen proposed wind-energy facilities in seven eastern states in the United States between April and November of 2007 and 2008. Acoustic surveys were placed into one of three geographic regions to allow for latitudinal comparisons: northeast, northern Allegheny Plateau, and mid-Atlantic. Nightly silver-haired, hoary, and eastern red bat calls/detector/night at two proposed sites in West Virginia were also compared to the number of mortalities at Mount Storm Wind Energy Facility, W. Va., using linear correlations. The authors found that nightly detection rates of silver-haired and hoary bats at the two sites in West Virginia were positively correlated with the number of dead silver-haired and hoary bats at the Mount Storm Wind Facility. However, no significant correlation was found between detection rate of eastern red bats and the mortality at Mount Storm. The nightly detection rates of silver-haired, hoary, and eastern red bats during fall migration peaked earlier in the year in the two northernmost geographic regions compared to the mid-Atlantic region. Conversely, nightly detection rates of the three species during the spring migration peaked earlier in the year in the mid-Atlantic region, compared to geographic regions farther north. In all regions, eastern red bats were more frequently detected later in the year than were hoary bats. This has implications for wind-energy facilities, in that the seasonal detection rates of hoary bats, silver-haired bats, and eastern red bats likely reflect their different migratory patterns, and these patterns may be useful in predicting the timing of mortality events at turbines.

Mitigation and Curtailment

Two publications examined mitigation and curtailment at wind-energy facilities to reduce the number of bat fatalities. Baerwald and others (2009) conducted a mitigation experiment at a wind energy facility in southwestern Alberta, Canada. Normal operating turbines at this facility had a cut-in speed of 4 m/s: the wind speed at which the turbine begins to generate electricity. The authors specifically tested the hypothesis that reducing the amount that turbine rotors turn in low wind speeds will reduce bat fatalities. They operationally altered randomly chosen turbines in two different ways. Fifteen turbines had their rotor start-up speed increased to 5.5 m/s, meaning that the turbines were idle and motionless during low wind speeds. Another six turbines were manipulated to change the pitch angle of their blades to reduce rotor speed in low wind, thereby lowering the generator speed required to start energy production, which caused turbines to be motionless similar to the other experimental treatment but with different implications for turbine operations. Both sets of experimental turbines killed fewer bats than did the control (normal operating) turbines, and there was no difference between the two experimental treatments. The corrected fatality rates for each species of migratory bat were reduced by between 50 percent and 70 percent at the experimental turbines. The effect of changes in operation was different between the two experimental turbines, with the increased rotor start-up speed (5.5 m/s) being more costly than changing the pitch angle of the blades.

Arnett and others (2011) also tested the effectiveness of raising the wind-turbine cut-in speed to reduce bat fatality. Wind-turbine cut-in speed was defined to be the lowest wind speed at which turbines generate power to the utility system. Raising the wind-turbine cut-in speed renders turbines non-operational until the higher cut-in speed is reached; then turbines begin to spin and produce power. This study took place at the Casselman Wind Project in Somerset County, Pa., during 2008 and 2009. Three turbine treatments were defined and assigned (in a randomized block design) to 12 turbines. Treatments were that turbines became operational and began to spin with (1) a cut-in speed of 3.5 meters per second

($m\ s^{-1}$; normal operations), (2) cut-in speed of 5.0 $m\ s^{-1}$, and (3) cut-in speed of 6.5 $m\ s^{-1}$. Treatment-related mortality was measured as the sum of all individual carcasses of bats estimated to have been killed during the previous night observed along transects near the turbines. The results of this study found no difference between the number of fatalities for the two raised cut-in speed treatments for both years. Observed bat mortality at fully operational turbines was, on average, 5.4 (2008) and 3.6 (2009) times greater than mortality associated with curtailed (that is, non-operating) turbines. The authors conclude that relatively small changes to wind-turbine operation resulted in nightly reductions in bat mortality, ranging from 44 percent to 93 percent, with marginal annual power loss (less than or equal to 1 percent of total annual output).

In both of the curtailment studies described above, all species of bats were combined, and species-specific effects of curtailment are unknown. Most fatalities at these curtailment sites were migratory tree bats.

Review Papers and Syntheses

Eleven papers found during this literature search were reviews or syntheses of bats and wind-energy issues. The first review paper published was in 2005 (Johnson, 2005). As of 2004, only 11 studies had been conducted in the United States to estimate fatality rates of bats at wind farms (Johnson, 2005). The numbers of fatality studies continued to increase in succeeding years. Five synthesis and technical guidance papers were published in 2007 (Arnett and others, 2007; Barclay and others, 2007; Kunz and others, 2007a; 2007b; Kuvlevsky and others, 2007). By 2006, Arnett and others (2008) were able to summarize the results from 21 studies of patterns of bat fatalities at 19 wind-energy facilities across North America. The patterns of bat fatalities that emerged from these various syntheses provided the scientific community the ability to construct numerous hypotheses about the causal reasons bats collide with turbines. These hypotheses and their resulting predictions were summarized by Cryan and Barclay (2009). Sovacool (2009) compared bird fatalities from wind energy, fossil fuel, and nuclear electricity in an attempt to contextualize the negative effects to bird populations. According to the author, fossil-fueled facilities are about 17 times more dangerous to birds on a per Gigawatt hour (GWh) basis than wind and nuclear power stations. Bats were included in the title of this paper; however, they were lumped with birds, and their unique life-history strategies were not considered in the paper. Willis and others (2010) provided a response to Sovacool (2009) that examined the various problems with lumping birds and bats together when comparing mortality resulting from the three methods of electricity generation. The most recent review publication was Cryan (2011), and his review summarizes bat mortality caused by wind turbines and the potentially significant effects of this mortality on certain bat populations.

The following general patterns and findings common to all of the review papers are listed below:

- Bat-fatality rates at wind turbines are variable across sites and regions of North America. Estimates of bat fatalities were highest at wind-energy facilities located on forested ridges in the eastern United States and the prairies of eastern Canada, and were lowest in the Rocky Mountain and Pacific Northwest regions.
- Bat-fatality rates range from just below one bat per installed megawatt per year (bats/MW/year) to as high as 70 bats/MW/year.
- Three species of migratory tree bats compose the majority of fatalities (hoary, eastern red, and silver-haired bats), and hoary bats compose about half of all documented fatalities in North America.

- Silver-haired bat fatalities were more frequently found in Canada, Iowa, and the Pacific Northwest relative to the eastern United States, whereas eastern red bats were commonly found in eastern forested sites.
- In Texas and Oklahoma, wind-energy development has the potential to negatively impact migratory Brazilian free-tailed bats (see Miller, 2008; Piorkowski and O'Connell, 2010).
- Fatalities were skewed toward males of the four most commonly killed species at most facilities.
- Most fatalities occur during a period of time that coincides with autumn migration, although few studies spanned the entire season when bats were active.
- Larger, taller turbines killed more bats per turbine when compared to smaller turbines. The highest bat-fatality rates occurred at turbines with towers of 65 m or taller.
- Bats collide with spinning turbine blades and do not strike stationary blades or towers.
- The majority of bats appeared to be killed on low wind-speed nights when power production was proportionally low but turbine blades were still moving, often at or close to fully operational speed.
- There appeared to be no difference in bat-fatality rates between turbines equipped with Federal Aviation Administration (FAA) lights and those that were unlit.
- Factors influencing fatality rates remain unclear, and it is not known yet how to identify and avoid high-risk sites for bats and wind energy.
- Population sizes of migratory tree bats are unknown because of their cryptic habits and limitations in how their numbers can be estimated. There is currently no established method of assessing how quickly the current rates of bat mortality at turbines could cause population declines.
- Studies in Canada and the United States have independently shown that curtailment, or preventing turbine blades from turning during relatively low wind speeds in late-summer and autumn, can reduce bat fatalities by as much as 40–90 percent.

II. Annotated Bibliography

The following is an annotated bibliography of 36 peer-reviewed publications and five unpublished theses in alphabetical order. For research papers, annotations include an overview of objectives, methods, key findings, and conclusions. For review or synthesis papers, the main highlights are provided.

Arnett, E.B., 2006, A preliminary evaluation on the use of dogs to recover bat fatalities at wind-energy facilities: Wildlife Society Bulletin, v. 34, p. 1440–1445.

This study was a baseline effort to assess the efficiency of dog-handler teams to recover bat fatalities at two wind-energy facilities in West Virginia and Pennsylvania. <u>Objectives</u>: (1) to train dogs to find bat carcasses; and, (2) to conduct pilot studies to determine the search efficiency of dog-handler teams under different vegetation conditions. <u>Methods</u>: The study took place at Mountaineer Wind Energy Center in West Virginia and the Meyersdale Wind Energy Center in Pennsylvania. The author trained two chocolate labs, one male and one female, for seven days prior to field testing. Dogs were trained by seeding a transect with bat carcasses representing different species at various stages of decay. Search efficiency of the dog-handler team was tested simultaneously with human searchers during scheduled trials at the two wind-energy facilities in late summer 2004.
<u>Key Findings</u>:

- Overall dog-handler efficiency (percent of trial bats found) for all trials and bats combined, and using combined findings from both dogs, was 71 percent at Mountaineer and 81 percent at Meyersdale, compared to 42 percent and 14 percent for humans, respectively.
- Quite a bit of variability was found in searcher efficiency (both dog-handler and humans) based on vegetative cover, terrain, and amount of high-visibility habitat found at the two sites.

Conclusions: Although the findings from this pilot study were promising, more research is warranted to better understand patterns and account for limitations and biases influencing the efficiency of dog-handler teams as a tool to improve fatality estimates for bats at wind-energy facilities.

Arnett, E.B., Inkley, D.B., Larkin, R.P., Manes, S., Manville, A.M., Mason, J.R., Morrison, M.L., Strickland, M.D., and Thresher, R., 2007, Impacts of wind-energy facilities on wildlife and wildlife habitat: Bethesda, Md. , The Wildlife Society, Wildlife Society technical review 07-1,

This technical review summarizes information on the impacts of wind-energy facilities on wildlife and wildlife habitat, including state and federal permitting processes, wildlife fatality, habitat loss and modification, animal displacement and fragmentation, offshore development, and issues surrounding monitoring and research methodology, including the use of technological tools. In the review, a summary section is provided on bats and bat fatalities from wind turbines. This review provided 12 recommendations that should help managers and decision-makers meet the challenges of developing wind energy responsibly: (1) improve state agency involvement and consistency for requirements and regulation; (2) renewable portfolio standards (for example, regulations that require increased production of energy from renewable energy sources, such as wind, solar, biomass, or geothermal); (3) develop federal and state guidelines; (4) avoid siting wind facilities in high-risk areas; (5) reduce fragmentation and habitat effects; (6) conduct priority research; (7) evaluate pre-construction assessments and predicted impacts; (8) conduct more consistent, longer-term studies; (9) develop and evaluate habitat-related mitigation strategies; (10) employ principles of adaptive management; (11) conduct regional assessments and forecasting of cumulative land-use and impacts from energy development; and, (12) improve public education, information exchange, and participation.

Arnett, E.B., Brown, W.K., Erickson, W.P., Fiedler, J.K., Hamilton, B.L., Henry, T.H., Jain, A., Johnson, G.D., Kerns, J., Koford, R.R., Nicholson, C.P., O'Connell, T.J., Piorkowski, M.D., and Tankersley, R.D., Jr., 2008, Patterns of bat fatalities at wind-energy facilities in North America: Journal of Wildlife Management, v. 72, p. 61–78.

This synthesis examined the patterns of bat fatalities from post-construction studies at wind-energy facilities. Objectives: (1) present unifying and unique patterns from the studies; (2) discuss the scope, biases, and limitations of existing efforts; and, (3) identify information gaps and offer suggestions for future research needed to develop mitigation strategies to minimize or eliminate bat fatality at wind facilities. Methods: Authors reviewed 21 studies from 19 different wind-energy facilities in 5 regions of the United States and one province in Canada. These studies took place from 1996 to 2006 and represent only those published in peer-reviewed journals or unpublished reports available publicly.

Key Findings:

- The duration of most studies was short.
- Only eight studies used bat carcasses to quantify searcher bias and scavenger removal.

- Most studies calculated an overall bias correction factor for the entire study period and across different habitat conditions.
- Estimates of bat fatalities were highest at wind-energy facilities located on forested ridges in the eastern United States and lowest in the Rocky Mountain and Pacific Northwest regions.
- In most regions and individual studies, bat fatalities were heavily skewed to migratory foliage-roosting species including hoary bats (*Lasiurus cinereus*), eastern red bats (*L. borealis*), and migratory tree and cavity roosting silver-haired bats (*Lasionycteris noctivagans*).
- Hoary bats constituted high proportions of fatalities at most facilities.
- Silver-haired bats were found more frequently in Canada, Iowa, and the Pacific Northwest relative to the eastern United States, whereas eastern red bats were commonly found in eastern forested sites in the midwestern United States.
- Fatalities were skewed toward males for the four most commonly killed species at most facilities.
- The highest bat fatalities were consistently reported during late summer and early fall, although few studies spanned the entire season when bats are active (generally April–November).
- Evidence was found that larger, taller turbines killed more bats per turbine compared to smaller turbines.
- Findings from these studies support the contention that bats collide with spinning turbine blades and do not strike stationary blades or towers.
- The majority of bats appear to be killed on low wind nights when power production seemed insubstantial but turbine blades were still moving, often at or close to full operational speed.
- There appeared to be no statistically significant differences in fatality between turbines equipped with FAA lights and those that were unlit.

