EFFECTS OF OFFSHORE WIND FARMS ON BIRDS

"CUISINARTS OF THE SKY" OR JUST TILTING AT WINDMILLS?

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ABSTRACT

A significant concern in the development of offshore wind farms is their potentially negative effect on birds. The general public's perception of these effects does not always agree with the scientific evidence, however. To bridge this information gap, this study seeks to review and analyze the existing literature on bird-wind interactions in order to assess what we know and to recommend mitigation solutions. The findings are then used to examine the impacts of a proposed offshore wind farm south of Cape Cod, Massachusetts. Much of our knowledge of avian effects at offshore wind farms comes from one site in Denmark, which demonstrated a disturbance effect on sea ducks caused by turbines, resulting in minor indirect habitat loss and a barrier to movement. Collisions with turbines remain the largest potential threat to birds from any wind farm, however, and evidence from extensive work at onshore sites has demonstrated that collisions will occur no matter where a farm is located. The magnitude and severity of all impacts, not just collisions, could best be minimized by the careful siting of proposed wind farms, although there are several other effective ways to mitigate impacts through design and planning. The proposed wind farm south of Cape Cod puts multiple groups of birds—passerine and seabird, migrant and local—at risk of collisions and other impacts. One species of primary concern is the federally-endangered roseate tern (*Sterna dougalli*), which has a large breeding and pre-migratory staging population near the proposed wind farm. In addition to requiring thorough pre- and post-construction avian monitoring regimes, U.S. policymakers should address our lack of offshore experience by limiting the size and scale of proposed projects until impacts on birds are better understood.

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TABLE OF CONTENTS

ABSTRACT

ACKNOWLEDGEMENTS

1. INTRODUCTION 1

2. POTENTIAL EFFECTS OF OFFSHORE WIND TURBINES ON BIRDS 9
- 2.1. Collisions with turbines 10
- 2.2. Disturbance: indirect habitat loss and barriers to flight 15
- 2.3. Direct loss of habitat and habitat alteration 19
- 2.4. Other possible effects 21

3. SCIENTIFIC EVIDENCE FOR OFFSHORE WIND FARM EFFECTS 24
- 3.1. Impacts of the Tunø Knob offshore wind farm, Denmark 25
- 3.2. Onshore evidence for offshore impacts: collisions 33
- 3.3. Onshore evidence for offshore impacts: disturbance 41
- 3.4. Onshore evidence for offshore impacts: direct habitat loss 42
- 3.5. Scientific evidence: the problem and the solution 44

4. PLANNING AND DESIGN OF OFFSHORE WIND FARMS 46
- 4.1. Mitigation methods: site planning 46
- 4.2. Mitigation methods: structural choices 51
- 4.3. Achieving "mitigation" 57

5. CASE STUDY: CAPE WIND OFFSHORE WIND FARM 59
- 5.1. Plans, process, and permitting 61
- 5.2. Bird use of Nantucket Sound and possible wind farm impacts 69
- 5.3. Analysis of possible avian impacts from the Cape Wind project 77
- 5.4. The bottom line 83

6. CONCLUSION 85

TABLES AND FIGURES 88

REFERENCES 104

APPENDIX A: Acronyms 114

APPENDIX B: Research methods 115

LIST OF TABLES

Table 1. Site characteristics of the nine offshore and two nearshore wind farms operational in 2003.

Table 2. Planned offshore wind farm developments in New England.

Table 3. Potential effects of offshore wind turbines on birds, separated by turbine element and groups impacted.

Table 4a-c. Summary of the results of the Tunø Knob avian impact studies.

Table 5. Important avian species groups potentially impacted by an offshore wind farm in Nantucket Sound.

LIST OF FIGURES

Figure 1. Map of the nine offshore and two nearshore wind farms operational in 2003.

Figure 2a-b. Maps of wind resources and ocean depths in southern New England.

Figure 3. Map of planned offshore wind farm developments in Massachusetts.

Figure 4a-b. Map of Tunø Knob offshore wind farm site and study area.

Figure 5. Possible spatial arrangements of offshore wind turbines.

Figure 6. Map of planned configuration of Cape Wind offshore turbines in Nantucket Sound.

Figure 7a-b. Diagram of GE 3.6 Offshore wind turbine and height comparison.

