PAPER

Avian Issues for Offshore Wind Development

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ABSTRACT

Wind energy is the fastest growing source of electricity in the U. S., and the energy potential in the offshore environment is enormous. Environmental concerns have focused on effects on birds, and in this paper we briefly review these effects in the context of methods for assessing preconstruction risk and postconstruction impact. Federal statutes and legislation, including the National Environmental Policy Act, Federal Energy Act of 2005, the Endangered Species Act, and the Migratory Bird Treaty will require that prospective developers conduct some form of avian risk assessment prior to construction. Such preconstruction studies should utilize a Before-After-Control-Impact (BACI) design.

Offshore wind farms pose three primary threats to birds: barrier effects due to flight avoidance, habitat loss (due to displacement), and fatalities resulting from collisions with turbine blades. All have been demonstrated at land-based and coastal wind farms, and flight avoidance and shifts in habitat use have been demonstrated in the offshore environment for a limited number of species in Europe. The additive effect of these impacts to bird populations may be trivial under current levels of development, but could become ecologically significant as offshore installations increase as projected.

Interpreting the ecological significance of these effects requires additional research, especially on understanding the importance of winter foraging habitat and population delineation, particularly for waterfowl. Such research and preconstruction studies will be expensive, and we suggest public funding of these efforts and private-public partnerships as is currently underway in some states.

Introduction

The present and looming threat of global warming requires immediate action to increase the production of renewable energy and dramatically reduce greenhouse gas emissions that result from the burning of fossil fuels. In the U.S., production of electricity from land-based wind energy has been the most rapidly developing source of renewably produced electricity, and wind energy is viewed as an important source of climate change mitigation. Conservation concerns regarding wind energy development focus on the effects of these installations on birds and bats. Raptors and bats, in particular, are prone to collision with the rotating blades of wind turbines, and development of large commercial wind farms on undeveloped ridge tops, grasslands and shrublands modifies habitat, potentially displacing threatened wildlife species (NRC, 2007). Additional habitat effects come from the development of transmission lines needed to take electricity produced by wind in remote areas to the load centers of the more densely populated urban areas.

Offshore wind energy development presents considerable opportunity for the production of electricity, and electricity from this source is expanding rapidly in Europe. Economics and technology currently limit offshore wind energy development to waters less than 30 m deep, but the wind blows stronger and more reliably offshore, and certain habitat impacts are reduced or avoided. Threats to birds don't disappear, but shift to different issues and species groups. In this paper we review the avian issues that arise in the development of offshore wind energy projects and that should be considered by all prospective developers of wind energy in the offshore environment. We focus primarily on appropriate methods for preconstruction risk assessment and postconstruction impact assessment. Avian issues associated with deep-water (herein defined as >30 m) wind energy projects, which currently are not economically or technologically feasible, will be touched on as well.

Several detailed reviews of wind energy effects on wildlife primarily from land-based wind turbines have appeared recently (GAO, 2006; Kunz et al., 2007; Kuvlesky et al., 2007; NRC, 2007). We encourage interested readers to consult these reviews for a more exhaustive treatment of this subject. Offshore wind energy development is advanced in Europe, but no offshore facilities are operating in the U.S. as of this writing. Our knowledge of effects of offshore wind energy on birds, particularly on avian habitat use, comes from observations on these projects.

A recent issue of the journal *Ibis* published the proceedings of the annual conference of the British Ornithological Union, *Wind, Fire, and Water: Renewable Energy and Birds*, April 2005 (e.g., Langston, Fox, and Drewitt 2006) on issues of concern with the development of wind energy, including offshore waters, and more information is appearing in the peer-reviewed literature. Most recently, the Minerals Management Service released the new Draft Environmental Impact Statement (DEIS) for the proposed Cape Wind Project in Nantucket Sound (http://www.mms.gov/offshore/RenewableEnergy/RenewableEnergyMain.htm). The DEIS includes detailed reports on data collected as part of the avian risk assessment, including the work of Mass Audubon and the authors of this paper. Our treatment of this topic reflects our lessons learned on this

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project—possibly the first offshore wind farm in the United States.

Our primary emphasis in this paper is on the importance of a rigorously designed preconstruction risk assessment that is explicitly linked to postconstruction impact assessment and mitigation. Considerable uncertainty exists in the impact of offshore wind energy development on birds. Concerted and coordinated efforts to reduce uncertainty whenever feasible, particularly when threatened and endangered species are involved, are urgently needed especially as wind energy development proceeds rapidly. At the end of this paper we describe what we consider to be the research questions that should be addressed to reduce uncertainty surrounding the ecological impact of wind energy development in the offshore environment.

While our discussion will be limited to avian species, evidence is mounting that bat mortality at land-based turbines may be a greater concern than avian mortality (Kunz et al., 2007). The omission of bats from our discussion does not imply that we think the risk is necessarily low. Bats are known to fly across large stretches of ocean during migration (e.g., Cryan and Brown, 2007 and references therein; Huppop and Hill, 2007) but estimating the risk of offshore wind energy development to bats is currently not possible because there are few if any systematically collected data on bat activity in the offshore environment.