Conclusions: The authors end by addressing the limitations of the studies reviewed: (1) most work conducted was short term, and the frequency of the study was inadequate to assess seasonal and annual variability; (2) fatality estimates could not be directly compared among studies because of different sampling protocols; (3) sizes of search plots varied among studies; (4) search effort, intensity of searches, and experience of observers varied across studies; and, (5) most studies failed to adequately account for habitat variability during fatality searches.

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

This paper describes an experiment to test the effectiveness of raising the turbine cut-in speed to reduce bat mortality at a wind facility in Pennsylvania during 2008 and 2009. Wind-turbine cut-in speed was defined to be the lowest wind speed at which turbines generate power to the utility system. Raising the wind-turbine cut-in speed renders turbines non-operational until the higher cut-in speed is reached; then turbines begin to spin and produce power. Objectives: (1) to determine if rates of bat fatality differed between fully operational turbines with a cut-in speed of 3.5–5.0 m s^{-1} and turbines with raised cut-in speeds of either 5.0 m s^{-1} and 6.5 m s^{-1}, and (2) to quantify the economic costs of different curtailment programs and timeframes. Methods: The study took place at the Casselman Wind Project in Somerset County, Pa., over a 2-yr period (2008–2009). Three turbine treatments were defined and assigned in a randomized block design to 12 turbines. Treatments were (1) fully operational, (2) cut-in speed of 5.0 m s^{-1}, and (3) cut-in speed of 6.5 m s^{-1}. Treatment-related mortality was measured as the sum of all individual carcasses of bats estimated to have been killed during the previous night observed along transects near the turbines.

Key Findings:

- No difference was found between number of fatalities for the two cut-in speed treatments for both years.
- Observed bat mortality at fully operational turbines was, on average, 5.4 (2008) and 3.6 (2009) times greater than mortality associated with curtailed (that is, non-operating) turbines.

Conclusions: Relatively small changes to wind-turbine operation resulted in nightly reductions in bat mortality, ranging from 44 percent to 93 percent, with marginal annual power loss (less than or equal to 1 percent of total annual output).

Baerwald, E.F., and Barclay, R.M.R., 2009, Geographic variation in activity and fatality of migratory bats at wind-energy facilities: Journal of Mammalogy, v. 90, p. 1341–1349.

This study examined geographic variation in activity levels and fatality rates of bats at one proposed and eight existing wind-energy facilities across southern Alberta, Canada. The authors hypothesized that migratory bats use specific migration routes associated with landmarks and roost availability. They predicted that migratory bat activity would vary among the different habitats and that bat fatalities at wind turbines would correlate with activity rate. Objectives: to determine if bat activity and fatality were concentrated in certain areas or evenly distributed across the landscape. Methods: Bat activity was monitored acoustically from July 15 to September 15, 2006 and 2007, at seven proposed or existing wind-energy installations. Anabat II detectors were installed in pairs (one approximately 1.5 m from the ground and the other 30 m from the ground) on meteorological towers. The authors compiled fatality data collected between 2001 and 2007 from nine wind-energy facilities. They also searched for bat carcasses at two sites from July 15 to September 30, in 2006, and 2007, and at another site from July 15 to September 30, 2007. Fatality rates were adjusted per turbine for searcher efficiency and scavenger removal rates.

Key Findings:

- Bat activity varied among sites with the highest activity of migratory-bat passes detected at Site 1, the westernmost site near the Rocky Mountains.
- Pooled across all sites, total migratory bat activity did not differ between detection heights. However, when separated by species, the activity of hoary bats and silver-haired bats differed between the two detection heights with hoary bats being less common at ground level than at 30 m and silver-haired bats more common at ground level than at 30 m.
- Searcher efficiency was estimated to be 78 percent and carcasses lasted an average of 5.6 days.
- Corrected fatality rates varied among the nine sites sampled, from 31.41 plus or minus 3.04 bats/turbine/year to 1.26 plus or minus 0.18 bats/turbine/year, with higher rates at western wind-energy facilities and lower rates at eastern facilities. Fatality rate increased with turbine height.
- Fatality rate was not influenced by migratory bat activity at ground level, migratory bat activity at 30 m, or the interaction between migratory bat activity at ground level and turbine height.

Conclusions: Migratory bats in southern Alberta appear to be concentrating along select routes and activity rates of both hoary and silver-haired bats were higher near the foothills of the Rocky Mountains to the west than on the prairie grasslands farther east. Fatality rates of bats varied among all sites, partly due to differences in turbine tower height, but also due to the differences in activity of migratory bats at 30 m. The results of this study indicated that factors in addition to turbine height and migratory bat activity influence fatality rates at wind turbines. The authors suggested that the number of turbines may play a role: facilities with many turbines may experience a dilution effect with lower fatality rates per turbine than facilities with few turbines.

Baerwald, E.F., and Barclay, R.M.R., 2011, Patterns of activity and fatality of migratory bats at a wind energy facility in Alberta, Canada: Journal of Wildlife Management, v. 75, p. 1103–1114.

Using acoustic monitoring and carcass searches, the authors examined temporal and spatial variation in activity levels and fatality rates of bats at one wind-energy facility in southern Alberta, Canada, in 2006 and 2007. Objectives: to test the hypotheses regarding the influence of weather variables and turbine characteristics on migratory bat activity and fatality. The authors predicted that weather conditions conducive to migration would increase activity of migratory bats and therefore would increase fatality rate. They also predicted that weather and turbine characteristics would affect fatality rate independent of the number of bats migrating on a particular night (for example, bats attracted to turbines). Methods: Weather data were collected from a meteorological tower located on the wind energy facility and included wind speed and direction data at 50 m above ground level and temperature and barometric readings at 2 m above ground-level. Activity was monitored using Anabat II detectors on meteorological towers and turbine nacelles from July 15 to September 30, 2006 and 2007. Nacelles are the covers at the top of the turbine that house all of the generating components of a wind turbine, including the generator, gearbox, drive train, and brake assembly. Carcass searches were also conducted during the same time periods for both years and were adjusted for searcher efficiency and scavenger removal rates. Four different statistical analyses examined whether: (1) activity rate varied with weather; (2) variation in fatality rate was influenced by turbine location and characteristics; (3) variation in fatality rate was influenced by activity rate; and finally, (4) fatality rate depended on weather variables, while controlling for variation in activity of bats.

Key Findings:

- Activity of migratory bats was greater in low wind speeds and was lower when the wind was from the north or northeast. Hoary bats were more active with falling barometric pressure but were not influenced by any other weather variable. Silver-haired bat activity was greater in warmer ambient temperatures and low wind speeds and decreased when the wind was from the north or northeast.
- Fatality rates differed among turbines; higher rates were found at turbines in the north end of the facility in comparison to the south end. There were no differences in fatality rates at turbines on the east side versus the west side of the facility, at turbines on the end of a row versus in the middle of a row, or at turbines lit by aviation lighting versus those unlit.
- Bat fatalities increased with total migratory bat activity; however, when separated by species, hoary bat fatalities per night did not increase with their activity and silver-haired bat fatalities per night did increase with their increased activity.
- Total nightly fatalities increased with increased moon illumination and were influenced by the interaction between barometric pressure change and the activity of migratory bats. Although fatality rates increased as activity increased, if activity was low and there was a large drop in barometric pressure, the fatality rate was high. Hoary bat fatality rate increased with falling barometric pressure but not with any other variable or interaction tested. Silver-haired bat fatality rate increased with increasing activity, increasing fraction of moon illuminated, and southeasterly winds.

Conclusions: Migration behavior of bats is a very complex issue, but it offers potential ways to reduce fatalities at wind-energy facilities if we can understand the relationships between weather, activity, and fatality. As an example, if increasing moon illumination and falling barometric pressure increase the risk of fatality, then matching these parameters with changes to wind-turbine operations might reduce fatalities.

Baerwald, E.F., D’Amours, G.H., Klug, B.J., and Barclay, R.M.R., 2008, Barotrauma is a significant cause of bat mortalities at wind turbines: Current Biology, v. 18, p. 695–696.

The authors describe a study where they found that barotrauma was a significant cause of bat fatalities at wind turbines in southwestern Alberta, Canada. The decompression hypothesis, as described by Baerwald and others, 2008, proposes that bats are killed by barotrauma caused by rapid air-pressure reduction near moving turbine blades. Objective: to test the decompression hypothesis. Methods: Hoary bats and silver-haired bats killed at a wind facility were examined for external and internal injuries.
Key Findings:

- Of 188 bats killed at turbines the previous night, 87 had no external injuries that would have been fatal.
- Of 75 fresh bats necropsied, 32 had obvious external injuries, but 69 had hemorrhaging in the thoracic and/or abdominal cavities.

Conclusions: Barotrauma helps explain the high fatality rates of bats at some wind-energy facilities. Even when echolocation allows bats to avoid turbine blades, they may still be incapacitated or killed by the internal injuries caused by rapid pressure reductions.

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

This paper describes the results of a large-scale mitigation experiment to reduce bat fatalities at a wind facility in southwestern Alberta, Canada, during the peak period of migration for hoary and silver-haired bats in 2006 and 2007. Normal operating turbines at this facility had a cut-in speed (the wind speed at which the turbine begins to generate electricity) of 4 m/s. 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 which triggers generator rotation, a wind speed of 4 m/s. Objective: to test the hypothesis that reducing the amount that turbine rotors turn in low wind speeds reduces bat fatalities. Methods: Twenty-one randomly chosen turbines were operationally altered in two ways in 2007. Fifteen had their rotor start-up speed increased to 5.5 m/s, meaning that the turbines were idle and motionless during low wind speeds. The other six turbines were manipulated to change the pitch angle of their blades to reduce rotor speed in low wind, thereby lowering the generator speed required to start energy production, which caused turbines to be motionless. This procedure was similar to the other experimental treatment but had different implications for turbine operations. Fatality searches were conducted once per week using transects and two searchers. Corrected fatality rates were compared between experimental and control turbines both in 2006 (when no experiment was conducted) and in 2007.
Key Findings:

- In 2006, there was no difference in corrected bat-fatality rates between turbines later selected as experimental or control.
- In 2007, both sets of experimental turbines killed fewer bats than did control turbines, and there was no difference between the two experimental treatments.
- Corrected fatality rates for each species of migratory bat were reduced by between 50 percent and 70 percent at the experimental turbines.
- By increasing the rotor start-up wind speed, the amount of time the turbines produced electricity was reduced by an average of 42.3 percent.

Conclusions: The two experimental changes made to operation of turbines had a similar effect on their operation at low wind speeds and therefore resulted in lower bat fatalities. However, the effect of changes in operation was different in terms of costs with increased rotor start-up speed (5.5 m/s) being more costly than changing the pitch angle of the blades.

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

The size and height of wind turbines have increased over the years, from 18-m diameter rotors on top of 24-m towers, to the newest turbines with 90-m diameter rotors and towers as tall as 94 m. Objective: to test the hypothesis that wind turbine size and height influence fatality rates of bats and birds and to determine whether the effect differs between the two groups. Methods: Authors compiled data on the characteristics of 33 North American wind-energy facilities and on bat and bird fatalities. Data were available from some published scientific papers, but primarily from unpublished government, industry, and consultant reports, and from personal communications. Fatality rates were determined based on searches for carcasses under turbines.
Key Findings:

- Increased rotor-swept area was not a significant factor in fatality of birds or bats.
- Fatality rates of both bats and birds were relatively low at short turbines (less than 65 m high), but bat fatalities increased exponentially with turbine height, while bird fatalities did not change.
- The highest bat-fatality rates occurred at turbines with towers 65 m or taller.

Conclusions: Increased rotor diameter and tower height of turbines may result in greater energy output per turbine, but these larger turbines have higher bat-fatality rates than bird-fatality rates.

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

This commentary proposes a hypothesis that tree bats collide with turbines while engaging in mating behaviors that center on the tallest trees in a landscape. The author further proposes that these behaviors occur because of two different mating systems: resource defense polygyny and lekking. Key points: Tree bats may use the highest trees in a landscape as rendezvous points during the mating period, and this behavior places them at risk of collision with the blades of wind turbines. Reproductive bats could be attracted to the turbines when looking for mating opportunities and mistake the turbines for the tallest trees. Male European tree bats have been observed defending roosting structures needed by females during the mating season (late summer and autumn). This mating strategy is called resource defense polygyny. However, tree bats in North America (species of *Lasiurus* or lasiurines) differ in roosting habits and behavior from European species because they roost alone or in small family groups in tree foliage during spring and early summer. Foliage roosts used by female lasiurines during fall migration are most likely abundant and not easily defended by male bats. Lekking is a mating system for species in which females range widely or resources (food or roost) are too finely distributed for males to defend. Lekking could explain why so many lasiurines are recovered in greater number and more frequently than any other species of bats killed by wind turbines in North America. An interesting characteristic of lekking that makes this high casualty rate among lasiurines plausible is that males tend to create dense aggregations during late summer and autumn to sites visited by females for mating. Conclusions: Research focused on hypotheses of attraction should be prioritized. If courtship and mating activities occur at wind turbines, turbines have the potential to create population sinks that attract bats from far away, and selectively kill bats that are primed for reproduction.

Cryan, P.M., 2011, Wind turbines as landscape impediments to the migratory connectivity of bats: Environmental Law, v. 41, p. 355–370.

