Wind energy development: methods for assessing risks to birds and bats pre-construction

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Abstract: Wind power generation is rapidly expanding. Although wind power is a low-carbon source of energy, it can impact negatively birds and bats, either directly through fatality or indirectly by displacement or habitat loss. Pre-construction risk assessment at wind facilities within the United States is usually required only on public lands. When conducted, it generally involves a 3-tier process, with each step leading to more detailed and rigorous surveys. Preliminary site assessment (U.S. Fish and Wildlife Service, Tier 1) is usually conducted remotely and involves evaluation of existing databases and published materials. If potentially at-risk wildlife are present and the developer wishes to continue the development process, then on-site surveys are conducted (Tier 2) to verify the presence of those species and to assess site-specific features (e.g., topography, land cover) that may influence risk from turbines. The next step in the process (Tier 3) involves quantitative or scientific studies to assess the potential risk of the proposed project to wildlife. Typical Tier-3 research may involve acoustic, aural, observational, radar, capture, tracking, or modeling studies, all designed to understand details of risk to specific species or groups of species at the given site. Our review highlights several features lacking from many risk assessments, particularly the paucity of before-and-after-control-impact (BACI) studies involving modeling and a lack of understanding of cumulative effects of wind facilities on wildlife. Both are essential to understand effective designs for pre-construction monitoring and both would help expand risk assessment beyond eagles.

Key words: bats, before-after-control-impact (BACI), birds, human–wildlife conflicts, pre-construction risk assessment, wind energy

Wind power generation is a rapidly growing form of renewable energy (Energy Information Agency 2015). Although the per GW-produced carbon footprint of a wind energy facility is less than that of fossil-fuel-based energy production, there are still environmental impacts of wind energy development. These impacts include direct and indirect effects to wildlife through fatality, habitat alteration, and loss associated with land clearing and road building (Fargione et al. 2012, Katzner et al. 2013).

Fatalities caused by wind turbines especially impacts volant species; tens of thousands of birds and bats are killed annually at wind facilities (Arnett and Baerwald 2013, Loss et al. 2013, Smallwood, 2013, Hayes 2014, Erickson, 2014). However, such fatalities are not evenly distributed; in some localities, bird and bat fatality is very high, whereas, in other places, fatality rates are low. It is also true that fatality events differ in consequences for different species, such that common and numerically abundant populations may be less affected by fatalities than rare and low-density species. As such, impacts of fatalities to populations of rare and low-density species or to more abundant species facing multiple threats are often considered to be the most consequential negative effects of wind turbines on wildlife.

Because of these negative effects, substantial effort at some facilities has been put into assessing risk from turbines to birds and bats before turbines are installed (i.e., pre-construction). The goal of this review is to summarize current approaches to voluntary pre-construction assessment of risk to volant wildlife from wind turbines. Our review is organized in the following way. (1) We first lay out the scope of the problem and describe the breadth (number of species) and depth (numbers of individuals) of blade-strikes to birds and bats. (2) We then discuss how and why pre-construction monitoring is conducted, focusing on the voluntary tiered system outlined by the U.S. Fish and Wildlife Service (USFWS). (3) We identify gaps in methods and models used to assess risk of fatality at turbines and to place that risk in the context of cumulative effects across multiple wind energy facilities.

Scope of the problem

Impacts of wind energy on birds and bats are covered in greater detail in previous articles of this special section of *Human–Wildlife Interactions* (Hein et al. 2016, Johnson et al. 2016). Here, we briefly summarize the problem to lay the framework for subsequent issues we cover.