Wind energy projects pose a threat to birds, but the population-level significance of these effects is not yet known. It is also predicted that disruption and warming of climate will have major effects on many of these same bird species. Current warming has resulted in detectable phenological changes in birds and many other species (e.g., Parmesan and Yohe, 2003; Root et al., 2003). Range extensions attributable to warming climate have also been detected (Sorenson et al., 1998; Thomas and Lennon, 1999; Price and Root, 2002; Valiela and Bowen, 2003; Rehfisch et al., 2004). Tundra breeding grounds for many migratory waterfowl that winter in the offshore environment of the U.S. is warming more rapidly than the global average (IPCC, 2007). Widespread breeding failure of some marine birds has been linked to shifting food supply caused by warming ocean temperatures (Jahncke et al., 2008). In addition, mining fossil fuels has substantial and measurable impact, and other effects of fossil fuel use such as air pollution and oil spills may also negatively affect bird and bat populations. The combined negative effects of fossil fuel use could be far more devastating to the persistence of certain avian species than increased mortality due to collisions with turbine rotor blades or towers, the possible loss of winter foraging habitat, or increased migration distances, but at the moment there is no way of assessing these differences.

The Regulatory Nexus

Unlike much of the land-based wind energy development that occurs on private land, all of the offshore wind energy development will occur in the public domain and consequently involve state and/or federal environmental review. It is this review that provides the regulatory driver for considering avian issues. We briefly review the most relevant statutes below.

1) National Environmental Policy Act and Federal Energy Policy Act of 2005

Most offshore wind development will occur in federal waters, and because of the resulting federal nexus will require environmental impact assessment under the National Environmental Policy Act. Further federal involvement in the environmental review of offshore wind development comes from the Federal Energy Policy Act of 2005, which directed the U.S. Department of Interior's Minerals Management Service to establish the Outer Continental Shelf (OCS) Alternative Energy and Alternate Use (AEAU) program. A recent result of this program was the completion and release in October 2007 of a Programmatic Environmental Impact Statement (PEIS) that examined the potential environmental effects of alternative energy development, including wind, on the OCS over the next 5-7 years (http://www.ocsenergy.anl.gov/). Offshore wind development will also occur in state waters and be subject to the rules of environmental review of individual states, in some cases simultaneously with federal review. The Army Corps of Engineers (ACE) retains authority for offshore wind development in the Great Lakes, and has permitting authority under Section 10 of the Rivers and Harbors Act of 1899 (RHA).

The web of statutes just described can lead to complicated regulatory review. In the case of the Cape Wind Project, the turbine location exists outside the three mile limit of Massachusetts' territorial waters. Initially, federal review was coordinated by the ACE, but with the passage of the Federal Energy Policy Act, review authority was transferred to MMS. The ACE maintained permit authority and continues to review the project under its permitting authority of the RHA. State review is also relevant for this project as the Massachusetts Environmental Policy Act (MEPA) covers the underground cabling from the wind project to its connection with the grid on land. The Cape Wind review has been underway since late 2001, in part because the drafting of the environmental impact statement began anew when review authority was transferred to MMS in 2005.

2) Endangered Species Act (ESA)

The ESA, passed in 1973, states that knowingly "taking" a federally listed species is illegal. "Take" has a broad definition and includes harassing, harming, pursuing, hunting, wounding, as well as killing a listed species. The statute is administered by the U.S. Fish and Wildlife Service (Service). In the context of federal review in the event that a listed species may experience a "take" as a result of the construction and operation of a proposed project, the reviewing federal agency is required under Section 7 of the Act to consult with the Service. Based on the result of that consultation, the Service may issue an "incidental take" permit. Typically, some form of mitigation is required to effectively compensate for any incidental take.

Individual states may also have similar statutes with an independent but similar process for listing species, and a species may not be federally listed, but may fall under protection of a state endangered species act. Massachusetts, for example, has an Endangered Species Act with listed species that include but are not limited to federally listed species. The statute is administered by the Massachusetts Natural Heritage and Endangered Species Program (Heritage Program), which maintains a database of locations of sightings of listed species. Prospective developers of wind energy projects notify the Heritage Program of the location of proposed projects, and the Program scans the database to determine if the listed species has been reported in the project vicinity. In the offshore environment currently accessible to wind energy development the principle federally endangered and threatened avian species include certain defined populations of roseate and least terns, and piping and snowy plovers.