This review summarizes bat mortality caused by wind turbines and the potentially significant effects of this mortality on certain bat populations. The article includes an overview of bat migration, discusses natural and human-caused mortality of migrating bats, provides background on bat fatalities at wind turbines, and highlights the importance of future innovative research.

Key points:

- Many species of temperate-zone bats migrate long distances; however, the details of their migratory movements and seasonal whereabouts are mostly lacking. This information is lacking for several reasons: (1) bats migrate at night; (2) they are inactive during the day; (3) they roost in concealed and frequently inaccessible locations; and, (4) there have been few recorded observations of actively migrating bats.
- Migration in bats most likely evolved in response to their distinctive thermoregulatory strategies and life histories. They mate during autumn and winter, and females often migrate in spring while they are pregnant, with some moving to habitats and regions of the continent separate from males during the early summer. Many species of bats can also drop their metabolism throughout the year and enter torpor to save energy when climate, weather, or food availability is unfavorable. Bats also have high rates of adult survival, resulting in longevity. Reproductive success is also high due to their putting considerable time and energy into taking care of a small number of young. These life-history strategies result in bat populations growing slowly and possessing an inability to quickly rebound after rapid declines in population size.
- Migration can be a perilous endeavor. Migrating bats may experience higher natural mortality than species that do not migrate.
- Collisions of migrating bats with buildings, communication towers, and aircraft have not been an obvious conservation issue in the past.
- Wind turbines are an emerging threat to bat migrations.
- Bat-fatality rates at wind turbines are variable across sites and regions in the United States. Fatality rates range from just below one bat per installed megawatt per year to as high as 70 bats per megawatt per year. Based on published fatality rates and the number of currently installed wind turbines, an estimated 450,000 bats may already perish at turbines each year in North America.
- Three species of migratory tree bats compose the majority of fatalities, and hoary bats compose about half of all documented fatalities in North America.
- Factors influencing fatality rates remain unclear, and studies at sites in North America have not found any consistent relationships between local landscape features and fatality rates, nor do we have a clear understanding of the regions or types of habitats where fatalities most likely occur. Therefore, it is not known yet how to identify and avoid high-risk sites for bats and wind energy. Most fatalities occur during a period of time that coincides with mating and autumn migration.
- Population sizes of migratory tree bats are unknown because of their cryptic habits and limitations in how their numbers can be estimated. Therefore, there is no way of assessing how quickly the current rates of bat fatality at turbines could cause catastrophic population declines and possible species extinctions. However, more hoary bats have been estimated to die at certain wind-energy facilities in

the United States in two to three years than have ever been collected and preserved as scientific study specimens in the museums of the Americas.

- Research on the proximate causes for bat fatalities at wind turbines is essential to help gauge the gravity of the situation and the need for conservation measures. Turbines may act as barriers to migration and disrupt necessary migratory connectivity. They may also act as population sinks and bottlenecks. Without knowing the exact reasons why bats are susceptible to turbines, scientists trying to find ways to minimize fatalities will continue to grope for solutions.
- None of the bat species most affected by wind energy are protected by federal conservation laws such as the Endangered Species Act (ESA). Neither are these bats protected by legislation pursuant to international treaties such as the Migratory Bird Treaty Act.
- Studies in Canada and the United States have independently shown that curtailment, or preventing turbine blades from turning during relatively low wind speeds in late-summer and autumn, can reduce bat fatalities by as much as 40 to 90 percent over the course of the studies.

Conclusion: The author concludes that a legal framework for proactively monitoring and protecting all migratory wildlife before their populations become endangered may be the type of foresight needed to help drive scientific advances. This may also allow us to better predict and deal with emerging threats to migratory wildlife.

Cryan, P.M., and Barclay, R.M.R., 2009, Causes of bat fatalities at wind turbines—Hypotheses and predictions: Journal of Mammalogy, v. 90, p. 1330–1340.

This synthesis reviews the hypothesized causes of bat fatalities at wind turbines. The hypotheses of cause fall into two categories: proximate and ultimate. Proximate causes explain the direct means by which bats die at turbines and include bats colliding with turbine towers, colliding with rotating blades, or suffering internal injuries after being exposed to rapid pressure changes near the trailing edges and tips of the moving blades (barotrauma). Hypotheses of ultimate causes are numerous and include three general categories: random collisions, coincidental collisions, and collisions that result because bats are attracted to turbines. Random collisions are those that occur due to chance alone or no assumptions of circumstance or attraction. Coincidental collisions involve bats being victims of unfortunate behavioral circumstances that put them at risk of colliding with turbines (for example, turbines are located along migratory pathways). Hypotheses of attraction propose that there is some attractor or combination of attractors drawing bats to wind turbines. Table 1 of this publication provides an overview of the hypotheses and their corresponding predictions. The authors conclude that the conservation implications of bat attraction to wind turbines are by far the most serious of the causes and suggest that testing the general hypotheses of attraction be a top research priority.

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

Little is known about the behavior of bats during migration and what aspects of this seasonal behavior make them particularly susceptible to mortality from wind turbines. Objective: to analyze a 38-yr data set of observations on hoary bats on Southeast Farallon Island to determine if moonlight and weather conditions influenced the occurrence of bats on the island. The authors also examined the temporal relationships of migration events involving hoary bats and similar species, and then related those findings to observed bat fatalities at wind turbines. Methods: This study took place at Southeast Farallon Island (SEFI), part of the Farallon National Wildlife Refuge. Personnel at the Point Reyes Bird

Observatory recorded daily observations from routine censuses of birds and marine mammals and recorded regular observations of hoary bats from as early as 1968. Logistic regression was used to model the influence of weather and moonlight on bat arrival to the island and bat departure from the island. To summarize the seasonal timing of known events involving migration by species of *Lasiurus*, the authors compiled records from the literature.

Key Findings:

- Bats were observed more frequently in September than any other month and usually visited the island between the last week of August and the end of October.
- For describing the arrivals of bats, the model that included wind speed, barometric pressure, cloud cover, and moon illumination ranked the best.
- The top-ranked model describing departures included only wind speed, cloud cover, and moonlight.
- Low wind speeds, moon illumination, and relatively high degrees of cloud cover were important predictors of both bat arrivals and departures, whereas low barometric pressure was an additional condition that helped predict arrivals.
- The majority of records compiled from the literature occurred on days between early September and late October, with a peak in mid-September.

Conclusions: The results from this study show that bats were more likely to arrive and depart from the island on evenings when wind speeds were relatively low. There was a predominance of hoary bat arrivals and departures on SEFI during darker phases of the moon and during overcast nights. There were five reasons this study's findings are relevant to the problem of bat fatalities at wind turbines: (1) arrivals of migrating tree bats at particular sites may be predictable events; (2) there is conclusive evidence that tree bats migrate over offshore waters, on which future construction of wind turbines has been proposed; (3) migratory hoary bats use vision to navigate during migration and are drawn toward visual stimuli; (4) there is a clear relationship between the timing of autumn migration by species of *Lasiurus* and collisions with anthropogenic structures; and, (5) there is a possible behavioral explanation for bat collisions with wind turbines.

Fiedler, J.K., 2004, Assessment of bat mortality and activity at Buffalo Mountain Windfarm, eastern Tennessee: Knoxville, Tenn., University of Tennessee, Unpublished Master's Thesis. 166 pp.

This thesis describes an investigation of bat mortality at Tennessee Valley Authority's Buffalo Mountain Windfarm (BMW) in eastern Tennessee. Objectives: (1) to document the extent of bat mortality at BMW and then examine the mortality for spatial, temporal, and species patterns; (2) to determine bat activity using bat detectors and mist netting; and, (3) to determine the relationships between bat activity and mortality. Methods: Mortality monitoring was conducted during a three-year period beginning late September 2000 and concluded the end of September 2003. Carcass searches were conducted twice weekly from April 1 through November 1. Logistic regression was used to identify possible explanatory variables to predict nights when a fatality event would likely occur. Explanatory variables included daily generation of the wind facility, average wind speed, average wind direction, average temperature, minimum and maximum temperature between 1800 and 0600 hours, and the difference between minimum and maximum temperature. Biases in searcher efficiency, proximity and density of scavengers in the area, and changes in vegetation structure were accounted for by conducting six search bias trials. Bat activity data were collected with mist-netting and acoustic monitoring (Anabat II detectors).

Key Findings:

- Over the course of the study, a total of 120 bat fatalities of six species were found.

- Seventy percent of bat fatalities occurred from August 1–September 15.
- An adjusted mortality rate of 20.82 bats/turbine/year was calculated for BMW.
- Eastern red bats (*Lasiurus borealis*) made up the majority of bat fatalities overall at 61.3 percent. Tricolored bats (*Perimyotis subflavus*) and hoary bats were the next two most common fatalities overall (22.4 percent and 10.1 percent, respectively). The remaining bat fatalities consisted of three species: big brown bats (*Eptesicus fuscus*), silver-haired bats, and one Seminole bat (*Lasiurus seminolus*).
- More males than females were killed.
- The peaks in bat mortality coincided with months of low winds and less wind-energy-facility generation.
- A fatality occurrence was more likely during slightly cooler nights with calmer, less variable winds.
- Searcher detection rates for carcasses was highly variable and ranged from 9 to 75 percent for the six trials.
- The average number of days a scavenged carcass remained onsite for the six trials ranged from 3.2 to 16.7 days.
- Thirteen possible scavenger species were identified, and 36 percent of planted carcasses were removed from the site before the search the next morning.
- Acoustical monitoring of bat activity showed that annual bat-activity levels were consistently greater during late summer and early fall than spring and summer.
- Bat activity near water was greater than away from water.
- On nights where fresh fatalities occurred, bat-activity levels were greater than on nights where no fatalities occurred.
- Turbine collisions of red bats and hoary bats were disproportionately greater than acoustical monitoring indicated at BMW.

Conclusions: Several biases may affect estimates of bat mortality rates at wind facilities. These include searcher efficiency, scavenging rates, search interval, background mortality rates, crippling bias, plot size, and seasonal vegetation cover. The author recommends that individual wind-energy facilities estimate these biases and their precision when calculating mortality rates, as both regional and site-specific variables can influence them.

Grodsky, S.M., 2010, Aspects of bird and bat mortality at a wind facility in southeastern Wisconsin—Impacts, relationships, and cause of death: Madison, Wis., University of Wisconsin, Unpublished Master's Thesis. 99 pp.

This thesis presents results of a post-construction study of bird and bat mortality at wind turbines at the Forward Energy Center in southeastern Wisconsin. The thesis consists of two chapters both intended to be submitted for publication in peer-reviewed journals. The first chapter describes a study assessing bird and bat mortality at a wind energy facility in southeastern Wisconsin. The second chapter investigates the cause of death for wind turbine-associated bat fatalities. The results of the second chapter are summarized in the publication following this thesis (see below), so this summary will describe the results of the first chapter only. Objectives: (1) to determine estimated mortality rates for birds and bats, both migratory and non-migratory; (2) to examine species composition of wildlife mortality; and, (3) to correlate variables associated with bird and bat mortality. Methods: This study took place in the fall from July 15–October 15, 2008 and 2009, and the spring from April 15–May 31, 2009 and 2010. Twenty-nine wind turbines were randomly selected and searched for fatalities using a stratified sampling technique. Searcher efficiency trials were conducted to estimate percentage of

carcasses not seen and recovered by individual searchers. Scavenger removal rates were estimated using removal trials. A mortality estimator was used that accounted for searcher efficiency, scavenger removal, search interval, density-weighted area searched, and visibility within search transects. Covariates included in the analysis were weather variables, turbine operating status, bat activity data from Anabat detectors, and distances to a nearby marsh and mine. A generalized linear mixed model was used to look at the relationship between bird and bat mortality and covariates.
Key Findings:

- A total of 20 birds were recorded during carcass searches, and the estimated bird-mortality rates averaged across all study periods were 0.0255 birds/turbine/day and 0.0170 birds/MW/day.
- Most bird species recorded as fatalities were nocturnally migrating passerines.
- A total of 122 bat carcasses were found (of five species).
- More than half of the bat mortalities were hoary bats and silver-haired bats. When eastern red bat carcasses were included, the migratory tree bats accounted for 69 percent of the bat mortality.
- Most bats were adults, and females outnumbered males.
- Averaged across all study periods, migratory bat mortality rates were 0.158 bats/turbine/day and 0.105 bats/MW/day. Non-migratory bat mortality rates were 0.0382 bats/turbine/day and 0.0255 bats/MW/day.
- Most bat mortality occurred from late August through the second week of September.
- Modeling suggested that temperature affected bat mortality significantly and distance to the marsh affected bat mortality marginally. All other covariates modeled did not influence bat mortality.
- Searcher detection rate was 38 percent for bats and 63 percent for birds.

Conclusions: The underlying trend to all current mortality studies in the Midwest is that there is significantly higher bat mortality rates compared to bird mortality rates.

Grodsky, S.M., Behr, M.J., Gendler, A., Drake, D., Dieterle, B.D., Rudd, R.J., and Walrath, N.L., 2011, Investigating the causes of death for wind turbine-associated bat fatalities: Journal of Mammalogy, v. 92, p. 917–925.