There are many ways to evaluate the number of birds or bats killed at wind turbines. The simplest approach is to tally (for monitored sites) and, subsequently, model counts (to fill in gaps from unmonitored sites) of individual wildlife killed (e.g., Arnett and Baerwald 2013, Loss et al. 2013, Hayes 2014). Although such an approach is technically accurate and useful as a first cut at estimating and citing numbers of fatalities, the downside is that it creates the false impression that all fatalities are demographically, ecologically, and legislatively equivalent. For example, both European starlings (*Sturnus vulgaris*) and golden eagles (*Aquila chrysaetos*) are killed at wind turbines in the United States (Erickson et al. 2014). Yet, from ecological and management perspectives, fatality of these species differs. Demographically or at a community level, loss of a single eagle differs in meaning than loss of a single starling, because golden eagles are apex predators with populations estimated at <0.2% the size of starling populations (Partners in Life Science Committee 2013). Likewise, from a legislative perspective, eagles are federally-protected under the Bald and Golden Eagle Protection Act and, as a non-native species, starlings receive no protection. Similar arguments can be made when assessing bat fatalities (especially in areas with and without white-nose syndrome); for this reason, effective pre-construction monitoring does not ignore the species involved.

The diversity of avian species that have been killed by wind-turbine blade-strikes is remarkable, and birds seem to be killed in (or over) all land-cover types (Erickson et al. 2014). The greatest proportion of birds killed are passerines (65%), some of which are rare and of conservation concern, while others have large populations and fatality at turbines may be compensatory. Nevertheless, taxa killed that have been the focus of the greatest conservation concern are diurnal birds of prey, especially large soaring species, such as eagles and vultures (e.g., white-tailed eagles [*Haliaeetus albicilla*]; Dahl et al. 2012). These birds of prey are found close to turbines, because turbines often are located in areas where updrafts occur that soaring birds rely on such updrafts to gain altitude. Further, because their natural survival rates are high, fatality from wind turbines is unlikely to be compensatory. Finally, within the United States there are legal incentives to minimize fatalities, as "take" of eagles without a permit is illegal, and there is no provision within the Migratory Bird Treaty Act that permits take of any bird species covered.

Expressed as a proportion of total population size, effects on bat populations are likely greater than those on most avian populations (Arnett and Baerwald 2013, Hayes 2014). In North America, tree-roosting bats are considered especially susceptible to fatality from turbines (Cryan et al. 2014). This may be in part because tall monopole turbines appear to serve as an attractant for these species (e.g., Cryan et al. 2014). Research suggests that raising cut-in speeds (i.e., the wind speed at which the generator is connected to the grid and generating electricity) of wind turbines is effective at reducing bat fatalities (Arnett et al. 2011). Nevertheless, the rapid decrease in some bat populations caused by white-nose syndrome (Blehert et al. 2009) means that wind-turbine-caused bat fatality may have greater demographic consequence than would have been the case 15 years ago. Moreover, the likely change in conservation status resulting from white-nose syndrome (Alves et al. 2014) will affect bats' regulatory status and, thus, scrutiny of new installations (see the recent listing of the northern long-eared bat, <http://www.endangeredspecieslawandpolicy.com/2015/04/articles/fish-wildlife-service/northern-long-eared-bat-listed-as-threatened>).

The indirect effects of wind turbines on birds and bats are less clearly understood than are the direct effects. There is evidence that some grassland songbirds are not displaced by the presence of turbines (Hale et al. 2014). Other studies suggest positive and negative consequences of turbines for prairie chickens (*Tympanuchus cupido*; Winder et al. 2014*a, b*; 2015). In contrast, migrating golden eagles in Canada and soaring raptors in southern Mexico that were not struck by turbines were displaced from their flight routes (Johnston et al. 2013, Villegas-Patraca et al. 2014). For species such as eagles that rely on updrafts to subsidize flight, displacement may have important costs, especially when considered in the context of the cumulative effects of multiple strings of turbines along ridges. There is, to our knowledge, no published literature on indirect effects of wind turbines on bats and only little pertaining to birds.

Pre-construction assessment for birds and bats

Background

Voluntary pre-construction risk assessment to birds and bats can follow a variety of approaches and use a wide range of survey techniques. Nevertheless, the process of assessment usually follows 3 consecutive phases: preliminary site evaluation; site-specific evaluation, and site-specific risk assessment. Within the United States, this process is formalized by the tiered structure that the USFWS provides in guidance for planning and developing land-based wind energy (USFWS 2012). Surveys for wildlife start with qualitative assessment to determine if species of concern or their habitats are potentially present (Tier 1). Subsequently, a quantitative assessment is used to characterize habitat types and potential use by species of concern (Tier 2). More detailed studies of wildlife at proposed sites are recommended if assessments at Tiers 1 and 2 suggest risk to species of concern (Tier 3).