3) Migratory Bird Treaty Act (MBTA) and Bald and Golden Eagle Protection Act (BGEPA)

The MBTA and BGEPA are strict liability statutes administered by the Service and unlike the ESA currently lack a consultation process. Under the MBTA, certain activities that take migratory birds, such as hunting, are permitted but there is no provision in the MBTA for incidental take. Enforcement of MBTA violations is at the discretion of the Service and prosecution is under the discretion of the Department of Justice. There is some question whether wind energy projects are subject to enforcement under the MBTA (Blades and Firestone, 2008), but this question is currently moot, as to our knowledge no case against wind projects has been filed under the MBTA. The Service has a history of working with groups/industries to minimize MBTA violations (e.g., 2005 Avian Protection Plan Guidelines), and enforcement discretion typically weighs the conservation impact of the activity, i.e., are bird species of concern involved, and whether violations involve egregious cases wantonly harming or trading in species on the list.

Currently there are no federal guidelines for the siting of wind energy projects in the offshore environment (guidelines are under development). Voluntary interim guidelines for development of land-based wind energy projects have been developed by the Service and implemented by Service field staff (see www.fws.gov/habitatconservation/wind.pdf) and several states have developed guidelines.

Assessing Risk and Impact to Birds

Numerous studies on land-based projects in the U.S. and Europe, and offshore projects in Europe have amply demonstrated three potential threats to birds that use the offshore environment:

1) Barriers to movement causing deflection of birds around turbine arrays;
2) Loss of habitat caused by avoidance of arrays; and
3) Direct mortality resulting from collision with rotating turbine blades and turbine towers

An avian risk assessment should 1) measure the probability and magnitude of these threats (i.e., impact); and 2) develop predictions regarding the ecological consequences of these impacts. Specifically, an offshore risk assessment should be viewed as the development of scientifically based predictions about the potential impact of a specific wind energy project to the bird species that use the air and water space in the project area. The postconstruction impact assessment is therefore an explicit test of the predictions generated during the risk assessment. Preconstruction risk assessment is also important for designing appropriate mitigation for predicted impacts, and postconstruction impact assessment should verify whether the mitigation is sufficient, or if risk assessments were incorrect, whether the proposed mitigation needs to be re-evaluated. As we discuss below, describing avian activity is substantially easier than predicting risk from the measures of activity.

Methods for Assessing Risk to Birds

In this section we briefly review and recommend specific "methods and metrics" for conducting preconstruction risk assessments and postconstruction impact studies for birds and offshore wind energy development. Preconstruction risk assessments should develop questions based on prior knowledge and experience that focus available resources on gathering the necessary data to describe avian activity within the project area that directly relates to risk "exposure" (*sensu* Kunz et al., 2007) for the species of greatest concern. For example, preconstruction risk assessments in the development of Danish offshore wind farms focused on species with 1) special protection, 2) that were vulnerable because they persistently flew at rotor swept height, and 3) had life history traits that increased their sensitivity to increased mortality (high annual adult survival and low reproductive potential) (Fox et al., 2007).

In addition to determining which variables to measure, an important question to answer is "how long" (seasons, years) each variable should be measured. The answer to this question should reflect available knowledge of the underlying variation in the system being assessed. Our Cape Wind assessments were based upon on a minimum of three years of observation of tern and winter waterfowl activity in Nantucket Sound (e.g., Allison et al., 2006). Our surveys indicated that tern activity varied substantially (Sadoti et al., 2005); more than 5,000 terns were recorded in 11 aerial surveys in 2002, more than 10,000 terns in 13 aerial surveys in 2003, and approximately 800 terns in 11 aerial surveys of Nantucket Sound in 2004. A minimum of three years of sampling was recommended for the Cape Wind project review (Mass Audubon and USFWS and Mass Wildlife Scoping Comments to the ACE), and has been recommended as a standard in other studies (Petersen et al., 2006; Desholm et al., 2005).

Recent detailed reviews of various methods for measuring avian (and bat) activity have been published (Desholm et al, 2005; Desholm et al., 2006; Kunz et al., 2007). Methods for risk assessment fall into several main categories including: 1) visual observation; 2) radar; and 3) acoustic surveys and monitoring. Each of these techniques has different strengths and drawbacks for describing avian activity, distribution, and risk exposure. These methods should be used in combination to assess the risk to birds from the threats posed by wind turbines described above (barriers, habitat loss, and collision risk). Thermal imagery (e.g., Thermal Avian Detection System (TADS); Desholm, 2005), molecular methods, and telemetry also hold promise as research tools for better understanding the ecological impact of offshore wind energy projects, but will generally fall outside the realm of risk assessment for the typical project. In the context of the U.S. regulatory environment, it is important to distinguish between what is required as part of the avian (and bat) risk assessment and what we would like to know, but can only be addressed with research that most effectively involves the collaboration between the wind industry and the scientific community.

Visual Methods

Surveys of avian activity and abundance in the project area particularly in the rotor swept zone are best used to determine the effects of wind energy projects on avian habitat use and as a supplement to radar-based surveys (see below).