This study investigated the causes of death for wind-turbine-associated bat fatalities at the Forward Energy Center in southeastern Wisconsin. Objectives: (1) to use veterinary diagnostic procedures to determine the cause of lesions found on bats killed by wind turbines; (2) to correlate patterns of injuries with causes of death; and, (3) to create guidelines for future studies. Methods: Bat carcasses were collected July 15–October 15, 2009, using techniques described above in Grodsky (2010). Thirty-nine bat carcasses were radiographed and evaluated by a board-certified veterinary radiologist who was unaware of the postmortem findings. Data recorded included the location, number, and type (that is, fracture classification, dislocations) of skeletal injuries and any abdominal or diapharagmatic hernias. The thoracic cavity was examined for radiographic signs of pneumothorax (air in the thoracic cavity), hemothorax (blood in the thoracic cavity), chest wall trauma, atelectasis, or pleural fluid accumulation. Eighteen bat carcasses were also dropped off the top of the turbine nacelle 91.44 m above ground level to see whether bats could break bones from a free fall. These dropped bats were then radiographed and the same veterinary radiologist reviewed the radiographs. Bats were also necropsied, and histologic sections of the lung and middle ear tissues were made. All brain samples were also tested for rabies.
Key Findings:

- Of the 39 bats radiographed, at least one broken bone was detected in 74 percent of the bats. Fractures to the wing bones were the most common, and the majority of the fractures were comminuted (that is, shattered or crushed into many pieces). Fractures to the skull, scapula, lumbar vertebrae, ribs/sternum, and pelvis were the next most common injuries.

- Of the 18 bats dropped, no new bones were fractured in most of the bats postdrop (80 percent).
- Of 33 bats necropsied, the most common lesions found were pneumothorax and hemothorax. An equal mix of inguinal and diaphragmatic hernias was the next most common injury.
- Of the 28 bats processed for histopathology, 5 (21 percent) had no pulmonary hemorrhage, 3 (13 percent) had mild hemorrhages, and 8 (33 percent) had moderate and severe hemorrhages.
- Middle ears from 24 bats were sampled and 11 (48 percent) bats had no hemorrhage in middle ears or surrounding structures, 4 (17 percent) bats had middle ear hemorrhage, and 8 (35 percent) bats had hemorrhage in and around the middle or inner ears.
- All bats tested negative for rabies.
- Thirty-eight bat-carcass locations were measured relative to distance from base of the turbine. The majority of the bats (71 percent) were found within 30 m of the base of the turbine. The highest percentage of bats (29 percent) was found within 10 m of the base of the turbine.

Conclusions: The exact cause of death (that is, barotrauma or direct collision) could not be determined in most bats due to the variability of injuries and a lack of exclusively attributable lesions. The authors suggest that the cause of death for bats killed at wind turbines is not exclusively or predominantly barotrauma or direct collision but rather an indiscernible combination of both. Visually inspecting bat carcasses is not adequate for conclusively diagnosing fatal injuries, including broken bones. The authors conclude that there may be delayed lethal effects of wind turbines on bat mortality. Bats could become crippled by either inner ear damage or by bone fractures, but survive long enough to exit the search area of mortality studies.

Gruver, J.C., 2002, Assessment of bat community structure and roosting habitat preferences for the hoary bat (*Lasiurus cinereus*) near Foote Creek Rim, Wyoming: Laramie, Wyo., University of Wyoming, Unpublished Master's Thesis. 164 pp.

This thesis examined bat community structure and roosting habitat preferences for the hoary bat (*Lasiurus cinereus*) proximate to the Foote Creek Rim Wind Power Facility in south-central Wyoming. Objectives: (1) assess bat-community composition proximate to the wind-energy facility; and, (2) quantify roosting habitat for the hoary bat. Methods: Mist-netting surveys were conducted over streams and ponds, and acoustic surveys (Anabat II) were conducted on rim-top, over ponds surrounding the rim, and over streams and ponds on the Medicine Bow National Forest. Searches for carcasses were conducted on transects within 30×30-m plots centered on selected turbines on Foote Creek Rim. Proportions of bats recovered during carcass searches in 2000 and 2001 were compared to those captured in mist-nets during the same period using a Chi-square test. Radio-telemetry was used to track hoary bats to daytime roosts, and habitat surrounding known roosts was quantified and compared to habitat surrounding randomly selected sites.

Key Findings:

- Bats in the genus *Myotis* represented approximately 81 percent of all bats captured (*Myotis volans* and *M. lucifugus*) in mist nets.
- The hoary bat was the fourth most abundant species captured with mist nets.
- Bat activity on the rim was exceedingly low compared to sites off the rim.
- Acoustic surveys revealed similar proportions of each group of bats found in mist-netting surveys, indicating that the assemblage of bats in the study area was comprised primarily of *Myotis* species (*M. lucifugus* and *M. volans*).

- Carcass searches in 2001 found 22 hoary bats and one big brown bat (*Eptesicus fuscus*).
- Over 3 yr of searches, hoary bats represented the overwhelming majority of recovered bats.
- Bat mortality at wind turbines by species was disproportionate to the relative abundance determined by mist netting.
- Radio transmitters were attached to 14 adult hoary bats, 6 of which were never located. Eight individuals were tracked to 17 different roosts. Instrumented bats roosted primarily in live lodgepole pine trees, although two individuals were found in medium-sized understory deciduous shrubs.
- Hoary bats preferred trees that were taller, had more canopy cover, and were near water.

Conclusions: The author concludes this thesis by summarizing bat-turbine interactions. Deaths of bats at wind-energy facilities at the time of this thesis had only recently been reported and addressed. Records of turbine-related bat mortality were steadily increasing in the United States, and the cumulative results suggested two noteworthy trends: (1) most deaths are detected from late summer to early fall; and (2) bats in the genus *Lasiurus* (specifically *L. borealis* and *L. cinereus*) appear to represent the majority of recovered carcasses.

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

This study directly addresses the causal factors of why bat fatalities occur at wind-energy facilities. The authors carried out this study by using thermal infrared (TIR) cameras to monitor the activity of bats at the Mountaineer Wind Energy Center in West Virginia. Objectives: (1) to document how bats behaved while flying within the rotor-swept zone where there was potential for direct contact with turbine rotors; (2) to examine temporal patterns of activity and to determine if environmental variables such as wind speed and temperature were associated with variation in bat activity levels; and, (3) to compare activity levels between lighted and unlighted turbines at the facility and to test if aviation obstruction lighting mounted on turbines attracts bats (either directly, or indirectly through increased insect abundance). Methods: Three TIR cameras were mounted on tripods and were placed 0.5 m apart to form a single observation point. Real-time streams of radiometric data from each of the three cameras was captured using software and laptop computers. This observation station was placed near the base of wind turbines at dusk and was positioned as close to 30 m as possible from the base of each turbine. Three 9-hr video sequences were recorded nightly for 10 nights. To test the potential of aviation lighting on the turbines to attract bats, cameras were placed alternatively at randomly selected lighted and unlighted turbines for 5 nights each. Data were analyzed by manually observing playback of all video sequences in real time and recording the appearance and timing of flying objects.

Key Findings:

- For all cameras combined, 4,568 moving objects were observed: 1,810 were bats (39 percent), 872 insects (19 percent), 46 birds (1.0 percent), 5 aircraft (0.1 percent), and 1,835 unknown (40 percent).
- Most bat activity near wind turbines occurred in the first 2 hr after sunset.
- Among the flying bats, the altitude above ground level (AGL) was highly variable, with some individuals flying within 10 m AGL and others foraging at or above the height of the turbine nacelle (70 m AGL).
- The vast majority of bats observed were flying at the medium-altitude band (within the rotor-swept zone; 65.0 bats/night). This was greater than three times the number observed flying at low or high altitudes (22.7 and 11.2 bats/night, respectively).
- Aviation lighting did not appear to affect the incidence of foraging bats around turbines.

- Mean turbine RPM and insect abundance were the most significant predictors of the number of bat passes observed.
- Clear instances of bats avoiding turbine blades and of bats being directly struck by blades were recorded. From 998 total bat observations, avoidance was observed 41 times (4.1 percent). Direct contact with blades was seen 5 times (0.5 percent).
- Exploratory behavior of bats was observed; bats often made several check passes or made repeated flight loops near the moving blades.

Conclusions: The rate of mortality at the Mountaineer facility suggests that bats are more abundant near turbines, and this study provides evidence that collisions may be nonrandom interactions between bats and moving turbine blades. One of the most important observations from this study was that bats were observed actively investigating both moving and motionless turbine blades; this suggests that the bats may be attracted to the turbines as potential roosting trees. The authors suggest that this study has ramifications for mitigating bat fatalities at wind facilities. For example, curtailment operations could occur during predictable nights or periods of high bat kills and could reduce fatalities considerably, with potentially modest reduction in power production and associated economic impact on project operations.

Huso, M.M.P., 2010, An estimator of wildlife fatality from observed carcasses: Environmetrics, v. 22, p. 318–329.

This research article addresses the problems of estimating numbers of wildlife fatalities from observed carcasses. Objectives: (1) formalize the conceptual model of fatality and define relevant parameters to provide a unifying framework for discussion; (2) develop an estimator of fatality when probability of detection is less than 1; (3) evaluate the bias and precision of the estimator using simulation and examine its sensitivity to magnitude of parameters as well as to assumptions regarding distributions of parameters; and, (4) compare the bias and precision of this estimator with two other estimators in common use. Methods: Simulations were conducted and included four major components: (1) simulate the fatality process; (2) simulate the carcass persistence (CP) using three distributional assumptions; (3) simulate the search process, using six search intervals; and, (4) simulate the observation process using two distributional assumptions to produce simulated carcass counts. Recorded bat echolocation calls at proposed turbine locations in Casselman, Pennsylvania were used in the simulation.

Key Findings:

- The proposed fatality estimator accounts for searcher efficiency, scavenger removal, search interval, density-weighted area searched, and visibility within search transects.
- None of the three estimators compared were unbiased under all conditions.
- Bias in the proposed estimator never exceeded plus or minus 27 percent, whereas bias in the other two estimators was always negative and exceeded that of the proposed estimator in 98 percent and 93 percent of the simulated conditions, respectively.
- The proposed estimator was relatively robust to variation in sources and magnitudes of imperfect detectability, but was sensitive to distributional assumptions regarding carcass removal rates and searcher efficiency.
- The proposed estimator offers significant improvement over two current estimators and provides relatively unbiased estimates of fatality that can be applied under a variety of conditions and survey protocols.

Jain, A.A., Koford, R.R., Hancock, A.W., and Zenner, G.G., 2011, Bat mortality and activity at a northern Iowa wind resource area: American Midland Naturalist, v. 165, p. 185–200.

This study examined bat collision mortality, activity, and species composition at an 89-turbine wind-resource area in farmland of north-central Iowa from mid-April to mid-December, 2003, and mid-March to mid-December, 2004. Objectives: (1) estimate the number of bat fatalities due to turbine collisions; (2) compare bat echolocation activity between areas with wind turbines and adjacent crop fields; and, (3) describe any trends in bat activity and mortality related to seasonal, weather, and habitat-related factors. Methods: The study took place at Top of Iowa Wind Resource Area (WRA). Twenty-six of 89 wind turbines were searched for evidence of collision-induced mortality. A stratified, randomized design was used to sample turbines. Three-m wide, 76 m-long transects under the turbines were kept free of vegetation by using herbicides and manual weeding. The average total area searched under each turbine was 1,742 square meters (m^2), which was about 30 percent of the 5,776 m^2 search plot. Searches occurred every 2 to 3 days. Fatality estimates were adjusted for search probability, carcass retention while exposed to scavengers, search efficiency, and proportion of turbines searched. Search efficiency and scavenge rates were estimated using small birds, since bat carcasses were not available. Mortality was compared between turbines with three different types of FAA lighting. Bat activity was monitored with two Anabat II detectors at 14 of the 26 turbines. One detector was placed at the base of the turbine and another was placed at the edge of an adjacent field. Total passes recorded at turbines versus adjacent sites were analyzed using a paired t-test. Geographic Information System (GIS) was used to estimate the distance of the nearest woodlot to each turbine monitored. Bat activity at turbines with three different types of FAA lighting was also compared.
Key Findings:

- In 2003, 30 bat carcasses of 5 species were found (11 hoary, 9 little brown, 5 eastern red, 3 big brown, and 2 silver-haired bats). In 2004, 45 bats of 6 species were found (11 hoary, 13 eastern red, 8 little brown, 5 big brown, 7 silver-haired, and 1 eastern pipistrelle *sic* tri-colored bat).
- All bats were found from June to October in 2003 and from June to September in 2004.
- Eighty-three percent of the bat carcasses in 2003 and 67 percent in 2004 showed obvious signs of trauma with bone fractures and hemorrhaging.
- Two of the 19 carcasses in 2003 had internal thoracic hemorrhaging without other evidence of physical trauma (barotrauma), but there was no evidence of barotrauma in 2004.
- Adjusted estimates of bat mortality of Top of Iowa WRA were 396.05 plus or minus 71.71 (95 percent CI) bats (4.45 bats/turbine, 4.94 bats/MW) between April, 2003, and December 15, 2003, and 635.83 plus or minus 111.89 (95 percent CI) bats (7.14 bats/turbine, 7.94 bats/MW) between March 24, 2004, and December 15, 2004.
- No significant difference in bat mortality was observed between turbines with the three different types of FAA lighting.
- There was no significant difference between bat activity at turbine sites and adjacent crop fields without turbines in 2003 and 2004.
- There was no significant effect of distance to nearest woodlot on the number of bat calls recorded at turbines.
- No difference was found in bat activity at turbines with red blinking and non-blinking beacons.

Conclusions: The estimated mortality at this wind facility was higher than those of other wind facilities in the Midwest. Several factors were discussed that may cause bats to be susceptible to collision with wind turbines. These included local and regional habitat, population levels of bats, flight heights, weather and visibility conditions, turbine lighting, and use of the regions immediately around the turbines.