Although many species are monitored during development of wind energy sites, assessment usually focuses on species that are protected by law and those that are known to be affected at other sites. These species typically include large birds (especially raptors, seabirds and grassland grouse) and bats (especially tree-roosting species). Surveys conducted are usually intended to provide a detailed understanding of abundance, habitat associations, and behavior of those focal species and to provide a framework to estimate and mitigate risk to species and habitats. Tools that typically are used include standard survey techniques for birds (point counts and raptor nest searches) and for bats (e.g., acoustic monitoring, roost surveys, and exit counts).

At each phase of this process, "go" or "no-go" decisions are made by participating developers regarding wind facility siting and construction. Go-decisions often lead to: (a) increased levels of monitoring wildlife abundance, distribution, and behavior; (b) predictive modeling based on counts, behavioral observations, or in certain limited cases, telemetry data; and (c) extrapolation from behavior observed at other sites with similar characteristics. When there are predicted impacts to protected or listed species, then additional permits and mitigation often are required of developers.

Step 1: preliminary site evaluation

The first phase of pre-construction surveys (Tier 1 in USFWS 2012) provides a framework to help developers evaluate and select potential sites for construction. Qualitative surveys that focus primarily on habitats and species of concern are conducted to identify the value of an area for wildlife. Such landscape-level surveys generally involve a basic review of literature and databases in which readily available information (e.g., wildlife sightings, capture records, museum specimens, landscape-level range maps) is summarized. Most management agencies require that this existing information come from credible sources, such as reports from government agencies, nongovernmental organizations, the academic community, local experts, or data collected by the developers or their consultants.

Participating developers consider this review in a basic evaluation of the area for wildlife. If potential sites for wind development with not-known value for wildlife are identified, the next phase of pre-construction surveys tends to focus on these specific sites. If the entire area under consideration has known value for wildlife, there are 2 options. First, developers may choose to abandon siting the project in that area (a "no-go" decision). Alternatively, if it is possible to compensate for take in an economically viable manner, developers may expand preconstruction surveys by proceeding to Step 2.

Step 2: site-specific evaluation

The second phase of pre-construction surveys (Tier 2 in USFWS 2012) focuses on gathering additional site-specific information at potential wind development sites. Using the initial review in phase 1 as a starting point, reconnaissance site visits are conducted to confirm species presence and to ground truth available habitat and habitat features associated with species presence. Guidelines for this process generally recommend habitat-based resource mapping surveys focused on identifying important habitat for birds and bats. For example, areas that encompass known bat hibernacula, maternity colonies, migratory stopover areas, or migratory routes should be identified (Ontario Ministry of Natural Resources 2011).

It is often difficult to identify significant wildlife habitat for solitary or hard-to-detect species and for species with nomadic lifestyles or pronounced migratory seasons (Baerwald and Barclay 2009, 2011; Piorkowski et al. 2012). In such cases, by mapping specific habitat features and resources that are potentially suitable for a species (e.g., water sources, foraging habitat, roosting and nesting sites), it is possible to make basic assessments about whether an area has some value (Ontario Ministry of Natural Resources 2011). This approach is useful, because it allows identification of areas with concentrations of multiple resources (i.e., resource hotspots). Once hotspots are identified, monitoring surveys (e.g., mobile acoustic transects, point count surveys) can then be located to maximize probability of detecting target species. For raptors, this means placing counters along ridges with updrafts and, thus, bird concentrations (PGC 2007). For bats, this often means focusing on water sources and other concentration areas.

Gauging value of an area for wildlife based on available resources and species presence (Ontario Ministry of Natural Resources 2011) provides developers with a rudimentary value that identifies habitat suitability (USFWS 2011). However, although this information may confirm the presence of a species, these surveys rarely give information on abundance and distribution or on the actual value of the site to that species. Nevertheless, data collected in this phase can allow developers to identify specific sites with relatively less value to birds and bats that are then considered in the final phase of pre-construction surveys for wind energy development.