Surveys of offshore waters by plane have been used to describe avian distribution and activity in proposed project areas and surrounding waters, and are necessary to address the hypothesis that the presence of the wind farm causes habitat displacement (and loss). Waterfowl often feed in large rafts of hundreds or thousands of ducks and the location of these rafts shifts seasonally and between years (e.g., Allison et al., 2006), presumably in response to shifts in food supply.

Surveys of avian distribution and activity by plane are typically conducted on a predefined survey route or grid and are repeated at different times during the season of interest, and over a period of one or more years. Optimal flight heights for conducting plane surveys for seabirds are between 75 m and 150 m asl. Lower flight heights may influence bird behavior, whereas higher flight heights will reduce species identification and detectability. The detectability of birds can also be an issue due to sea state, relative angle of the sun (glare), and observer variability (e.g., visual acuity).

Boat surveys cover less area, but can be used to estimate flight heights more accurately than from a plane. Observers from boats may detect fewer birds, especially during poor viewing conditions, but they may be able to detect and identify smaller birds than can be seen at the elevation of a plane. The presence of boats can also disturb some species, (e.g., sea ducks) scattering individuals and affecting the estimates of abundance and flight height.

Both boat and plane surveys, while useful, have the serious limitation that they require good weather conditions—especially visibility—for the human observers. Surveys of avian activity during periods of poor visibility (fog, rain, or night) for obvious reasons do not happen—it is during periods of poor visibility that birds are assumed to be at greatest risk of collision. Nighttime observations from boat and plane have been substantially limited in the past, but continued advancements in the quality of night-vision optics may increase the value of these techniques and greatly increase our understanding of nighttime avian activity, especially if conducted in conjunction with radar (see below).

Radar

Various types of radar, including Doppler and tracking radar, have been evaluated for their use in risk assessment, but marine navigation radar adapted for avian monitoring is the best available tool for measuring flight direction and passage rates of migrants. This type of radar plays an important role in evaluating risk due to barriers to movement and can provide necessary data on avian activity that can be used to develop collision risk models (Desholm et al., 2005). Radar has the distinct advantage of being able to measure avian activity during periods of low visibility, including complete darkness. Marine radar also has significant limitations in that it cannot distinguish among species of birds, between birds and bats, and individual birds and distant small flocks of birds—in such cases, visual confirmation of a sample of radar tracks is necessary.

Radar targets can be categorized by size (e.g., small, medium, and large according to predetermined size ranges), and when operating in horizontal mode radar can provide information on flight direction and speed when target tracks are corrected for wind velocity. Radar units can be "flipped" to track vertically to record flight heights of targets thereby providing information on the abundance of targets in the proposed rotor swept area, considered to be the zone of greatest avian risk. Vertical tracking radar can also provide information on target size, but not target velocity.

Radar of two different wavelengths is commonly used in preconstruction assessments: X-band (3 cm) and S-band (10 cm). There is apparently no consensus on the standard wavelength (NRC, 2007), and both have been deployed to record targets and estimate avian activity. X-band radar is more sensitive than S-Band and therefore is more effective at detecting songbirds and bats, but X-band is also less effective at "seeing" through light to moderate precipitation. (Kunz et al. 2007).

In the Cape Wind radar studies, Geo-Marine Inc. used S-Band marine navigation radar operating in the horizontal mode simultaneously with X-Band marine radar operating in the vertical mode (e.g., Geo-Marine Inc., 2008), while other assessments have used X-band in both horizontal and vertical mode (Mabee and Cooper, 2004; Mabee et al., 2006). X-band radar has been used in many preconstruction studies and, therefore, use of X-band radar allows direct comparison of "target" activity at a larger number of wind project sites. (Dale Strickland, pers. comm.).

Radar operators employ specially designed, and often proprietary, software to improve data analysis by filtering out "noise", including ground clutter, and insects and precipitation, but occasionally rainfall and heavy insect activity are captured as targets, inflating estimates of target abundance.

A stable platform free of obstructions is necessary for the efficient operation of mobile radar units. Given the limited range of marine navigation radar (<12km), the ability to conduct radar studies as part of the risk assessment will be challenged as wind projects move further offshore because of the added cost of providing a stable platform, such as a jack-up barge (our own estimates yielded up to $20,000/week). Danish preconstruction radar studies at Nysted used a pre-existing observation platform for radar installation enabling the measurement of flight patterns in the project area prior to and after construction of the wind farm (Desholm and Kahlert, 2005). This data gathering was not possible at Horns Rev until after the project had been built (e.g., Petersen et al., 2006) because of the absence of a stable platform.

The need to control costs can confound risk assessments. In the Cape Wind environmental review, spring radar surveys were conducted from a jack-up barge on Horseshoe Shoal and covered the entire project area; fall migration radar surveys were conducted from a cliff edge on Cape Pogue, Martha's Vineyard, and did not cover all of the proposed project area on Horseshoe Shoal (www.mms.gov/offshore/alternativeenergy/CapeWindDEIS.htm). It was therefore not possible to compare spring and fall radar results because of the different locations. Cost of radar installation could be reduced if opportunities are provided for radar attachments to meteorological (MET) towers during feasibility studies, but a power source would need to be provided (e.g. Desholm et al., 2005).