Jameson, J.W., 2010, Tall structure attraction and mortality at wind turbines of migratory tree bats in Manitoba Canada: Winnipeg, Manitoba, Canada, The University of Winnipeg, Unpublished Master's Thesis. 135 pp.

This thesis consists of four chapters: a general introduction, a chapter on testing the reproductive landmarks hypothesis, a chapter on factors influencing bat mortality at a wind-energy facility in central Canada, and a concluding chapter with recommendations. This summary focuses on Chapters 2 and 3.

Chapter 2 tests the reproductive landmarks hypothesis to explain mortality of bats at wind turbines. The "Reproductive Landmarks Hypothesis (RLH)" posits that bats may be attracted to tall structures during migration and that this attraction serves in finding mates. Objectives: (1) to confirm the attraction of migratory tree bats to turbines and to other tall anthropogenic structures; and, (2) to determine whether this attraction is associated with migratory and/or reproductive behavior. Methods: This study took place during the summer and fall of 2008 and 2009 at the St. Leon Wind Energy Project in south-central Manitoba, Canada. Bat activity was sampled at four groups of three habitat types: telecommunication service towers, open fields, and woodlots. Acoustic activity was monitored using Pettersson D240X time expansion bat detectors. Detectors were placed at 30 m on the towers. Generalized linear models were used to compare bat activity among habitat types and sites. Feeding activity (feeding buzzes) was also quantified and compared among habitat types using generalized linear models. Bat activity was also compared between ground level and 30 m communication towers. Mortality surveys were conducted at five wind turbines between July 6 and September 27, and bat mortality was correlated with bat activity at ground level and 30 m at communication towers. Carcass surveys were also conducted at communication towers.
Key Findings:

- In 2008, 4.8 percent of total bat passes were collected at open fields, 54.1 percent at woodlots, and 41.0 percent at communication towers.
- In 2008, 64.0 percent of passes were identified as silver-haired bats, 8.7 percent were hoary bats, 19.0 percent were eastern red bats, 7.2 percent were big brown bats, and 1.1 percent were little brown bats.
- In 2009, 9.6 percent of total bat passes were collected open fields, 45.1 percent at woodlots, 37.6 percent at communication towers, and 7.7 percent at wind turbines.
- In 2009, 64.1 percent of passes were identified as silver-haired bats, 24.1 percent were hoary bats, 8.1 percent were eastern red bats, 3.2 percent were big brown bats, and 0.65 percent were little brown bats.
- High levels of bat activity were recorded at communication towers during migration.
- Activity of silver-haired bats at communication towers during the pre-migration period was below activity levels at woodlots and equal to activity levels at open habitat—this is consistent with the second prediction of the RLH, that activity at towers would be relatively low during pre-migration, as it is at wind turbines. Hoary bat activity was also consistent with this prediction.
- There were fewer tree-bat passes and less variability in activity at turbines when compared to communication towers.
- Equal proportions of feeding buzzes were observed across all habitats—this does not support the hypothesis that tall structure attraction in bats is linked to foraging behavior.

Chapter 3 of this thesis examines the factors influencing bat mortality at the St. Leon Wind Energy Project. Objectives: (1) to see if night-to-night variation in bat mortality is correlated with weather patterns in the vicinity of the turbines; (2) to see if night-to-night variation in mortality is correlated with insect abundance in the vicinity of the turbines; (3) to see if night-to-night patterns in mortality are correlated with bat activity at turbines; and, (4) to see if vegetation at the base of turbines significantly influences the accuracy of fatality estimates. Methods: Carcass surveys were conducted for 31 days in 2008 and 79 days in 2009. Turbines were selected randomly and carcass searches were conducted by a team of two searchers. Searchers surveyed a 40-m-radius circular plot at the base of each turbine. Searcher efficiency tests were conducted using bat carcasses at mowed and non-mowed turbines. Scavenging trials were conducted at mowed turbines in 2009. An effective daily-fatality rate was calculated for each turbine. Weather variables, insect abundance, and acoustic-activity data were also collected and used as predictor variables for mortality using generalized linear models.
Key Findings:

- In 2008, 55 bat carcasses were recovered and 32.7 percent were silver-haired bats, 52.7 percent were hoary bats, and 9.1 percent were eastern red bats.
- In 2008, adjusted mortality rate over the study period was 11.5 plus or minus 4.9 bats/turbine (7.2 plus or minus 3.1 bats/MW) for silver-haired bats, 15.7 plus or minus 5.5 bats/turbine (9.9 plus or minus 3.4 bats/MW) for hoary bats, and 2.0 plus or minus 1.0 bats/turbine (1.2 plus or minus 0.6 bats/MW) for eastern red bats.
- In 2009, only 33 bat carcasses were recovered and 57.6 percent were silver-haired bats, 36.4 percent were hoary bats, and 6.1 percent were eastern red bats.
- In 2009, adjusted mortality estimates were 7.7 plus or minus 2.1 bats/turbine (4.6 plus or minus 1.3 bats/MW) for silver-haired bats, 5.8 plus or minus 2.1 bats/turbine (3.5 plus or minus 1.3 bats/MW) for hoary bats, and 1.1 plus or minus 0.8 bats/turbine (0.7 plus or minus 0.5 bats/MW) for eastern red bats.
- No weather variables measured were correlated with bat mortality in 2008.
- In 2009, mortality of silver-haired bats was highest on calm, cold, humid nights when insect abundance was low.
- A significant positive correlation was found between bat activity measured at ground level and mortality of silver-haired and hoary bats in 2009.
- Adult males dominated mortality numbers in 2008; however, in 2009, most mortalities were subadult silver-haired bats and adult female hoary bats.
- Fatality estimates were considerably less reliable when vegetation was high.

Conclusions: Although the author was not able to directly test if tree bats were mating at communication towers or turbines, the results from this study were consistent with the Reproductive Landmarks Hypothesis. The author concluded that this study showed evidence that tree bats exhibit an attraction to tall structures during fall migration, the same time of year that they are killed at wind turbines. Mortality of silver-haired bats was high on calm, cold, humid nights when insect abundance was low.

Johnson, G.D., 2005, A review of bat mortality at wind-energy developments in the United States: Bat Research News, v. 46, p. 45–49.

This review describes the patterns of bat mortality at wind-energy developments in the United States as of 2004. In 2004, wind-power capacity in the United States was 6,740 MW, or enough to supply electricity to over 1.6 million homes.

- Eleven of the 45 species of bats in North America were included among the fatalities at wind farms, although none of these were classified as threatened or endangered by the federal government.
- Most (83.2 percent) fatalities involved migratory tree bats. Hoary bats (*Lasiurus cinereus*) comprised 45.5 percent of the 1,440 bats identified to species. Eastern red bats (*L. borealis*) were 26.3 percent of the fatalities and silver-haired bats (*Lasionycteris noctivagans*), 11.4 percent. The remaining fatalities were tri-colored bats (formerly eastern pipistrelles; *Perimyotis subflavus*, 8.5 percent), little brown bats (*Myotis lucifugus*, 5.9 percent), and big brown bats (*Eptesicus fuscus*, 1.9 percent). Six northern long-eared bats (*Myotis septentrionalis*) and single specimens of the western red bat (*Lasiurus blossevillii*), Brazilian free-tailed bat (*Tadarida brasiliensis*), long-eared myotis (*Myotis evotis*), and Seminole bat (*Lasiurus seminolus*) were also found killed at U.S. wind farms.
- In the Upper Midwest (UM), hoary and eastern red bats comprised most fatalities, whereas eastern red bat, tricolored bats, and hoary bats were most commonly killed in the East. In the Pacific Northwest (PNW), equal numbers of hoary and silver-haired bats were killed, whereas most fatalities in the Rocky Mountain West (RMW) were hoary bats.
- Approximately 90 percent of fatalities occurred from mid-July through late September. Collisions were lower during the breeding season and during spring migration.
- As of 2004, 11 studies had been conducted in the United States to estimate fatality rates of bats at wind farms. Estimated fatality rates adjusted for searcher efficiency and scavenger removal were 1.2 bats/turbine in the PNW and RMW, 1.7 bats/turbine in the UM, and 46.3 bats/turbine in the East.
- Studies suggested that mortality rates were highest in forested environments, moderate in open areas close to forests, and lowest in open areas.
- Inclement weather did not appear to correlate with mortality of bats.
- Warning lights for airplanes that were placed on turbines did not increase fatalities.

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

This paper documents mortality of bats at a large-scale wind-power development at Buffalo Ridge, southwestern Minnesota, from 1996–1999. Objectives: (1) to estimate the number of bat mortalities attributable to collisions with wind turbines for the entire Buffalo Ridge wind-energy facility; (2) to determine the species and groups at highest risk; and, (3) to determine what factors may be related to collision mortality. There were three phases to this study and the phases were based on the installation of different types of turbines. Methods: Fatality searches were conducted at a select number of turbines during each phase of the project. Each turbine was searched every 14 days from March 15 to November 15 each study year. A 100-m×100-m square plot was centered around each turbine and variable transect widths were used based on visibility within each habitat type. Carcass-removal trials and searcher-efficiency trials were conducted to estimate the time that bat fatalities remained in the search area and to estimate a rate of searcher efficiency.

Key Findings:

- Of the 163 bat fatalities that could be identified to species, hoary bats (*Lasiurus cinereus*) comprised 66 percent, and eastern red bats (*L. borealis*) comprised 23 percent. The remaining fatalities were silver-haired bats (*Lasionycteris noctivagans*), tricolored bats (*Perimyotis subflavus*), little brown bats (*Myotis lucifugus*), and big brown bats (*Eptesicus fuscus*).
- Both the hoary and eastern red bat samples were primarily males.
- Ninety-seven percent of the fatalities occurred from July 15 to September 15.

- Injuries sustained by bats included fractured wings, legs and necks; head wounds; and abrasions and abdominal injuries.
- Bat fatalities were fairly widespread throughout the study area.
- Fifty-four percent of all bat carcasses were found less than or equal to 10 m from a turbine, 43 percent were found from 10 m to 20 m, 3 percent were found from 20 m to 30 m and one (0.5 percent) was found greater than 30 m from a turbine.
- The mean number of fatalities at lighted turbines was not significantly higher than the mean number of fatalities at unlit turbines.
- For all three phases of the study, 541 bat collision fatalities were estimated to occur each year.

Johnson, G.D., Perlik, M.K., Erickson, W.P., and Strickland, M.D., 2004, Bat activity, composition and collision mortality at a large wind facility in Minnesota: Wildlife Society Bulletin, v. 32, p. 1278–1288.

The authors investigated bat activity, composition, and collision mortality at the Buffalo Ridge wind farm in southwestern Minnesota from June 15 to September 15, 2001 and 2002. Objectives: (1) to estimate relative abundance and composition of bat populations in the study area; (2) to estimate the number of bat fatalities attributable to wind-energy-facility development; (3) to determine whether the mortality was occurring to resident breeders, migrants, or both; and, (4) to determine what physical (for example, turbine characteristics) and biological (for example, habitat) factors might be associated with bat collision mortality in the study area. Methods: Bat activity was monitored using Anabat II bat detectors at potential foraging and roosting sites within commuting distance of the wind-energy facilities. To monitor bat activity within the wind-energy facilities, detectors were placed at each of three turbines each survey night and selection of turbine locations were made using a systematic design with a random start and removed to different turbines each night. Mist-netting surveys were conducted in woodlands and over ponds and other wetlands within 3.6 kilometers (km) of the wind facilities to obtain data on bat-species composition in the study area. Fatality searches were conducted by searching for carcasses daily at the three turbines where the Anabat detectors were placed the previous night. This activity was performed to determine relationships between bat activity at turbines and collision mortality levels. Eighty (in 2001) and 100 (in 2002) additional turbines were selected for fatality searches using a systematic design and random start. Turbines were searched every 14 days throughout the study. Fatality estimates were adjusted for removal bias and searcher efficiency. Poisson regression models were used to investigate the relationship between bat activity and mortality levels and cover type within 100 m of the turbines, distance from each turbine to the nearest wetland and woodland, and presence of FAA lighting.
Key Findings:
- More bat activity was found at foraging and roosting areas than at turbines.
- Peak bat activity at turbines followed the same trend as mortality and occurred from mid-July through the end of August.
- Distance to woodland was the only landscape variable significantly related to bat activity, and bat activity decreased with increasing distance from woodlands.
- There was no significant difference between number of bat passes and whether turbines were lighted.
- There was no relationship between bat activity and bat mortality at turbines.
- Mist-netting surveys captured big brown bats (64), silver-haired bats (17), little brown bats (11), eastern red bats (8), and hoary bats (3).

- Fatality searches found 151 bat casualties during the study, including 115 hoary bats, 21 eastern red bats, 8 big brown bats, 4 silver-haired bats, and 3 little brown bats.
- Eighty-two percent of fatalities occurred during the period July 16–August 31.
- Bat collisions occurred during inclement weather as well as during clear weather.
- Mean number of bat fatalities did not differ between lighted and unlighted turbines.
- Estimated total bat mortality for both wind facilities combined was 849 in 2001 and 364 in 2002, which equates to an estimated mean of 3.02 fatalities/turbine in 2001 and 1.30 fatalities/turbine in 2002.