Figure 8. Map of main landbird migrations around Cape Cod in spring and fall.

Figure 9. Map of main seabird migrations around Cape Cod in spring and fall.

Figure 10. Possible optimal arrangement of turbines on Horseshoe Shoal.

1. INTRODUCTION

The need to develop sources of renewable energy is undeniable. The international dependency on fossil fuels for energy production has led to some of greatest threats facing the world as we enter the 21st century. As the three International Panels on Climate Change showed the scientific world, we now stand on the brink of the largest human-made experiment ever conducted. However, this experiment—global climate change—is an uncontrolled one, driven by our over-exuberant consumption of carbon dioxide-releasing fuels. Even to governments like the United States that have refused to ratify the Kyoto Protocol and reduce greenhouse gas emissions, the environmental benefits of non-consumptive energy are persuasive when we are confronted with rising sea levels, shifting agricultural zones, droughts, and floods. For the United States, the catchphrase “energy security” has now become commonplace in the media. With limited national supplies of oil and natural gas, increasing our supply of “homegrown” energy provides economic and physical security.

Of all the renewable energies developed for implementation, wind energy has historically remained one of the most popular and economically viable options. Concerted worldwide research and development was put into wind energy in the 1970s when oil shocks instigated by OPEC caused traditional fossil fuel prices to skyrocket (Henderson et al., 2001). This energy crisis jumpstarted wind development both in Europe and in the United States, with ambitious states like California quickly becoming world leaders in wind energy (Ackermann & Söder, 2000). The 1980s brought oil stability, however, which slowed down the American market for wind energy and effectively ended U.S. wind development until the mid-1990s. In some European countries such as Denmark, wind energy development remained subsidized throughout the 1980s and 1990s, allowing these same countries to become world leaders in wind energy in the last ten years as concerns over climate change and energy autonomy have again brought wind energy into focus (Henderson et al., 2001). Current development of wind energy has been aided by growth within the industry, allowing productivity to increase and total costs to decrease. In recent years wind energy has grown at a remarkable rate, with cumulative capacity expected to increase world-wide by 25 percent per year through 2005 (Ackermann & Söder, 2002).

In the last ten years, interest has grown—first in Europe and now in the United States—in developing wind energy in offshore areas. Any part of the continental shelf that is greater than one kilometer from the shore is generally referred to as an offshore area. The reason for the shift in development to offshore areas from terrestrial (onshore) areas can be attributed to two factors (Rogers et al., 2003). First, governments and developers have finally recognized the large wind resources available in offshore areas. Offshore areas usually have higher wind speeds, more sustained and constant winds, less wind turbulence, and lower wind shear (Henderson et al., 2001). New advances in technology accompanied by lower costs of production now allow developers to exploit these areas rich in sustained wind (Henderson, et al., 2001). The second factor motivating the switch to offshore areas has been that from a political point of view, it is quite difficult to build wind farms in terrestrial areas.

Many of the most viable areas for onshore development of wind farms are in extremely visible locations, such as ridges or hilltops, and often in areas valued for their natural environment (e.g. Nyden, 2002). Due to these factors, a common roadblock in developing terrestrial wind farms is the public's "Not In My Backyard" (NIMBY) phenomenon, as well as the more radical "BANANA syndrome," or "Build Absolutely Nothing Anywhere Near Anybody" (Duwind, 2001). Consequently, the obvious solution to land-use disputes, as well as to issues of noise and visual pollution, is to build wind developments offshore (Henderson et al., 2001).

Offshore development in the United States has been very slow, compared to that of Europe. Plans and interest in offshore development began in the U.S. in the 1970s, but despite elaborate plans for chains of floating wind turbines producing hydrogen up and down the coast of New England, the United States has yet to build a single offshore turbine (Rogers et al., 2003). The world's first offshore development, a 35 m tall, 220 kilowatt (kW) producing tripod turbine called "Svante," was built in 1990 off the coast of Sweden, with other European projects quickly following (Westerberg, 2000). Rather than design wholly new structures for offshore areas, European offshore wind farms have gradually adapted onshore technology and design to the marine environment (Rogers et al., 2003). Today, there are nine operational offshore wind farms in Europe, with the vast majority having been built in the last four years (Table 1, Figure 1). Planned growth for European offshore development is huge, with nations such as the United Kingdom planning to develop wind farms at 13 sites by 2004 (OWEE, 2003). The United States, by comparison, is still trying to get rolling.