As described above, visual observation conducted simultaneously with at least some radar data collection is essential to confirm the identity of targets. In the offshore environment observers can be stationed in boats or on stable platforms. Radio communication between visual observers and radar operators enable simultaneous visual confirmation and identification of radar images, or targets, and can assess detectability of radar. For example, ground-truthing of radar data for the Cape Wind environmental impact assessment estimated that horizontal scanning radar detected 84% of visually recorded targets (GeoMarine Inc., 2008).

Acoustic Monitoring

The use of monitoring bird flight calls to estimate activity is well described in Kunz et al., (2007) and is a well characterized technique. Problems include the fact that not all birds call during flight and relating flight calls to avian activity or flight heights is difficult. Further linking flight call activity to fatality risk is even more problematic. Monitoring bat echolocation with acoustic devices is a principle means for characterizing bat activity in potential project areas, although this technique has only recently been applied systematically in land-based wind projects (Kunz et al., 2007), and again, we are not able to connect bat acoustic activity to fatality risk. The application of this technique to offshore risk assessment remains to be developed.

Other Techniques

Telemetry

Telemetry, where individual birds are instrumented with transmitters and tracked with radio receivers or by satellite, provides an excellent means for tracking use of the landscape (and offshore waters) by individual birds, but this techniques has limited utilization in avian risk assessments at wind projects. In most cases telemetry will be considered as a research tool. Telemetry is an expensive technique, and the process of capturing and instrumenting can be stressful to birds, especially if done during the winter months, and if transmitters are surgically implanted. Sample sizes are of necessity small. Nevertheless for some species, notably gregarious waterfowl, telemetry can provide information on temporal use of space that cannot be gathered easily in other ways.

We have used satellite telemetry to track habitat use of Long-tailed Duck (*Clangula hyemalis*) in Nantucket Sound. These ducks exit Nantucket Sound at dawn in great flights of thousands of birds, returning to the Sound at dusk. Knowing their nighttime roosting locations was relevant to a full avian risk assessment of the proposed Cape Wind project, and telemetry has enabled us to track precisely the locations, and sometimes shifting habitat use of this species. Radio telemetry was used to track individual Golden Eagles (*Aquila chrysaetos*) and helped determine "geographic affiliation" of resident eagles in relation to the Altamont Wind Resource Area (AWRA); such information was useful in determining the population-level effects of the high eagle mortality at AWRA (Hunt, 2002). Transmitters can also be used to track wintering species to their breeding grounds, a necessary activity for delineating breeding populations and interpreting possible ecological impact of a proposed project (see below). Small sample size does limit the ability to make inferences to the larger population.

Satellite Remote Sensing

A principle challenge of surveying avian activity in the offshore environment is the enormous area that must be covered, and, as turbine technology improves, this challenge will increase as wind energy projects move farther offshore into deeper waters and into the domain of pelagic bird species. We assume that abundance and activity of most migrating species, including songbirds, shorebirds, and waterfowl, as well as bats, will decrease as you move farther offshore, although in some areas, such as the Gulf of Mexico, millions of songbirds make lengthy water crossings.

Distribution and abundance of the activity of pelagic species may be highly variable as they shift activity in response to changing food supply (Powers, 1983). The possibility of using remote sensing technology to map avian activity using surrogates has yet to be implemented, but we believe is a promising possibility for mapping spatial and temporal variation in activity of pelagic bird species over large areas. For example, space-based satellites can record shifting intensities of photosynthetic pigments that indicate variation in abundance of phytoplankton. Such variation in the primary production affects the rest of the oceanic food chain, from zooplankton to fish, marine mammals, and birds.

We encourage the development of models that predict activity of pelagic bird species based on biological activity estimated from satellite imagery. These models could be tested and refined with systematic visual surveys. Such models would build on comparable approaches that have been used to define marine protected areas (CLF and WWF-Canada, 2006). This technique, however, would not provide activity estimates for avian species migrating through the pelagic environment.

The methods described above demonstrate our ability to characterize and enumerate avian activity in the offshore environment. Despite this ability, translating this activity to risk remains problematic. For example, despite the numerous studies documenting avian activity with radar, we lack the ability to predict avian fatalities with the necessary degree of precision, possibly because of the substantial habitat differences between the pre- and postconstruction environment (Kunz et al., 2007). Turbine placement in the offshore environment at Nysted altered benthic and pelagic communities with potential effects on bird habitat use (Leonhard and Birklund, 2006). In addition, as the detailed studies at Nysted indicated, certain bird species altered their activity and behavior in response to the presence of the turbines by flight avoidance or spatial shifts, confounding risk assessments by reducing collision risk, but potentially increasing other types of impact (Petersen et al., 2006).