Step 3: risk assessment

The third phase of pre-construction surveys (Tier 3 in USFWS 2012) involves quantitative or scientific studies to assess potential risk of the proposed project to wildlife. Because risk can result from complex interactions among species distribution, relative abundance, behavior, weather conditions, and site characteristics, these surveys are more involved than those in either of the 2 previous phases. Information gathered in Tier 3 can be used to make a final assessment as to whether the project should be developed or abandoned or to understand if more surveys are required to come to that decision. It also can be used as a foundation to implement avoidance or minimization measures or to develop post-construction mitigation or monitoring strategies.

Currently, there are no standardized, across-the-board protocols for site-specific pre-construction surveys. However, for certain taxa or in specific states, there are suggested frameworks (e.g., Pennsylvania Game Commission 2007, USFWS 2013), and management agencies often (but not always) ask that surveys be conducted so that data are generated that can be statistically evaluated and compared. There is no shortage of well-established survey techniques to assess bird and bat distributions and activity across a wide range of habitat types (Sutherland et al. 2004, Kunz and Parsons 2009, Strickland et al. 2011). Here, we review some of the more commonly used survey approaches, particularly as they pertain to bats and birds.

Digital acoustic surveys. The most commonly used method to monitor bat activity prior to construction of wind turbines is digital acoustic monitoring (Reynolds 2006, Kunz et al. 2007, Weller and Baldwin 2012). This technique provides an effective means to determine spatial and temporal patterns in bat occupancy and activity, but, at present, it cannot be used to estimate abundance (Gorresen et al. 2008). Although there are no standard protocols for acoustic surveys, they are generally categorized as either passive or active. Passive surveys involve deploying detectors at set locations for a pre-determined length of time (i.e., days, months, activity season; Rodhouse et al. 2011). The number of bat calls recorded passively is used to calculate a site-specific index of activity. Active, or mobile, acoustic surveys involve walking or driving pre-determined transect routes with acoustic detectors at regular intervals (i.e., nightly, weekly, or monthly). Because acoustic recorders are moved from place to place on a brief time cycle, active surveys can provide relatively greater spatial coverage but less temporal resolution than do passive surveys (Whitby et al. 2014).

Utility of pre-construction acoustic surveys for bats is predicated on them being a useful predictor of post-construction bat fatality from turbines (Johnson et al. 2004, Arnett et al. 2008). However, strength of the relationship between the two is not well-established (Piorkowski et al. 2012). There is sometimes a positive relationship between pre-construction bat activity and fatalities during the post-construction period (e.g., Baerwald and Barclay 2009, 2011). On the other hand, a recent review that focused on 12 sites found that pre-construction acoustic data did not predict bat fatalities (Hein et al. 2013). These findings are likely driven in part by the difficulty of interpreting acoustic activity in terms of risk and by lack of standardization in survey protocols. Although digital acoustic monitoring is sometimes used for birds, these tools are not well-developed and to our knowledge have not been applied to pre-construction monitoring at wind energy sites.

Radar surveys. Radar surveys have been used for pre-construction monitoring of birds and bats. The application of radar ornithology is used to study bird migration (Gauthreaux et al. 2003), roosting behavior (Gauthreaux and Russell 1998), collision risk at offshore wind facilities (Desholm and Kahlert 2005), and to track individual eagles and condors (*Gymnogyps californianus*) near existing wind facilities. Radar surveys can be used effectively to monitor bats migrating through wind power sites; however, to date, no peer-reviewed studies have used this technique. Radar is useful because it allows collection of data on minute-by-minute movements and on flight patterns of individual animals in and around a particular site (see for example, Figure 1 in Desholm and Kahlert 2005).

Using radar has 3 significant constraints relevant to pre-construction surveys. First, although a remarkable level of detail often is provided on individual behavior of individual species, it can be difficult or impossible to link behavior to known species or individuals. Second, because of the infrastructure required to generate and receive radar waves, radar is expensive, and its use may be constrained to existing weather, airport, or military Doppler radar facilities. Third, radar waves travel in a cone-shaped pattern that is narrow and low near the radar station, becoming wider and higher as they travel farther from the station. Thus, detection of birds and bats flying across a landscape are made only at the distance from the radar when the flight altitude intersects the radar cone. Despite these constraints, the broad-brush information that radar can provide may be exceptionally important when historical data are not present for a site or when animals are hard to detect. Identifying nocturnal bird or bat migration corridors is a good example of where radar is useful.