Despite a delayed start to U.S. offshore development, recently interest in the subject has heightened, especially in New England. A recent study of wind resources coordinated by the National Renewable Energy Laboratory found that the most promising areas for offshore development in the U.S. lie in the Northeast, parts of the Great Lakes, and much of the West Coast (Rogers et al., 2003). Water depth is currently a limiting factor on placement, however. When one accounts for this constraint, the best areas for development are in the Northeast, especially around Massachusetts (Figure 2a, 2b). Areas most cost effective for building wind turbines have water depths up to 18.3 m, which includes almost all of the area directly south of Cape Cod, especially Buzzard's Bay and Nantucket Sound (Rogers et al., 2003). It is not surprising, consequently, that the first offshore wind farm development in the United States is planned for Nantucket Sound.

In the last few years, federal tax benefits for renewable energy have given enough incentive to spark planned developments of offshore areas in the United States, beginning with Massachusetts (Table 2, Figure 3). Massachusetts has a small and experimental history in onshore wind energy, with six installations in the state (MA DOER, 2003). The projects range in scale from eight 40 kW turbines placed on a hilltop near Mt. Wachusett in 1984, to the 2001 development of a single 1.5 megawatt (MW) turbine placed on the coast in the town of Hull. The other developments include a number of smaller individual turbines around the state used for either experimental purposes (e.g., Mt. Tom) or private residential energy (e.g., Great Island, Westport). The first and foremost of the current offshore proposals is by Cape Wind Associates (Cape Wind) to build 130 turbines in an area of Nantucket

Sound known as Horseshoe Shoal (Coleman, 2003). The Cape Wind project plans to install 3.6 MW turbines, built specifically for offshore areas by GE Wind (formerly Enron Wind), for a maximum output of 420 MW of energy. Cape Wind filed notification forms with both the Massachusetts state government and the Federal government in the fall of 2001, and it is currently involved in an environmental impact study process prior to submitting their final Environmental Impact Statement (EIS) to the U.S. Army Corps of Engineers. Cape Wind has two offshore wind competitors in New England, Winergy LLC and Sea Energy Generation Inc. Winergy plans to build a total of four offshore wind farms in Massachusetts, part of a grand plan for at least 16 sites from Massachusetts to Virginia, many of them larger than the Cape Wind project (Winergy LLC, 2003). Winergy filed for permission to build with the federal authorities in March of 2003 and expects the permitting process to take three to five years (Leaning, 2003b). To date, no information is available on Sea Energy Generation's plans.

Due to its sheer scale and ambition, the Cape Wind project has quickly become a contentious political topic, causing deep divides in Massachusetts, particularly among environmentalists and residents of Cape Cod. As former Massachusetts Secretary of Environmental Affairs, Bob Durand, noted in the Environmental Notification Form (ENF) certificate for the project, "Few projects in the history of the MEPA [Massachusetts Environmental Protection Act] program have generated so much written commentary. I have received thousands of letters and e-mails regarding the Cape Wind Project" (Durand, 2002: 2). In the resulting war of words and rhetoric, contained in editorials of the *Cape Cod Times* and on websites and chat rooms, the two issues that those against the development most often bring up are the visibility of the wind farm and its effects on birds. These complaints are not especially surprising, given that a survey of European leaders of the offshore wind industry in 2000 found that the two issues most important to their country's populations in terms of negative impacts of wind farms were found to be birds and visual effects (Duwind, 2001).

The wind industry has a long history of interaction with birds. Evidence of serious negative impacts on birds first arose in the late 1980s, following the early reports of hundreds of raptors being killed every year by wind turbines in the Altamont Pass area of California (Kerlinger, 2001). The sense of risk was reinforced in the 1990s by similar problems with migrating raptors near Tarifa, Spain, where a number of endangered griffon vultures (*Gyps fulvus*) were killed by collisions with wind turbine rotors (Langston & Pullan, 2002). As a result of these problem sites that generated a lot of bad press for wind energy, a large and concerted international effort began in the early 1990s to carefully document the effects of wind farms on birds. For example, the U.S.-based National Wind Coordinating Committee has been organizing regular National Avian-Wind Power Planning Meetings since 1994. These meetings have allowed American and European avian researchers to share results, explore new methodologies, and critique findings. One of the outcomes of the meetings has been a guidance document on standardized methodologies for assessing avian impacts at wind farm sites (Anderson et al., 1999).