Research that better establishes the relationship between preconstruction activity and postconstruction impact is needed (see below), but in the absence of reliable risk indicators regulators will need to make permitting decisions with criteria that use the best available scientific information, design mitigation on the basis of preconstruction assessments, and employ adaptive management that incorporates new information as it becomes available.

Recent detailed reviews on methods and metrics (e.g., Kunz et al., 2007; Desholm et al., 2005) suggest that development of universally applied standards for describing avian activity in the offshore environment is forthcoming. Such standardization in pre- and postconstruction assessments is essential and making pre- and postconstruction data publicly available should be a permit requirement.

Assessing Postconstruction Impact

Postconstruction monitoring should be designed to test the predictions of impact generated by the preconstruction risk assessment, and, as such, should continue the same methods used in assessing preconstruction risk. Radar should be operated in the same way from the same platform; aerial surveys should follow the same flight path and same flight elevation. Additional methods can also be used as described below. Evaluating habitat shifts with plane surveys as described above, or using radar to detect shifts in flight direction are relatively straightforward, although surveys may need to be conducted over multiple years. Measuring collision fatalities is more difficult. Carcass searches commonly used in assessing collision mortality at land-based turbines is not feasible in the offshore environment. We discuss in some detail below results of different postconstruction assessments in the offshore environment.

Radar studies in both terrestrial and marine environments indicate that songbirds and waterfowl change flight paths to avoid wind turbines (e.g., on land—Milliken, *in press*). In Denmark, Desholm and Kahlert (2005) recorded changes in flight path and substantial shifts in the use of air space by migrating waterfowl. The distance at which "deflection" occurred was reduced at night, i.e., birds were closer to the wind turbines before changing flight direction, presumably because visibility is lower. Waterfowl that did fly through the turbine array exited the array quickly, or flew between the turbines to maximize distance from the turbine rows (Tulp et al., 1999; Pettersson, 2005; Petersen et al., 2006). A recent study suggests that waterfowl respond to a visual stimulus and not the noise of turning blades, as turbine operation had no detectable effect on avoidance (Larsen and Guillemette, 2007).

The effect of these shifts in flight direction, *aka* 'avoidance', is to reduce collision risk. Flight deflections also result in increased flight distance, calculated in some cases as 0.5% of the total migration distance (Petersen et al., 2006). There is concern as to whether this increased flight distance and concomitant energy expenditure (and fat consumption) during migration negatively affect survival of individual birds (Ballasus and Huppop, 2006). For example, birds arriving at migratory stopover sites with lower fat levels may need to spend more time at these sites "refueling", potentially arriving later at subsequent stopover sites or breeding grounds, which could negatively affect reproductive success (Newton, 2006).

Alternatively, satellite telemetry demonstrated that Brant (*Branta bernicula bernicula*) did not fly the shortest route between their breeding grounds and wintering areas, and that substantial time was spent at intermediate locations resting and feeding (Green et al., 2002). Thus, for waterfowl, such an increase in flight caused by avoiding wind turbines may have trivial effect. Increased flight distance may increase mortality risk for smaller birds that fly over water or other barriers from nesting grounds to winter habitat, (e.g., Blackpoll Warbler-Nisbet et al., 1963; Newton, 2006).

The combination of pre- and postconstruction plane surveys have demonstrated habitat shifts following construction of offshore wind farms (e.g., Petersen et al., 2006). These studies suggest that potential loss of foraging habitat is a major concern after wind farms become operational. For example, a recent survey of bird abundance at 19 globally distributed offshore and coastal wind energy installations indicated a decline in abundance of bird species, particular waterfowl and waders, although it could not be determined whether the observed results represented population declines or shifts in habitat use (Stewart et al., 2007). It is also not known whether those shifts are permanent or whether habituation to the presence of the turbines occurs with time. As described earlier, Common Scoter (*Melanitta nigra*) showed statistically significant shifts in habitat use after the construction of the Horns Rev wind farm, but later surveys indicated that individuals of this species were becoming more common within the project area, and the effect had disappeared (Petersen and Fox, 2007). A significant habitat shift was still discernible for Common Loon. (*Gavia immer*).

Such shifts may be ecologically insignificant when wind farms are few and far between, but projected plans for offshore wind development could result in substantial offshore areas being occupied by wind farms. For example, for Denmark to achieve a goal of 50% of its electricity from wind energy, the projected development of offshore wind in Denmark would occupy an estimated 1,000 km^2 (Nielsen, 2007) of the offshore waters compared with approximately 44 km^2 occupied by the two existing projects at Horns Rev and Nysted (Petersen et al., 2006). A proposal to establish a "Supergrid" in waters of the Netherlands, Germany, and the United Kingdom could result in multiple wind farms that occupy as much as 3,000 km^2 (www.airtricity.com/ireland/wind_farms/supergrid).