Conclusions: Mortality of bats at wind turbines does not appear to involve foraging bats. The peak in collision mortality corresponds to the period of post-breeding southward migration for hoary, eastern red, and silver-haired bats. Both Anabat and mist-net data indicate that relatively large breeding populations of bats were close to the wind facility when collision mortality was low to nonexistent.

Johnson, J.B., Gates, J.E., and Zegre, N.P., 2011a, Monitoring seasonal bat activity on a coastal barrier island in Maryland, USA: Environmental Monitoring and Assessment, v. 173, p. 685–699.

This study used acoustic monitoring to examine the seasonal bat activity on the Assateague Island National Seashore, a barrier island off the coast of Maryland, from 2005 to 2006. Objectives: (1) to establish seasonal bat activity patterns on Assateague; (2) to determine if bats use the barrier island during migration; and, (3) to determine if bat-activity patterns were correlated with weather conditions. Methods: Anabat II detectors were used to monitor bat echolocation passes at three bat-monitoring stations. The total number of bat passes was summed for each monitoring station as an index of bat activity. A time-series analysis was used to account for weather and to model nightly and seasonal bat passes. The time-series analysis accounted for autocorrelation. Generalized least squares was used to develop a predictive model of bat activity and to account for seasonal and climatic influences.

Key Findings:

- 39,384 bat passes were recorded from five species, including eastern red bats (59.33 percent of total bat passes), big brown bats (3.05 percent), hoary bats (0.10 percent), tricolored bats (0.10 percent), and silver-haired bats (0.07 percent).
- Bat passes generally increased beginning in April, peaked in August, and declined gradually until December, when relatively few passes were recorded.
- After accounting for seasonal trends and autocorrelation, all weather variables explained some residual variation in bat activity. However, the degree to which weather variables accounted for bat activity varied among the monitoring stations in terms of significance. Mean nightly temperatures consistently had a significant positive effect on bat activity, and mean nightly wind speeds consistently had a negative effect on bat activity.

Conclusions: This research concluded that bats migrate along the Atlantic coastline and use barrier islands, possibly for navigation or as stopover sites. This has implications for proposed offshore wind-energy facilities, in that bats migrating along the coast may collide with wind turbines. Wind turbines offshore may be attractive to bats as resting places or possible mating areas; this would increase the risk of bat mortality. Bats were less active during periods of low temperatures and high wind speeds, possibly above thresholds for wind turbine cut-in speed.

Johnson, J.S., Watrous, K.S., Giumarro, G.J., Peterson, T.S., Boyden, S.A., and Lacki, M.J., 2011b, Seasonal and geographic trends in acoustic detection of tree-roosting bats: Acta Chiropterologica, v. 13, p. 157–168.

This study examined seasonal and geographic trends in acoustic detection of migrating tree-roosting bats at 1 existing and 13 proposed wind-energy facilities in seven eastern states in the United States between April and November of 2007 and 2008. Hypotheses: (1) nightly detection rates of migratory tree-roosting species would peak earlier in the northeastern United States during fall migration and peak earlier in the mid-Atlantic United States during spring migration; (2) nightly species-specific detection rates would be correlated between surveys located in the same geographic region; and, (3) nightly species-specific detection rates would be correlated with nightly species mortality at the nearby wind energy facility. Methods: In 2007, acoustic bat surveys were conducted in Maine (2), New Hampshire (1), Pennsylvania (3), and West Virginia (1). In 2008, surveys were conducted in Maine (2), Vermont (1), New York (1), Pennsylvania (3), West Virginia (2), and Virginia (1). Each survey was placed into one of three geographic regions to allow for latitudinal comparisons: northeast (Maine, New Hampshire, and Vermont), northern Allegheny Plateau (southern New York and northern Pennsylvania), and mid-Atlantic (southern Pennsylvania, West Virginia, and Virginia). Anabat II detectors were used to record echolocating bats. Species-specific linear correlations were used to compare nightly silver-haired, hoary, and eastern red bat calls/detector/night between all possible pairs of survey locations within the same geographic regions. Nightly silver-haired, hoary, and eastern red bat calls/detector/night at two proposed sites in West Virginia were compared to the number of mortalities at Mount Storm Wind Energy Facility, also in West Virginia, using linear correlations.
Key Findings:

- Nightly detection rates of silver-haired and hoary bats at the two sites in West Virginia were positively correlated with the number of dead silver-haired and hoary bats at the Mount Storm Wind Energy Facility.
- No significant correlation was found between the eastern-red-bat detection rate and the mortality at Mount Storm Wind Energy Facility.
- Nightly detection rates of silver-haired, hoary, and eastern red bats during fall migration peaked earlier in the year in the two northernmost geographic regions compared to the mid-Atlantic region.
- Nightly detection rates of the three species during the spring migration peaked earlier in the year in the mid-Atlantic compared to geographic regions farther north.
- In all regions, eastern red bats were more frequently detected later in the year than were hoary bats.

Conclusion: The seasonal detection rates of hoary bats, silver-haired bats, and eastern red bats reflect their different migratory patterns, and these patterns may be useful in predicting the timing of mortality events at wind-energy facilities.

Klug, B.J., and Baerwald, E.F., 2010, Incidence and management of live and injured bats at wind-energy facilities: Journal of Wildlife Rehabilitation, v. 30, p. 11–16.

During studies of patterns and causes of bat fatalities at wind-energy facilities, the authors found numerous live and injured bats. Objectives: to examine the patterns of live-bat occurrences at three wind-energy facilities in southwestern Alberta, Canada, and to suggest methods for conducting searches at wind-energy facilities to increase the likelihood of finding live bats. Methods: Carcass searches were conducted at 40 turbines from July 15 through September 30, 2006, and at 42 turbines from July 15 through September 30, 2007. Two searchers used a spiral technique with a 45-m rope to search the base of turbines. If a live bat was found, it was immediately immobilized and transported to a vehicle for assessment and treatment. Bats were examined for obvious physical trauma such as hemorrhaging, broken or severed wings, and open lacerations. Bats were either euthanized if the injuries were deemed too severe or they were rehydrated and monitored for recovery if the injuries did not seem life-threatening.

Key Findings:

- Of 1,033 bats encountered during the two years of the study, 26 (2.5 percent) were alive.
- Significantly more live bats were found at turbines when searched daily than turbines searched weekly.
- Only eight of the live bats found had visible signs of skeletal damage or considerable soft tissue trauma.
- Injuries observed included wing fractures, wing amputation, leg fractures, and open abdominal wounds.
- Sixteen of the 26 live bats found were treated and 13 (81.3 percent) were successfully released.

Conclusions: Searching turbines daily results in the discovery of more live bats than does searching each turbine once per week. Dehydration appeared to be the immediate threat to survival for bats without severe injuries. The authors suggest that live and injured bats can be properly managed if personnel involved in fatality surveys at wind-energy facilities are authorized to handle live bats and are prepared to rehydrate suitable individuals and euthanize those with terminal injuries.

Klug, B.J., Turmelle, A.S., Ellison, J.A., Baerwald, E.F, and Barclay, R.M.R., 2011, Rabies prevalence in migratory tree-bats in Alberta and the influence of roosting ecology and sampling method on reported prevalence of rabies in bats: Journal of Wildlife Diseases, v. 47, p. 64–77.

This study examined rabies prevalence in hoary (*Lasiurus cinereus*) and silver-haired bats (*Lasionycteris noctivagans*) collected during mortality surveys at wind-energy facilities in southern Alberta, Canada, during 2007 and 2008. Objective: to estimate rabies prevalence in hoary and silver-haired bats obtained from carcasses collected at wind-energy facilities and compare this data to prevalence estimates reported in the literature. Methods: Bat carcasses were collected during mortality surveys conducted at three wind-energy facilities in 2007 and 2008 (see Baerwald and Barclay, 2009). When a bat carcass was discovered, it was identified to species, sexed, and aged. Carcasses were submitted for rabies diagnosis to the Centers for Disease Control and Prevention (CDC) in Atlanta, Georgia. A literature review was conducted on both peer-reviewed and government reports for reported rabies prevalence in bats in North America. Rabies rates were compiled for passive surveillance from public health records spanning the previous 56 yr, and were also obtained for active-surveillance estimates. Estimates of rabies prevalence from this study was compared to rabies prevalence in the literature using Chi-square or Fisher's exact tests.

Key Findings:

- Rabies testing yielded a single positive result from a total of 121 hoary bats and 96 silver-haired bats submitted for testing. The positive bat was a subadult silver-haired bat and was typed as the silver-haired bat variant.
- For both species, rabies prevalence was lower than the combined estimates of prevalence reported from passive surveillance.
- The prevalence estimates in this study did not differ from previous estimates for these two species based on active-surveillance studies.

- Rabies-prevalence estimates based on passive surveillance were higher than estimates from active surveillance across all bat species.
- Non-synanthropic bat species had higher rabies prevalence than synanthropic species.

Conclusions: Most previously reported rabies-prevalence estimates for hoary and silver-haired bats are overestimates due to a bias in sampling. Furthermore, high rabies-prevalence estimates in some bat species are partly due to a bias in sampling resulting from the difference in roosting ecology. The authors also point out that the influx of bat carcasses from wind facilities could have effects on the surrounding ecosystem by potentially increasing the risk of disease transmission to mammalian scavengers.

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

This paper synthesizes information on the impacts of wind-energy development on bats. The authors highlight ongoing development of wind-energy facilities in the United States, summarize evidence for bat fatalities at these sites, make projections of cumulative fatalities of bats for the Mid-Atlantic Highlands (Maryland, Pennsylvania, Virginia, and West Virginia), identify research needs to help reduce or mitigate adverse environmental impacts at these facilities, and propose hypotheses to evaluate where, when, how, and why bats are being killed.

Highlights:

- Since utility-scale wind turbines were first deployed in the United States in the 1980s, turbine height and the rotor-swept area has steadily increased with each new generation of turbines.
- Relatively small numbers of bat fatalities were reported at wind-energy facilities in the United States prior to 2001.
- Recent monitoring studies have indicated that some wind-energy facilities have killed large numbers of bats.
- Of the 45 species of bats found in North America, 11 have been identified during ground searches.
- Nearly 75 percent of carcasses found were foliage-roosting eastern red bats, hoary bats, and tree cavity-dwelling silver-haired bats, each of which migrate long distances.
- Number of bats killed in the eastern United States at wind-energy facilities installed along forested ridgetops has ranged from 15.3 to 41.1 bats/MW/yr. Bat fatalities reported from other regions of the western and mid-western United States have been lower, ranging from 0.8 to 8.6 bats/MW/yr.
- Most bat fatalities in North America have been reported in late summer and early autumn.
- Highest bat fatalities occur on nights when wind speed is low (less than 6 m s^{-1}).
- Bats are being struck and killed by the turning rotor blades of wind turbines; however, it is unclear why wind turbines are killing bats.
- Questions of why bats are killed at turbines include: Are bats attracted to wind turbines? Are bats attracted to sites that provide rich foraging habitats? Are bats attracted to the sounds produced by wind turbines? Do some weather conditions place bats at increased risk of being killed by turbines? Are bats at risk because they are unable to acoustically detect the moving rotor blades?
- The projected number of annual fatalities (rounded to the nearest 500) in the year 2020 range from 33,000 to 62,000 individuals, based on the National Renewable Energy Laboratory (NREL) WinDS model. Using the PJM (Pennsylvania, Jersey, Maryland Power Pool) grid operator interconnection

queue, the estimates of annual fatalities range from 59,000 to 111,000 bats. This breaks down to 9,500 to 32,000 hoary bats; 11,500 to 38,000 eastern red bats; and 1,500 to 6,000 silver-haired bats.

- There may be a substantial impact on both migratory and local bat populations; however, baseline population estimates and demographics are unknown for migratory tree bats.
- The authors propose 12 research directions in this paper and highlight that research should focus on regions and at sites with the greatest potential for adverse effects.
- The authors call for full cooperation and research support from the wind industry.
- Scientifically sound research and monitoring studies are needed to inform policy makers during the siting, permitting, and operation of renewable energy sources.

Kunz, T.H., Arnett, E.B., Cooper, B.M., Erickson, W.P., Larkin, R.P., Mabee, T., Morrison, M.L., Strickland, M.D., and Szewczak, J.M., 2007b, Assessing impacts of wind-energy development on nocturnally active birds and bats—A guidance document: Journal of Wildlife Management, v. 71, p. 2449–2486.

This publication complements and extends the National Wind Coordinating Committee document "Studying Wind Energy/Bird Interactions: A Guidance Document" (Anderson and others, 1999). The purpose of this document is to provide researchers, consultants, decision-makers, and other stakeholders with guidance to methods and metrics for investigating nocturnally active birds and bats in relation to utility-scale wind-energy development. The paper is organized with the following topics: (1) Limits of current knowledge about impacts of nocturnally active birds and bats; (2) Methods and metrics for observing nocturnal behavior of birds and bats; (3) Methods and metrics for collecting additional data on nocturnally active birds and bats; (4) Conducting pre- and post-construction monitoring; and, (5) Management implications. The authors emphasize that sampling protocols and methodology employed to quantify bird and bat mortalities must be rigorous and scientifically valid. Overall, these guidelines were developed to encourage efficient, cost-effective experimental designs that will result in comparable data.

Kuvlevsky, W.P., Jr., Brennan, L.A., Morrison, M.L., Boydston, K.K., Ballard, B.M., and Bryant, F.C., 2007, Wind energy development and wildlife conservation: challenges and opportunities: Journal of Wildlife Management, v. 71, p. 2487–2498.