Despite this scientific attempt to understand the impacts on birds, in the lay literature—newspaper articles, company brochures—the effects of wind turbines on birds are misrepresented, over-generalized, misunderstood, or poorly extrapolated. For the average citizen trying to make an informed decision between "Cuisinarts of the sky" and "humanity's solution to environmental problems," there seems to be no middle ground. Finding a solution to this dilemma is important for two reasons. First, there is the inescapable reality that these artificial structures may have significant negative impacts on the natural environment, especially in situations involving threatened or endangered species. Second, it has been shown through extensive experience in Europe that the public perception of bird impacts has historically proven to be one of the major factors deciding whether wind farms succeed in acceptance and gain permits in a geographical region (Duwind, 2001). Birds, consequently, "hold a lot of bargaining power" in political situations involving wind energy. Finding a resolution to the debate is not aided by the fact that often the only "science" that evaluates wind farms and their effects on birds is usually that done through required environmental impact assessments. While some of this information is valuable, developer-driven science required by environmental legislation has long been criticized as being incomplete, biased, and otherwise greatly flawed (Treweek, 1996).

Given the need to find a scientifically-supported conclusion to the birds versus wind farm debate, as well as the need to address the regionally important issue of the possible effects on birds of the Cape Wind proposal, this study seeks to answer the following questions:

(1) What types of effects on birds could arise through interactions with wind turbines, their construction or associated structures?

(2) How much scientific evidence is there for these various effects in offshore areas? If little, where else can we draw useful evidence?

(3) What are, and how important are, the planning and design factors that increase or decrease effects on birds?

(4) What are the implications of the previous answers for the planning, design, and debate around the proposed Cape Wind offshore wind farm?

The answers to these questions are discussed in the following four chapters. Each chapter roughly follows each question in order, with the fourth chapter being the case study of the Cape Wind project. A conclusion section follows the four analytic chapters.

2. POTENTIAL EFFECTS OF OFFSHORE WIND TURBINES ON BIRDS

A wind turbine is a construction that converts wind power into mechanical energy that is then converted to electricity. A wind farm implies a zoned area comprised of a group of turbines and the land or water on which they are situated. Turbines today are mostly of the "tubular" design—a narrow cylindrical tower with a box-like generator at the top attached to a three-blade rotor. Older turbines come in a variety of forms, including the Eiffel Tower-like horizontal- and diagonal-lattice turbines and the odd-looking vertical-lattice turbines (c.f., Thelander & Rugge, 2000). Height, color, rotor size and speed, and overall power are highly variable among modern tubular turbines, although the trend now is toward larger, slower, and more powerful turbines. This trend is especially true with new planned offshore turbines. For example, the first offshore turbine over 1.0 MW in power was built in Europe in 2000 and offshore turbines are expected to be up to 5.0 MW in the next few years (Henderson et al., 2001). The planned Cape Wind project in Nantucket Sound uses 3.6 MW turbines.

For offshore wind farms, a lot of the variability in design and structure that leads to environmental impacts depends on the characteristics of the location. Water depth and benthic conditions will determine what kind of foundations turbines will have. Current methods are as different as encasing the turbine in a large block of submerged concrete, versus drilling a deep hole into the sediment and securing the turbine within it (Byrne Ó Cléirigh, 2000). Seafloor disturbance from construction will depend on foundation type, which will then have varying effects on the surrounding habitat. Total area, spatial arrangement, distance to shore, and localized marine conditions (e.g., tides and currents) will also play important roles in the structural design of turbines and their environmental impacts.