Quantifying collision mortality at offshore wind farms with empirical evidence is not currently possible although estimates have been made; ocean currents may carry away carcasses and preclude using the standard techniques employed in land-based wind farms. Technology using collision-activated sensors has been developed (e.g., Wiggelinkhuizen, 2006), but this technology has several limitations (e.g., Desholm et al., 2005) and currently has limited practical application.

Thermal imagery (e.g., Thermal Avian Detection System [TADs]) has been utilized at the Nysted wind farm in Denmark (Desholm, 2005) as an alternative to direct visual observation by human observers. This system was established to view the rotor swept area of a single turbine and was designed to operate only when triggered by activity (caused by birds or bats) within the viewing area. Only one strike (a songbird or bat) was observed at the turbine in 2,400 hours of monitoring (Desholm, 2005; Petersen et al., 2006); otherwise no mortality has been observed or reported at either the Horns Rev and Nysted wind farms.

Modeling of collision risk at Nysted based on measured avian activity and estimated avoidance rates calculated that approximately 48 Common Eider during fall migration would collide with the turbines, or approximately 0.02% of the estimated 250,000 Eiders passing the wind farm each autumn (Fox et al., 2007). The results of the TADS monitoring were consistent with the low predicted collision rate; the probability of observing a single collision at one turbine were so low that the estimated 2,400 hours of viewing would have missed such an event. Thermal imaging also provides detailed data on the behavior of avian (and bat) species in the vicinity of the turbine and the rotor swept zone, but the technology currently is expensive and would appear to have limited application for quantifying and verifying collision rates, especially if only one turbine out of dozens in a project area could be sampled.

Visual observations of coastal wind farms in the Netherlands and Belgium have observed substantially higher bird collisions than those reported at Horns Rev or Nysted in Denmark. Avian composition and activity is likely different from that observed further offshore (e.g., coastal waters are closer to tern nesting sites), but the detailed observations provide useful information on avian avoidance rates and collision risk based on observations of flight height and collisions. Not surprisingly, substantially higher collision risks are observed for birds flying at rotor swept height versus all avian activity (including flying, resting, and feeding). In the Netherlands 2.5% of birds flying at rotor swept height collided with turbines, while the collision risk based on all activity was 0.008% (Winkelman, 1992a, 1992b). In Belgium, the collision probability of terns flying at rotor swept height was 0.110-0.118% (Everaert and Stienen, 2006).

In both studies, although avoidance (the inverse of collision probability) was high, absolute number of collisions was also higher than observed at the average land-based wind turbine (up to 6.7 terns per turbine per year). As these studies indicate the number of collisions is, in some general way, tied to avian activity. Even if avoidance is high, high activity levels, defined as the amount of time spent within the vicinity of the turbines, can lead to high and possibly unacceptable levels of avian mortality (e.g., Everaert and Steinen, 2006).

It is not known whether the additional avian mortality resulting from collisions with wind turbines is ecologically significant, i.e., leads to local (or global) population declines. Detailed population viability analyses for threatened or endangered species can generate predictions about the population impact of varying levels of predicted mortality, but such detailed analysis is not attempted for many avian or bat species.

Collision mortality at wind turbines appears trivial when compared to other known sources of avian mortality. For example, a total of approximately 90-100 Common Eiders were predicted to collide annually with turbines at the Nysted wind farm in Denmark as compared with 70,000 of this species legally shot during the hunting season (Fox et al., 2007). Similar projections could be made for these species in the U.S.

Raptors appear to be particularly vulnerable to collision with turbines. An offshore wind energy project near Smøla, Norway has been linked to high mortality and local population decline of White-tailed Sea Eagles that nest on islands in the vicinity of the project (Folkestad, 2006). Even with the high mortality observed at the Altamont Wind Resource Area in California, it has been challenging to establish that this mortality has resulted in a local decline of Golden Eagle (Hunt and Hunt, 2006).

After thorough review, the NRC (2007) report concluded that predicted collision mortality under different scenarios of expanded wind energy development in the mid-Atlantic Highlands of the U.S.

would not result in ecologically significant declines of migratory bird populations, but cumulative impacts could be a factor affecting local populations or populations of rare species (NRC, 2007). When federally-listed or state-listed species are involved, additional caution is required.

Knowledge Gaps and Research Needs

Substantial uncertainty remains in our ability to predict the impact of wind energy projects on birds in the offshore environment. Thus, a rigorous postconstruction monitoring protocol with long-term monitoring should be incorporated into permitting processes. Such a protocol should allow for independent assessment of the results. All information gathered should become readily available in the public domain to enable the development of improved and more cost-effective preconstruction risk assessments that lead to improved siting of future wind farms. To date, the best model for such an approach comes from Denmark with the construction and operation of the Nysted and Horns Rev wind farms, a comprehensive and well-designed risk assessment built on the Before-After-Control-Impact (BACI) model. This series of projects included frequent and public reporting, and the results are beginning to appear in the peer-reviewed literature. We look forward to a similar process currently being defined by MMS under the authority given to the agency by the 2005 Energy Policy Act, and the completion of the PEIS by MMS is an excellent start.