This review paper examines wind-energy development and wildlife-conservation issues focusing on the Lower Gulf Coast (LGC) of Texas, a region identified as having potentially negative impacts on migratory birds and bats, with respect to wind-farm development. The authors summarize what is known about how wind-energy developments influence wildlife populations and identify specific research opportunities and management challenges that can help mitigate the potential negative effects of wind-energy development. An overview of bird-collision mortality and habitat loss is presented. Bird collisions range from 0 to greater than 30.0 collisions/turbine/year. This variability is due to numerous factors, including: inconsistent experimental designs and data-collection protocols, layout design of the wind farm, weather conditions, topography, and bird species and the numbers of birds using the site and their behavior. Habitat loss associated with wind energy-developments can be an even greater threat to bird populations than collision fatalities. An overview of bats and the impact of wind-farm development on their populations is presented. Other wildlife have the potential to be impacted by wind-energy developments (including other birds indirectly affected, mammals, and herpetofauna), because developments alter wildlife habitat. These alterations include habitat disturbance, construction of additional electrical transmission lines, and the development of extensive road networks. The authors conclude by highlighting the LGC region in Texas and its unique vegetation communities and topography. Three migratory bird flyways converge north of Corpus Christi, Texas. This flyway funnels tens of millions of migratory birds along the LGC each year. Wind farms would severely affect these migrating birds. In addition to birds, wind farms located in LGC could negatively impact resident and migratory bat populations, notably the migratory Mexican free-tailed bat (*Tadarida brasiliensis*). The authors conclude with a list of research needs and a discussion of experimental designs for investigating wildlife and wind energy interactions. Several management recommendations are provided: (1) develop guidelines to assist wind developers in how best to site their projects; (2) provide a place to house the compiled data from all wind developments in each state; and, (3) provide incentives for the developers to avoid high-risk areas within each state, and if these high-risk areas cannot be avoided, provide ways to offset or mitigate the effects of developing in high-risk areas.

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

Small, night-migrating birds have been used as surrogates for bats when formulating hypotheses and suggesting research techniques for investigating migration patterns, but the appropriateness of this surrogacy is unknown. This purpose of this paper is to provide bat biologists with information on aspects of bird migration that might be useful in designing research on bat migration and wind-energy interactions with bats. Techniques for studying migration include searching for killed animals beneath tall structures, analyzing DNA and other chemical clues, making observations at night with optical instruments and radar, and banding bats. The author proceeds to describe the process of bird migration as it might pertain to bat migration. Based on ornithological data, bats would not be expected to fly in narrow corridors over level terrain or large bodies of water. However, when encountering mountains, some nocturnal migrants alter their course to fly along valleys and ridges, where winds and topography interact. There is enormous temporal variability in migration patterns for birds, and this should also apply to bats; studies on migration should not be short-term. There is also variability in the heights at which birds migrate. The height of bats engaged in long-distance migratory flight is also critical to understanding risks to mortality from wind turbines. Migrating bats may select narrowly defined height bands for favorable winds, and turbine blades may cut the air progressively above, at, or below this band. The author concludes by stating that biologists have been studying bird migration for many years and much of what is known may be useful in understanding the process of migration in bats (however, see Willis and others, 2010).

Miller, A., 2008, Patterns of avian and bat mortality at a utility-scaled wind farm on the southern High Plains: Lubbock, Tex., Texas Tech University, Unpublished Master's Thesis. 113 pp.

This thesis examines the patterns of avian and bat mortality at a utility-scaled wind farm at the Red Canyon Wind Energy Center in the southern portion of the Texas Panhandle. Chapter 1 provides a general introduction to wind-energy development and its effects on birds and bats. Chapter 2 looks at avian mortality patterns. Chapter 3 examines bat mortality patterns. This summary focuses on Chapter 3. Objectives: (1) assess the incidence and frequency of bat mortality; (2) model mortality rates; and, (3) identify the spatial and temporal distribution of bat mortality within the wind-energy development. Methods: Standardized carcass searches were conducted for 52 weeks, beginning in September 2006, on 28 of the 56 turbines. Bias corrections were made by conducting searcher efficiency and carcass-removal trials. Bias-correction trials were conducted seasonally to account for differences in vegetation and scavenger-predator characteristics. Spatial and temporal analyses were conducted using Poisson models.

Key Findings:

- During the study period, 56 bat mortalities were found.
- Brazilian free-tailed bats composed 94 percent of fatalities, hoary bats 4 percent, and red bats 2 percent.
- Mortalities were found beneath 24 of the 28 searched turbines.
- Peak mortality detections occurred in October.
- For Brazilian free-tailed bats, 41 percent of fatalities were adults, 43 percent were juveniles, and 16 percent unidentifiable to age. Fifty-three percent were male, 10 percent were female, and 37 percent were unidentifiable to sex.
- For hoary bats, 40 percent were adults, 40 percent were juveniles, and 20 percent were unidentifiable to age. Sixty percent were male, 20 percent female, and 20 percent were unidentifiable to sex.
- Turbines were classified as low, medium, and high mortality. Low-mortality turbines were estimated to kill 15.29 bats/MW. Medium-mortality turbines were estimated to kill 45 bats/MW, and high-mortality turbines were estimated to kill 106.67 bats/MW.
- Total mortality was estimated for the entire wind energy development as 36.87 bats/MW.

Conclusions: Bat mortality at this site was above the reported average bat mortality rate reported for new-generation wind projects in the United States (2.1 mortalities per MW per year). This is one of the first post-construction mortality monitoring studies conducted on wind energy development in Texas and the southwestern United States.

Osborn, R.G., Higgins, K.F., Dieter, C.D., and Usgaard, R.E., 1996, Bat collisions with wind turbines in southwestern Minnesota: Bat Research news, v. 37, p. 105-108.

Prior to this study, most studies on the biological effects of wind energy were designed to assess effects on birds. Bat collisions with turbines appeared to be infrequent and had therefore received little attention by natural-resource agencies or the scientific community. While conducting a study to assess the impacts of wind energy on birds in southwestern Minnesota, the authors found several bats. Objectives: (1) to document the species composition and timing of bat mortality associated with the Minnesota wind facility during 1994 and 1995; and, (2) to review some current theories regarding bat collisions with anthropogenic structures and to speculate on the possible causes of bat mortality at wind turbines. Methods: Buffalo Ridge Wind Resource Area (WRA) was searched for wildlife carcasses from April 1994 through December 1995. Search intensity varied by season: during spring and fall, all 73 turbine plots were searched once per week; however, during summer and winter, only 30 plots were searched once per week.

Key Findings:

- During 20 months of continuous monitoring, 13 bat carcasses were found, representing 5 species.
- Five of the carcasses found were hoary bats, four were silver-haired bats, two were eastern red bats, and one each of a big brown bat and a tricolored bat.
- Carcass-recovery dates ranged from May 12 to September 22. One collision (8 percent of total) occurred in spring, 11 (85 percent) during the summer, and one (8 percent) on the first day of fall.

- Six of the 13 bat carcasses (46 percent) were found within 15 m of turbines, and 69 percent were found within 20 m.
- On September 13, 1995, a tricolored bat carcass was found, extending the known range of this bat approximately 160 km farther west in Minnesota.

Conclusions: The timing of bat-carcass recovery at Buffalo Ridge WRA suggests that bats are susceptible to collisions with anthropogenic structures at times other than during migration. The findings from this study represent the first evidence of frequent bat collisions with wind turbines.

Piorkowski, M.D., and O'Connell, T.J., 2010, Spatial pattern of summer bat mortality from collisions with wind turbines in mixed-grass prairie: American Midland Naturalist, v. 164, p. 260–269.

This study examined the spatial pattern of summer bat mortality from collisions with wind turbines in the southern Great Plains, Oklahoma, during May–July, 2004 and 2005. The authors proposed to test the hypothesis that collision mortality was randomly distributed among the 68 wind turbines at the Oklahoma Wind Energy Center (OWEC). Objectives: (1) to estimate a summer-season, per-turbine rate of bat collision mortality; and, (2) to analyze the spatial distribution of collisions at the OWEC relative to vegetation cover, topography, and location of individual turbines. Methods: The bases of all 68 turbines were visually inspected for bird and bat carcasses in 2004 and 2005. Surveys occurred in late May and late June in 2004 and every 2 weeks from May 15–July 15 in 2005. Circular transects were walked around the base of each turbine at 5, 10, and 15 m from the base. An observer-detection rate was estimated in 2005 with blind field trials and models built to approximate free-tailed bats. Three estimates of mortality were calculated based on (1) raw carcass counts, (2) raw counts divided by observer-detection rate, and (3) raw counts modified by observer-detection rate and removal rate. Broad spatial distribution of mortalities were plotted using GIS, and "hotspot" analyses were conducted for fine-scale spatial distribution patterns.

Key Findings:

- Eleven turbine-killed birds of six species and 111 turbine-killed bats of seven species were found.
- First documented cave myotis (*Myotis velifer*) killed by a wind turbine.
- The majority of bat carcasses (94) were Brazilian free-tailed bats (*Tadarida brasiliensis*) representing 78 percent of all fatalities and 85 percent of all bat fatalities.
- Examination of 64 (58 percent) relatively fresh and intact bat carcasses indicated a female-biased sex ratio.
- Raw carcass counts yielded estimates of 0.53/fatalities/MW in 2004 and 0.56 fatalities/MW in 2005.
- For Brazilian free-tailed bats, rates adjusted for probability of detection and incorporating published removal estimates yielded 74–92 individuals (0.73–0.90/MW) in 2004 and 67–85 (0.66–0.83/MW) in 2005.
- Carcasses were detected up to 46 m from turbine bases; however, 77 percent were located within a 20-m search radius.
- Brazilian free-tailed bat mortality was not associated with topography or habitat when both years of the study were combined.
- Three turbines emerged as significant "hot spots" of collision mortality. These three turbines were located near the head of a forested ravine cut by an intermittent tributary to the Cimarron River. The three turbines were less than 5 percent of the turbines at OWEC, but they accounted for 16 percent of the Brazilian free-tailed bat carcasses collected during both years.

- Seventeen individuals were necropsied; 14 specimens had broken bones and 3 had no apparent skeletal injury. In the bats with no sign of injury, no obvious visceral hemorrhaging was observed potentially consistent with barotrauma.

Conclusions: The results from this study provide some of the first evidence for a steady rate of collision mortality of Brazilian free-tailed bats at a North American wind farm, most likely due to the site's proximity (roughly 15 km) to both a maternity colony and a bachelor colony. Authors rejected their original hypothesis of random collision mortality among the 68 turbines at OWEC. The cluster of three turbines emerged as a hotspot of collision mortality. This suggests that bats moving through this area were either more susceptible to collision or that the number of bats moving through the area was greater than at other areas of OWEC. They concluded that this provided support for the "coincidental collision" hypothesis of Cryan and Barclay (2009). If monitoring pointed to particular turbines as hotspots for mortality, then mitigating management (for example, curtailment of those specific units under specific conditions) could be developed.

Reynolds, D.S., 2006, Monitoring the potential impact of a wind development site on bats in the northeast: Journal of Wildlife Management, v. 70, p. 1219–1227.

This paper investigated spatial and temporal patterns of bat activity across a proposed wind-energy project site during the summer breeding season and the migratory season in the Tug Hill Plateau region of western New York. Hypotheses: (1) the physiogeography of the site would limit the species diversity and total bat abundance at the project site; (2) the bat community would be shifted towards species that are more commonly found at higher elevation (for example, hoary and silver-haired bats); and, (3) the climate of the project site would shift the sex ratio of the bat community towards males that were not as energy limited as reproductive females during the summer months. Methods: The study area was the Maple Ridge Wind Project, a 198-turbine project that began construction in August, 2005. Summer activity was sampled with mist netting and acoustical monitoring (Anabat II) in 2004. Migratory activity was sampled using acoustic monitoring during spring 2005, at two locations. Meteorological data was collected by the Maple Ridge wind-development group. Summer activity was analyzed using a 2-factor general linear model. Temporal patterns of bat activity during the spring migratory sampling period using a 3-factor general linear model.

Key Findings:

- Mist-netting was conducted at 24 sites and 35 bats of 3 species were captured. Northern long-eared bat (*Myotis septentrionalis*, 17), little brown bat (*M. lucifugus*, 15), and big brown bat (*Eptesicus fuscus*, 3).
- Summer acoustic sampling found that activity levels were highly skewed across sample sites.
- Bat activity was significantly influenced by habitat, with ponds being the only habitat showing preferential use by bats.
- Bats of the genus *Myotis* accounted for almost 95.7 percent of all bat calls and 98.8 percent of all feeding buzzes.
- Acoustic monitoring during the spring migratory period revealed a median activity level of 2.0 bats/night.
- On 20 April, 101 bat passes of the tricolored bat (*Perimyotis subflavus*) were recorded and on the 10 June, 115 bat passes of the hoary bat (*Lasiurus cinereus*) were recorded.
- Most of the migratory activity occurred at minimum wind speeds below 1.3 m/s.

- Temperature appeared to have a strong influence on migratory bat activity. Days with high migratory bat activity had a mean maximum temperature of 23.9 plus or minus 4.4°C compared to 9.8 plus or minus 4.8°C.

Conclusions: The results of this study strongly suggest that the Tug Hill Plateau region does not support a large bat population in terms of either species diversity or total bat abundance. Most of the bat migratory activity occurred when daily mean wind speeds were below 5.4 m/s. This is encouragingly close to the cut-in speed (the lowest economically useable wind speed) of a typical commercial wind turbine. (This study did not sample fall migration.)