It is also important to note that effects on birds can differ depending on their use of the wind farm area. A large distinction arises between local birds that use a proposed wind farm site frequently for foraging, breeding, or resting, and migrant populations that either pass through the area briefly or use it only for staging. Staging is the period before a large migration where birds gather in flocks and put on extra fat as reserves. Some historically-known staging areas can be of great importance to the survival of a species, due to the coincidence of staging and seasonal abundance of food. The impacts of a wind farm will not only differ in scale for local populations versus migrants, but the risks to species will depend on this distinction as well. Migrant passerines, for instance, will exhibit different flight behaviors (e.g., higher altitude and mostly at night) than local populations. A summary of potential effects of offshore wind turbines on birds, separated by bird group, is displayed in Table 3.

2.1. Collisions with turbines

Collisions may be the most obvious effect of wind turbines on birds, but the risk and cumulative effect of collisions is poorly known. Collisions can occur in several ways: first, when a bird collides with the non-moving part of the turbine (e.g.

hub, tower, or motor box), or second, when it makes contact with the spinning rotor blades. A third type of collision does not require physical contact with the turbine at all, but involves the bird being caught in the strong pressure wave, or “wake,” following passing of a rotor blade (Winkelman, 1992b). Wake collisions can cause the bird to become disoriented, lose control and collide with the turbine, or be thrown down into the ocean (or to the ground, if on land).

The occurrence of these three types of collisions is determined by a number of factors. Stationary collisions are essentially regulated by the same factors that result in collisions with towers. An extensive literature concerns itself with collisions of birds—mainly passerines migrating at night—with communication towers (c.f., Evans, 2000; Kerlinger, 2000). The conclusion of these studies is that towers generally accrue larger numbers of collisions with increased height and with certain types of illumination, such as revolving or steady (non-blinking) lights (see later discussion on lighting). Towers greater than 150 m tall are more often associated with higher mortality rates, as well as increased probability of large-scale “mortality events” (Kerlinger, 2000), although all towers need to be judged by the criterion of cumulative impacts. On land, not all stationary collisions result in mortality, as birds can often be knocked out and later regain consciousness. The chance of mortality greatly increases with offshore wind farms, however, as unconscious birds quickly drown.

The risk and frequency of both rotor collisions and wake collisions are related to the speed and size of the particular turbines. The smallest offshore wind turbine in operation today has a rotor diameter of 34 m. The new offshore wind turbines built by GE Wind, in contrast, have a rotor diameter of 100 m. Because of their massive size, these rotors revolve relatively slowly, between 8.5 and 15.3 revolutions per minute (GE Wind Energy, 2003). The slow revolving speed of these large offshore turbines is sometimes cited as a reason why bird collisions are less likely with today's technology (Chris Sherman, pers. comm.).

However, for a turbine such as the GE Offshore 3.6 MW, which is the planned model for Horseshoe Shoal, the outside tip of each rotor blade moves at a speed between 100 and 179 mph, depending on the wind velocity.[1] The rotor sweeps through a vertical area of over 1.9 acres (7850 m^2), with a blade passing any stationary point within that area every 1.3 to 2.3 seconds. The weight of the rotor of the GE turbines is unknown, but of the several wind turbines being constructed in 2002 with 80 m diameter blades, the V80-Optispeed had a rotor and nacelle weighing 95,000 kg, and the Nordex N-80 weighed almost 120,000 kg (Ackermann & Söder, 2002). These blades move with extraordinary force and momentum. It is not surprising, consequently, that some carcasses of raptors discovered at onshore wind farms have been found cleanly decapitated (Bradley, 2003).

The great speed of revolving rotor blades contributes to the effect known as motion smear—the degradation of the visibility of rapidly moving objects (Sinclair, 2001). This effect is held to be partly responsible for collisions, as birds may not be able to discern the individual rotating blades and consequently see them as a threat. The amount of motion smear is greatly decreased with fewer revolutions per minute (as in offshore turbines). But, for all blades, motion smear increases as you move

[1] The calculations are by the author, unless specified.

outward from the center of rotation. This effect will be most prominent in especially large blades. Researchers have experimented with paint patterns to decrease the effects of motion smear on birds; however, the efficacy of this technique is not yet known (Sinclair, 2001).