Comprehensive preconstruction risk assessments that compare potential risk within a broad geographic area and that define "high-risk" and "low-risk" zones will be costly. Establishing a fund, analogous to the Land and Water Conservation Fund derived from offshore oil and gas revenues, is one possible source of funding for comprehensive and geographically extensive risk assessments for birds and other wildlife. The state of New Jersey has commenced a publicly funded effort that could be a model for cost-effective and comprehensive risk assessments that minimize the impact of offshore wind energy development (GeoMarine Incorporated, 2007: Powerpoint Presentation, "Ocean/Wind Power Ecological Baseline Studies").

Additional research, outside of the permitting process, is needed to better understand the ecological consequences of observed effects of offshore wind energy development on birds. This research could also be funded by a combination of public and private funding sources (e.g., the proposed American Wind and Wildlife Institute (AWWI; see http://www.fws.gov/habitatconservation/windpower/Meeting_Feb_26_28_2008/Walker2.pdf).

The following potential research topics are listed in order of priority:

1) Cumulative impact of winter habitat loss

Shifting habitat use by waterfowl away from offshore wind energy installations is a consistently observed effect. As wind energy development expands in the offshore environment, loss of waterfowl foraging habitat may increase. Winter ranges for some species, such as Long-tailed Duck and Common/Black Scoter, stretch from waters off Newfoundland to the Carolinas or further south. Determining whether a loss of 5% or 10% of a species winter range is ecologically significant requires greater understanding of sea duck energetics, the distribution of food supply, and the dynamics of rate of depletion and replenishment after food harvest by sea ducks.

2) Delineating breeding populations of wintering waterfowl

In Denmark, waterfowl, including loons, were a focus of pre- and postconstruction assessments because this group possesses demographic characteristics that project scientists hypothesized made them vulnerable to the impacts of additional mortality or habitat displacement. Understanding the ecological consequences of winter mortality/habitat loss on species' populations is difficult without knowing which breeding populations are represented and the status of those populations. Telemetry, molecular markers, and stable isotopes are techniques commonly used for delineating populations. Population delineation of waterfowl is a major priority of the Services' Sea Duck Joint Venture Program.

3) Improve estimates of collision mortality, including effects of reduced visibility on collision risk

Addressing this issue is primarily a technical challenge because the ground searches employed in the terrestrial environment are not possible in the offshore environment. There is as yet no demonstrated relationship between the level of avian activity as determined from radar and collision risk for birds (Kunz et al., 2007). TADS is a promising but expensive technology for acquiring data that support and verify collision risk modeling.

4) Determining migratory bird and bat activity in the offshore environment

Although this review focuses on avian issues, considerable evidence has accumulated at land-based turbines that the risk to bats is greater than for birds. Radar studies suggest that bats respond later to the presence of the turbines (Milliken, *in press*), and other observations suggest that bats may be attracted to turbines (Kunz et al., 2007). It is known that the same bats that are at risk at land-based wind farms (migratory tree bats) also migrate offshore, but the numbers and patterns of spatial variation are not known beyond incidental observations.

Cape Wind radar studies recorded hundreds of thousands of targets (possibly birds and bats) during spring and fall migration, but we don't know the extent to which these numbers diminish as we move further offshore.

5) Development of measures comparing the environmental impacts, including impacts to bird populations, of different sources of electricity

As indicated at the beginning of this paper, the climate change consequences of fossil fuel use are an important driver of the development of wind energy. The mining of fossil fuels also has enormous environmental impact, but we are very limited in our ability to compare this impact against the threats posed by wind energy development described here (NRC, 2007).

Conclusion

The impact of wind energy development on wildlife, including avian species, is a significant and rapidly growing area of scientific and management concern, as evidenced by the rapidly growing body of published literature and reports. Nevertheless, given the pace and scale of offshore wind energy development in Europe (under construction) and the U.S. (proposed), it is unlikely that the needed expansion of knowledge to make the best permitting decisions will keep pace with the rate of wind energy development—a pace that is driven by concerns over fossil fuel prices and supply, and the threat of a rapidly warming climate. Ultimately, any renewable energy development must be accompanied by massive efforts to increase energy conservation and efficiency—little will be gained if wind energy contributes to increasing energy consumption while resulting in no reductions in greenhouse gas emissions.

With attention focused on the environmental impacts of wind energy development we are encouraged by efforts of regulators and the wind industry to forge alliances with the scientific community in the hope that this demonstrates a commitment to reduce uncertainty and minimize environmental impacts through learning and to applying the lessons learned.

Acknowledgments

We thank the Massachusetts Technology Collaborative, the USFWS Sea Duck Joint Venture Program, Foundation M, and the Island Foundation for their financial support of our work on the Cape Wind Environmental Review. We also thank Robert Buchsbaum, Lou Wagner, and several anonymous reviewers whose comments helped us improve the quality of this manuscript.

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