Rollins, K.E., Meyerholz, D.K., Johnson, G.D., Capparella, A.P., and Loew, S.S., 2012, A forensic investigation into the etiology of bat mortality at a wind farm—Barotrauma or traumatic injury?: Veterinary Pathology, accessed February 14, 2012, *http://vet.sagepub.com/content/2012/01/30/0300985812436745*. [published online January 30, 2012]

The authors in this paper studied the causes of bat mortality at a central Illinois wind-energy facility compared to bat mortality from collisions with buildings in Chicago, Illinois (Ill.). They designed a 2-part forensic investigation to examine two competing hypotheses for the mortality of bats at turbines: (1) blunt force trauma from being struck by moving turbine blades and (2) barotrauma. Objectives: (1) to test whether postmortem decomposition and environmental conditions would influence the development of morphologic artifacts of pulmonary barotrauma using laboratory mice; and, (2) to examine salvaged bats collected from a wind-energy facility compared with a control group of bats that had died following collisions with buildings. Methods: The authors conducted two experiments. The first experiment used laboratory mice and performed a decomposition trial, an elevated temperature trial, and a freezing trial. After each trial, lungs, heart, and trachea were removed from each mouse and fixed for routine processing and staining. Lungs were examined for signs of vascular congestion, erythrocyte extravasation, and edema, and for each parameter, samples were scored for extent of damage. The second experiment examined 53 bats salvaged near buildings in downtown Chicago, Ill., and compared these with 262 bats salvaged from the wind-energy facility. Both bats killed by buildings and bats killed at the wind-energy facility were radio-graphically examined for bone lesions consistent with traumatic injury. Additionally, 66 of the 262 bats from the wind-energy facility were necropsied and examined for supplemental lesions consistent with trauma. All bats killed by buildings were assessed for external lacerations, but were not available for full necropsies. A subset of each group of bats was also examined for evidence of auditory barotrauma.

Key Findings:

- Decomposition caused changes in vascular congestion, erythrocyte extravasation, and edema in murine lungs. Vascular congestion scores increased 2 hr postmortem, edema scores increased after 24 hr, and erythrocyte extravasation scores increased after 72 hr.
- Elevated temperatures (33°C) accelerated postmortem morphologic changes in mice.
- Freezing and freezing/thawing trials increased erythrocyte extravasation and edema compared to fresh lung tissue.
- Bone fractures were detected in 9 of 53 (17 percent) building-killed bats, whereas 152 of 262 (58 percent) turbine-killed bats had bone fractures.
- Among bats without fractures, turbine-killed bats had significantly more cases with external lacerations than building-killed bats.
- Only one (1 of 42; 2 percent) building-killed bat showed evidence of tympana (ear drum) rupture, whereas 11 of 81 (14 percent) of turbine-killed bats showed evidence of ruptured tympana.

However, only 5 of 81 (6 percent) of the bats with tympana ruptures had no detectable evidence of traumatic injury; this suggests that a small fraction of turbine-killed bats had lesions possibly consistent with barotrauma.

Conclusions: Determining the causes of lung damage from salvaged bats can be confounded by common postmortem artifacts (for example, decomposition, temperature differences) as well as the competing hypothesized causes of traumatic injury (for example, blunt force trauma, barotrauma, laceration). Because these competing factors cannot be confidently excluded during a pathological examination, pulmonary barotrauma should not be diagnosed from salvaged bat carcasses unless assessments are also made for ruptured ear drums. The authors conclude that their results point to a need for improvements in the current monitoring procedures at wind-energy facilities and in the experimental approaches used to determine whether barotrauma or other causes contribute to bat mortality.

Smallwood, K.S., and Karas, B., 2009, Avian and bat fatality rates at old-generation and repowered wind turbines in California: Journal of Wildlife Management, v. 73, p. 1062–1071.

This study examined avian- and bat-fatality rates at old-generation and repowered wind turbines at Altamont Pass Wind Resource Area (APWRA) in California. The APWRA began operations during the 1980s and until recently was the world's largest wind farm. In 1998, the APWRA comprised about 5,400 wind turbines of various models. In 2005, 126 turbines were replaced with 31 horizontal-axis wind turbines. The new turbines were more widely spaced and operated at a lower rotor speed, which were traits thought by some to be safer for birds. Objectives: to compare estimates of fatality rates between (1) the periods 1998–2003 and 2005–2007; and, (2) a repowered wind project and the concurrently operating old-generation wind turbines. Methods: Fatality searches were performed at selections of turbines. Searches were performed by walking parallel transects about 4–8 m apart. Fatality rates were adjusted for carcasses not found due to searcher-detection error and for scavenger removal. Bat–fatality rates were estimated by applying scavenger-removal and searcher-detection rates estimated for small-bodied bird species. Therefore, estimates of bat–fatality rates were likely biased low.

Key Findings:

- For APWRA-wide fatality rates, between 1998–2003 and 20052007, estimated mean adjusted fatality rate increased 23 percent for all birds combined.
- Comparing only adjusted fatality rates from old-generation turbines mutually monitored both 1998–2003 and 2005–2007, fatality rates increased 51 percent for all birds combined.
- The first repowering project in the APWRA did not change fatality rates for any species or group of specie, because fatality rates did not differ between the old vertical-axis turbines and the new horizontal-axis turbines.
- The adjusted fatality rate of bats increased from zero at the old vertical-axis turbines to 16.4/yr at the new, repowered turbines, but this difference was not significant, probably due to small sample sizes.
- Compared to the concurrently operating old-generation turbines during 2005–2007, adjusted fatality rates in the repowered turbines were 66 percent lower for all birds combined.
- The adjusted fatality rate of bats was nearly 800 percent greater at repowered turbines compared to the concurrently operated old-generation turbines, but this large difference was not significant, probably due to sample sizes.

Conclusions: Repowering the entire APWRA would likely reduce fatality rates a great deal for birds, especially if considered on a power-generation basis and if carefully done by locating new turbines where they pose the least hazard. A possible downside to repowering, however, may be increased bat fatalities caused by wind turbines. Extrapolating the mean adjusted bat-fatality rate from the repowered turbines to a completely repowered APWRA, about 454 bat fatalities/year might result, but using more realistic scavenger-removal and searcher-detection rates could increase this number to the thousands of bats. More research is needed to address bat fatalities at the APWRA.

Sovacool, B.K., 2009, Contextualizing avian mortality—A preliminary appraisal of bird and bat fatalities from wind, fossil-fuel, and nuclear electricity: Energy Policy, v. 37, p. 2241–2248.

This article examines the threats that wind farms pose to birds (and bats) when compared to threats from fossil-fuel and nuclear electricity. The authors conducted a survey of 600 studies, articles, and reports investigating avian deaths and wind farms published from 1998 to 2008. The authors address three common problems with these studies: (1) they rarely compare their results with studies of other wind farms to contextualize their estimates; (2) most do not compare the possible avian deaths from wind electricity with other sources, and when they do, studies typically do not compare them to other energy sources; and, (3) no studies attempted to calculate the number of avian deaths per kilowatt-hour from energy sources, so that more meaningful comparisons might be made between different forms of electricity supply. To address these shortcomings, the author assessed and compared the avian deaths per GWh from three electricity systems: wind farms, fossil-fueled power plants (coal, natural gas, and oil generators), and nuclear plants. Averaged over six wind farms, 339 turbines were responsible for 0.279 avian deaths per GWh. The assessment of avian mortality for fossil-fuel power plants was estimated to be 5.18 fatalities per GWh. Finally, the total avian deaths per GWh for nuclear power plants was estimated to be about 0.416. The author concludes that for wind turbines, the risk appears to be greater to birds striking towers or turbine blades and for bats suffering barotrauma. For fossil-fueled power stations, the most significant fatalities come from climate change, which is altering weather patterns and destroying habitats that birds depend on. For nuclear power plants, the risk is almost equally spread across hazardous pollution at uranium mine sites and collisions with draft cooling structures. Fossil-fueled facilities are about 17 times more dangerous to birds on a per GWh basis than wind and nuclear power stations, according to the author. Putting this in absolute terms, wind turbines may have killed about 7,000 birds in 2006 but fossil-fueled stations killed 14.5 million and nuclear power plants 327,000. Far more detailed, rigorous, and sophisticated analyses are called for in the future. This preliminary study has quite a few shortcomings that are further discussed by the author. [The author lumped birds and bats together for this analysis. Also note that Willis and others (2010) disputes the methods and findings of this paper.]

Weller, T.J., and Baldwin, J.A., 2011, Using echolocation monitoring to model bat occupancy and inform mitigations at wind-energy facilities: Journal of Wildlife Management, v. 9999, p. 1–13, accessed January 23, 2012, at *http://www.fs.fed.us/psw/publications/weller/psw_2011_weller001.pdf*.

This research article combines results of continuous echolocation and meteorological monitoring at multiple stations to model the conditions that explain the presence of migratory bats at a wind-energy facility in southern California. Objectives: (1) to characterize year-round patterns of bat activity at a wind-energy facility in southern California; (2) to determine survey effort necessary to characterize bat-activity levels at the facility; (3) to model bat presence on-site with respect to date and meteorological conditions; and, (4) to determine whether incorporation of a full suite of meteorological conditions could improve predictions of bat presence. Methods: This study took place at the Dillon Wind Energy Facility (DWEF) near Palm Springs, California. This site is within the San Gorgonio Pass Wind

Resource Area, one of the oldest and largest wind-energy developments in the world. Bat activity was monitored using Anabat II detectors attached to four meteorological towers at three different heights (2 m, 22 m, and 52 m above the ground). Detectors were operated nightly for 17 months from October 25, 2007 through March 31, 2009. Bat passes were classified as either "LowF" or "HiF." Most migratory species of bats use LowF echolocation calls. Site-occupancy models were used to estimate the probability of LowF bat presence on a given night. Presence and detection probability was estimated as a function of detector height, mean nightly wind speed, wind direction, temperature, and proportion of moon illumination.

Key Findings:

- Overall LowF bat-passes rates increased with detector height from 2 m [0.14 bat passes/detector night (dn)] to 22 m (0.26 bat passes/dn), and 52 m (0.43 bat passes/dn).
- Passes of LowF bats comprised 49.2 percent, 83.6 percent, and 98.5 percent of bat passes recorded at 2 m, 22 m, and 98.5 m, respectively.
- Detection probabilities ranged from 0.027 (SE = 0.014) at 2 m to 0.564 (SE = 0.032) at 52 m.
- Mean wind speed had the highest relative importance for predicting LowF bat activity in all but 2 time periods.
- Mean nightly wind speeds were lower on nights when LowF bat passes were recorded than on nights when they were not in all time periods.
- Proportion of moon illumination was important for predicting bat activity in 4 time periods.

Conclusions: Despite low overall bat-activity levels, the authors were able to build models that successfully predicted conditions when LowF bats were present. The models developed confirmed results from wind-energy developments in other regions and habitats which have demonstrated that bat activity is generally higher at lower wind speeds and higher temperatures. The results also highlight the importance of modeling conditions that explain bat activity on a seasonal basis. There were marked differences in activity levels seasonally, and the relative importance of explanatory variables also differed seasonally. The authors conclude that using this model-based approach could improve the effectiveness and efficiency of mitigations for bat fatalities at wind-energy facilities. If properly conducted, echolocation monitoring may provide a reliable index to expected bat fatality levels at wind-energy facilities.

Willis, C.K.R., Barclay, R.M.R., Boyles, J.G., Brigham, R.M., Brack, V.B., Jr., Waldien, D.L., and Reichard, J., 2010, Bats are not birds and other problems with Sovacool's (2009) analysis of animal fatalities due to electricity generation: Energy Policy, v. 38, p. 2067–2069.

This forum paper is a response to Sovacool's (2009) comparison of North American bird (avian) and, presumably bat (chiropteran) mortality resulting from three methods of electricity generation. Although bats figure prominently in the title of Sovacool's paper, the text is virtually devoid of data on bats. The authors of this response point out that bats are not birds. Bats occupy an entirely different ecological niche than almost all birds, since bats are the primary consumer of night-flying insects. It has become increasingly clear that, in general, mortality at wind turbines is an issue that affects bats more than birds, and it is bats that face the most widespread and worrisome species-level conservation consequence from wind turbines. Bats investigate wind turbines; birds do not. Migrating bats appear to be attracted to wind turbines, and there is little evidence that birds are attracted. Bats are also prone to depressurization injuries (barotraumas) at turbines, to which birds are less susceptible. Sovacool's (2009) estimate of the average number of birds killed per GWh of wind power is incorrect and omits a large body of easily accessible, published data. Sovacool also states that death rates of all flying animals from wind turbines have decreased in recent years; however, this is not true for bats. There is clear evidence that, as turbines have become taller, bat mortality has increased. Sovacool also implies that pre-construction monitoring and mitigation at proposed wind-energy sites reduce the risk of mortality for birds and bats, which is simply not true for bats. Sovacool reviewed 600 sources, but failed to reference the primary literature on bat fatalities at wind turbines. The authors of this forum paper conclude by pointing out that Sovacool advocates averaging data across many species, large areas, and long time periods to estimate the total number of animals killed by three different electricity systems. This approach fails to address the importance of spatial and temporal variation when contextualizing the conservation implications of different electricity systems. Sovacool's conclusions are based on fundamental errors and could influence energy policy in ways that are counter-productive for the wind energy industry and the conservation of both groups of flying vertebrates: birds as well as bats.

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