In discussions surrounding the effects of collisions on birds, it is important to look at how collisions can actually impact species. One outgrowth of these discussions is the concept of looking at the “cumulative impact” of wind turbines on birds. Some authors have gone to great lengths to trivialize the effects of wind turbines on birds by comparing extrapolations of numbers of birds killed by turbines to other sources of mortality. Erickson et al. (2001) for instance, compared the approximately 10,000 to 40,000 bird deaths per year from wind turbines in the U.S. to estimated mortality from vehicles (60 million – 80 million) and communication towers (4 million – 50 million). Calculating estimates of mortality at current land-based turbines in the U.S. presents impressive challenges based on the paucity of studies and utter failure in most studies to follow standard and accepted methodologies (c.f. Morrison, 2002).

Even if we accept these estimates, the comparison of Erickson et al. has a still greater shortcoming. The study only compares total mortalities from various sources, and not the risk that each source poses. For instance, Erickson et al. suggest that mortality from wind turbines is negligible since vehicles are responsible for so many more bird deaths per year, in comparison. But what risk do cars pose? There were approximately 230 million registered motor vehicles in the United States in 2000 (TranStats, 2003), giving vehicles as a whole the rather low average of 0.3 bird fatalities per vehicle per year. This is seven times less than the purported average of 2.19 avian fatalities per turbine per year attributed to wind turbines in the U.S. by the same study (Erickson et al., 2001). The problem is that while existing wind turbines contribute only a small sum to the total mortality of birds in the United States, that does not provide any justification for lack of concern over the potentially high level of mortality that may be added with each new turbine built. Clearly, studies like Erickson et al. demonstrate that bird populations are under significant negative pressures from a variety of sources. Wind farm studies should take this into account, considering the effect of the turbine on species and populations in the wider context, rather than in a statistical vacuum.

The study of Erickson et al. (2001) does give rise to a valuable point, however, which is the problem of relying on numbers and statistics when evaluating effects of wind farms on birds. Of all the wind farms in existence, few have ever been documented as having "significant" numbers of collisions. One of these is Altamont Pass, in California, where a large site with over 5,000 operating turbines has been associated with large numbers of bird fatalities, including many raptors such as the golden eagle (*Aquila chrysaetos*; Hunt et al., 1998). In a one-year study involving only a representative 400 of those turbines, Thelander and Rugge (2000) documented 95 fatalities from collisions, of which 51 percent were raptors. Overall they estimated 0.15 bird fatalities per turbine per year (0.06 for raptors), which they considered to be a relatively low number. However, when applied to the Altamont region as a whole, it corresponded to 750 bird deaths per year (300 of which would be raptors). To understand the impact of these figures it is important to note that species that will be most heavily impacted by turbines are slow-breeding ones with normally high levels of adult survival (Morrison et al., 1998). This characteristic describes most raptors and large seabirds. Due to the high levels of mortality at Altamont, Hunt et al. (1998) found the surrounding population of golden eagles to be significantly declining.

While this example provides little guidance for offshore cases, it illustrates the point that numbers such as deaths per turbine per year mean little without the surrounding context. Even when added up to cumulative bird deaths per year, the Altamont numbers may not have been significant to bird populations except for the fact that the fatality representation was falling unequally on raptors, including the highly sensitive eagle population. This result may have been easily missed at other sites and is only the result of the prolonged interest in understanding the impacts on birds at Altamont.

2.2. Disturbance: indirect habitat loss and barriers to flight

Wind turbines are known to disturb the surrounding environment in a number of ways that affect birds in addition to the threat of collision (Table 3). Depending on the environmental conditions and spatial arrangement of the turbines, they create several varieties of noise including broadband, impulsive, and low frequency (Therkelsen et al., 1998). Broadband is by far the most common noise emitted and is aerodynamic in nature, resulting from the flow of air over and past the blades. Broadband noise increases as rotor speed increases (Therkelsen et al., 1998). These noises may disturb birds, ousting populations that use the area on a constant basis, as well as discouraging birds from flying through the area.

Noise disturbance can be compounded by visual disturbance, from either the presence of the wind turbines or the large, rotational movements of the blades. Increased human activity in the vicinity of the turbines (e.g. for maintenance) can further cause birds to avoid the area. For most species, increased noise, visual stimuli, and human presence would lead to an increased avoidance of an area, although it is possible that species could habituate to this environment or even learn to exploit it.