Observational count surveys. Birds are especially well-suited to aural or daytime visual counting by human observers. There are well-established point count and transect techniques in the literature for breeding bird surveys (e.g., Bibby et al. 2000), and these have sometimes been applied to wind energy facilities (Hale et al. 2014). The most commonly applied observational counts relevant to pre-construction surveys at wind turbines are those linked to raptor migration and assessing eagle use.

The Hawk Migration Association of America (HMANA; Carey 2014) has protocols it recommends for pre-construction monitoring at potential migration sites and concentration areas (HMANA 2014). Those protocols call for "at least three years of pre-construction data for projects where landscape features, natural history patterns, or other data suggest raptor concentration is possible." Although HMANA is a migration-focused organization, its protocols recognize that there are year-round risks to birds and that the risk to birds may be through blade-strike or avoidance behavior, as well as habitat degradation or alteration. Thus, timing of pre-construction assessment is essential. For example, in the mid-2000s, numerous pre-construction studies in the central Appalachians were conducted at the peak of raptor migration (September to October). This timing is appropriate to monitor movements of broad-winged hawks (*Buteo platypterus*) but inappropriate to assess migration of golden eagles, which tend to pass through the region in mid- to late November. It is also not always the case that pre-construction surveys are conducted for the recommended 3 years.

Within the United States, the USFWS also provides recommendations specific to pre-construction surveys for eagles via its Eagle Conservation Plan Guidance (ECPG; USFWS 2013). The ECPG recommends use of 800-m, fixed-radius point counts, conducted over a period of >1 hour, to record the presence and behavior of large birds. These protocols suggest a stratified, random, spatial distribution to cover 30% of the area within 1 km of proposed and alternative turbine locations. Counts are distributed throughout the day for 1 to 2 hours per turbine and should be conducted for ≤2 years pre-construction. Unlike typical point counts for breeding birds, eagle counts record location, duration, and altitude of eagle flight. Point count data can then be used within a Bayesian modeling framework to identify risk of strike (see below; USFWS 2012) and is sometimes used to construct utilization distributions to guide turbine siting.

Capture and tracking surveys. Animal capture and tracking studies sometimes also have been used for pre-construction assessment. For bats, this often means mist-netting individuals and tracking them with VHF telemetry to identify roost or foraging sites and to categorize habitat use (Bontadina et al. 2002, Ancilloto et al. 2015). The USFWS specifically discourages capture and telemetry of eagles for pre-construction assessment, because of potential affects to small eagle populations and in part because of the infrequency of scientific publications that come from consultant-driven surveys.

Capture and tracking has been used with effectiveness to understand prairie chicken response to wind energy development within a before-after-control-impact (BACI) framework. The approach to this work involved assessing pre- and post-construction space use and fecundity (Winder et al. 2014*a*), demography (Winder et al. 2014*b*), and nest site selection and nest survival (McNew et al. 2014).

Risk assessment via interpretation or modeling. Pre-construction risk assessment also has been completed via extrapolation from studies at other sites and via models using site-specific data to inform facility layout.

Although site-specific monitoring is most appropriate for pre-construction monitoring, site-specific studies can be challenging, and there is a suite of information that can be gathered by inferring behavior based on data collected at other sites. This weight of evidence approach has been applied in many settings (Anderson et al. 1999, Cryan 2008, Cryan and Barclay 2009). Further, information on species-specific responses to variation in habitat can be used for a wide variety of pre-construction activities. For example, Katzner et al. (2012) showed that migrating Golden eagles responded to topographic features, thus, identifying a mechanism to guide turbine siting. Likewise, other work has shown that specific turbines and specific habitat features increase likelihood of fatalities of raptors in Spain (Barrios and Rodríguez 2004).