This disturbance caused by wind turbines can have two major impacts on birds: the indirect loss of habitat and the creation of a barrier to flight patterns. An indirect habitat loss could occur when resources that are important to a species, but are otherwise not uniformly distributed over the entire oceanic region, are located within the area disturbed by a wind farm. The species would have access to the resource originally, but would avoid the area once a wind farm is built, resulting in a loss. Resources defining habitats could be as specific as rare eelgrass beds, or as general as an area of unusually warm, cold, deep, or shallow water. Disturbance effects and the size of the avoidance area are correlated to the number of turbines in a given area and the shape (circular, rectangular, or elongated) of the wind farm. Therefore, larger farms could lead to larger losses of habitat.

Habitat losses due to avoiding disturbance are labeled “indirect,” as unlike “direct” habitat losses (see next section), the wind farms are not physically excluding birds from the habitat but making the habitat less desirable. Indirect habitat losses of this type are not restricted to wind farms, but have been documented with birds in response to a variety of human-made structures. Roads may be the clearest example, where birds have been shown to be particularly sensitive to noise (Forman et al., 2002).

Indirect habitat losses will mostly be an issue to local species relying on specific areas for their resources. These populations may have access to a resource in only one area and unless they abandon historical breeding or wintering grounds, would be unlikely to find a replacement for the resource. Consequently, wind farms could lead to a decreased abundance of food gathered by a summer population, for example. This effect, in turn, would reduce breeding success and population recruitment, exacerbating other negative pressures on the population—whatever they may be. For a wintering population that is displaced from a favored feeding ground, wind farms could cause increased mortality due to starvation or through the hardship of forcing the population to relocate to another wintering area. While an indirect loss of habitat seems most relevant to local populations, it could potentially impact migratory populations that use a specific area as a staging ground. Many species, especially non-passerines, show high levels of site fidelity to staging grounds (Berthold, 2001). In some cases, the timing of staging will specifically coincide with seasonal abundances of certain food sources, such as with the red knot (*Caladrus canutus*) and horseshoe crab eggs in Delaware Bay (Myers et al., 1987). Consequently, the loss to a species of the use of a staging ground could be potentially disastrous.

The second possible effect of wind farm disturbance is to act as a barrier to movement. Barriers occur when species choose to fly around a wind farm rather than fly through it. While this behavior can reduce collisions, the negative impacts of barriers to movement arise when wind farms are located in specific areas that are important to the movement of species. Generally, these negative impacts can occur in two ways. First, if a wind farm intersects a major migration route, that can cause extra stress to species passing through, or it can force the birds to exert extra energy through rerouting around the wind farm. Birds in migration, especially passerines over oceans, typically have abnormally high blood pressures and metabolisms due to the strenuous nature of the endeavor (Alerstam, 1993). Over-water migrations of passerines encountering adverse weather conditions have resulted in reports of extremely large mortality rates (Berthold, 2001). The placement of an ill-planned offshore wind farm could add to this stress and possibly lead to unforeseen direct or indirect avian mortality. However, under most conditions it is known that passerine migration offshore occurs well above the height of turbines, thus decreasing the risk of wind farms as barriers for migrating passerines (Berthold, 2001). Seabirds in migration, while they may be more willing to fly around the wind farm, would be far less impacted by this barrier because they are better prepared and adapted to long flights over water without rest (Nelson, 1980).

The second negative impact of barriers occurs when wind farms directly block daily home-range movements of species—such as those flying to and from preferred feeding and roosting sites. For offshore wind farms, this second category is of small concern due to the lack of a surface topography leading to restricted freedom in daily movements. For example, on the open ocean, birds generally have more choices of direction of route of movement than do birds in hilly regions. This freedom of mobility is, of course, subject to the particulars of a certain location, and the placement of wind farms between routes of daily movement should in general be avoided. Hypothetically, if a wind farm were placed between two areas of importance to a species (e.g. roosting and feeding habitat) and if either the wind farm were significantly large or the birds were funneled into the area with the wind farm, the barrier effect could be quite significant.

2.3. Direct Loss of Habitat and Habitat Alteration

Direct habitat loss results when the habitat is built upon, physically altered, or otherwise "lost" as a direct result of a wind farm. For offshore wind farms, significant impacts to birds of direct habitat loss would be rare and easily foreseeable. The only space lost from an offshore turbine would be the area on the sea floor used for the foundation and the water and air space containing the turbine and rotor. While direct habitat loss could occur during construction (see later discussion), permanent loss of any significance to birds would only occur if the losses incurred by individual structures were enough cumulatively to upset a balance and destroy a fragile part of the ecosystem. This would be akin to building a wind farm on top of a small, isolated coral reef.