A more robust approach to understanding risk can be achieved through site-specific modeling (Bennett et al. 2013). Modeling is useful because animal behavior, and, thus, risk from turbines, is influenced by landscape features. When use of a landscape is not random, behavioral responses to landscape features can be modeled to better understand and predict site-specific risk (Smallwood et al. 2009, Miller et al. 2014). To date, use of models to understand resource selection and risk has been restricted only to a couple of examples, and even fewer of these models have been empirically tested and validated.

In Spain, where griffon vultures (*Gyps fulvus*) regularly collide with wind turbines, de Lucas et al. (2012) put a scaled-down and topographically accurate physical model of a wind facility within a wind tunnel to understand air movement through the site. Their goal was to determine if vultures followed wind currents when traversing a wind farm and to predict specific locations where the species might be most vulnerable to collision with turbine. Although there are well-known constraints to up-scaling or down-scaling physical phenomena, their approach apparently was reasonable at predicting risk to birds at their site.

Statistical models also have been used to predict risk to Golden eagles and other raptors. Miller et al. (2014) built resource selection functions (Manly 2002) from telemetry data of migrating golden eagles in the Appalachian Mountains and overlaid those on resource selection probability resource selection functions for wind turbines in the same region. By overlaying the 2 functions, they were able to describe regional risk, as well as site- and turbine-specific risk to golden eagles, and to identify sites that were relatively high and low value to eagles and turbines. A key next step in this process is empirical validation of these models.

In cases where telemetry data are lacking, detailed observational data can be used to create similar site-specific models. Smallwood et al. (2009) used direct observations of burrowing owls (*Athene cunicularia*) and California ground squirrels (*Spermophilus beecheyi*) and 2 modeling approaches (discriminant function analysis and fuzzy logic) to create risk maps that guided re-powering of the Altamont Pass Wind Resource Area. While not specifically geared toward pre-construction risk assessment, such an approach could be useful in areas where there are high densities of at-risk species.

Finally, the USFWS has developed a Bayesian risk model that uses observational (count) data to estimate total number of bald eagles (*Haliaeetus leucocephalus*) and golden eagles likely to be killed over the lifetime of a wind facility (USFWS 2013). This number is derived from point count data (described above) collected during the pre-construction phase, and risk assessment is based on minutes eagles spend within the project footprint.

Gaps and opportunities for growth in pre-construction risk assessment

Pre-construction assessment of potential wildlife risk at wind facilities is important from a regulatory and conservation perspective. However, there is little indication that pre-construction surveys are actually useful, and evidence for a relationship between pre-construction surveys and post-construction fatality is often lacking (Ferrer et al. 2012, Hein et al. 2013).

Lack of knowledge about effective pre-construction monitoring stems in part from the paucity of peer-reviewed BACI studies at wind facilities. One of the few such studies conducted surveyed for migrating golden eagles in eastern British Columbia (Johnston et al. 2013, 2014); it indicated that, prior to turbine construction, eagles regularly crossed through the proposed facility below turbine height (150 m above ground level). However, post-construction monitoring indicated that eagles responded to the presence of turbines, making relatively fewer dangerous crossing flights than anticipated (Johnston et al. 2014). More generally, BACI studies can be difficult to implement, because access to proposed facilities often is unavailable, and, when access is granted, many proposed facilities are not built, due to a multitude of economic, legislative, viewshed or environmental concerns. Scarcity of carefully constructed BACI studies is one of the most important knowledge gaps in developing pre-construction surveys. Such studies should include further field testing of modeled risk taken from existing models (cited above) and newer versions.

Additional knowledge gaps our literature review identified include the items listed below.

- Pre-construction surveys are not conducted in a standardized manner, and data often are held privately, meaning that they cannot be used by public agencies to inform conservation decisions or compiled and analyzed for global trends.
- Pre-construction assessments only rarely consider cumulative effects of multiple wind facilities; this limits inference to the scale at which

decisions are made.

- USFWS risk models were developed for golden eagles but are also being applied to bald eagles; the degree to which this is reasonable is not known.
- Pre-construction risk models have not been tested for their efficacy; thus, their usefulness in reducing bird and bat fatality is not yet known.
- Most pre-construction models are built for eagles. It is important also to focus on other bird and bat species. For example, there have been large kills of songbirds and bats, especially at eastern North American wind-turbine facilities.

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