The most likely effects of a wind farm on the immediate surrounding habitat would be to alter it, in either positive or negative ways. In the positive sense, turbines could create perches for birds, creating new habitat in an offshore setting. However, the space for perching, especially for larger seabirds (e.g., cormorants) on offshore turbines would be extremely limited. The cylindrical tower would not be conducive to perching, nor would the mechanical hub at the top, given its close proximity to the rotor. One might think that creating perches for birds would be a good idea, however the ability of birds to perch on turbines has long been associated with high risk of collision (Orloff & Flannery, 1992). For this reason, even light boxes low on the turbine tower often come with "bird-spikes" to prevent perching (Pepper, 2001).

The submerged base of the turbine, however, could act as considerable habitat for aquatic animals. Mussels, snails, and other invertebrates could colonize the turbine foundation, creating food for other species. This, in turn, would result in what is known as the "reef effect"—fish would gather by the turbine foundations as they do around docks, both feeding off the marine community on the turbine and also using the base as protection in the otherwise open ocean. A reef effect could considerably improve food resources for birds feeding in the vicinity of a wind farm. The abundance of marine life could be encouraged by wind farms behaving as fish refuges, because trawling and other highly extractive forms of fishing would be unfeasible at most such sites. However, the ability of birds to capitalize on these food resources would be dependent on their willingness to enter the wind farm area.

Wind farms could also alter the surrounding habitat negatively. Underwater vibrations and electromagnetic impulses released by the generator and cables could disturb fish populations. The water around the turbines could be polluted from spilled materials during maintenance activities or from chemicals washed into the ocean during turbine cleaning. These activities are unlikely to be monitored, either for actions or for chemical agents used.

Lastly, turbines could interrupt naturally-occurring processes of sedimentation. For example, the placement of turbines in sandbanks could cause localized accretion of sand, raising the substrate level and consequently lowering the suitability of the benthos for sand eels, a primary food source for many seabirds (Langston & Pullan, 2002). The negative habitat impacts of wind turbines are most likely to be highly site-specific and might be able to be controlled or mitigated. The negative impacts of the habitat alterations would primarily be of significance for local or staging populations of birds.

2.4. Other possible effects

One potentially large impact on birds could arise during construction of a wind farm (Table 3). In general, just the constant presence of ships, humans, and large machines at the construction site could displace sensitive species from the area. Furthermore, the drilling, trenching, and other preparatory measures necessary to install turbines and lay electrical lines could cause severe disruption to the seafloor community. A large bed of mollusks, if destroyed in construction, could take up to several years to re-colonize and grow. Consequently, while impacts of construction (and disassembly) can be quite severe on bird populations, the effects in most cases should be temporary. Nevertheless, it is possible to cause significant damage to birds in a short-term period (especially for sensitive or declining species), so construction impacts should be well understood and mitigated where necessary.

Two other factors, cabling and lighting, have possible impacts that would be site-specific depending on the design of the wind farm. Only in rare cases should offshore turbines be required to use above-ground cabling to connect the turbines to the mainland. Over-water electricity lines could be extremely harmful to birds, as they present immense electrocution risks, as well as providing tempting places to perch or even nest. Underwater, buried cabling is the standard among currently-operating offshore wind farms, and this presents far fewer risks to birds. While the impact of cabling on fish and other sea life is unknown, it would affect birds only as any impact traveled up through the food web.

Lighting of turbines, however, could pose a larger threat to birds. In the United States, offshore objects are subject to multiple federal regulations on lighting. The U.S. Coast Guard requires ship-lights on turbines at 10 m above the high-water mark, while the Federal Aviation Authority (FAA) has guidelines mandating lit markings placed on structures taller than 200 feet (Therkelsen et al., 1998). Thus most new large offshore turbines in the United States would be required to include these aviation lights. The ship-lights on turbines could illuminate the ocean water, allowing pelagic birds to fish near the turbines at night. This positive effect of lighting has been observed near offshore oilrigs, which have far more powerful lights than would be present on turbines (Langston & Pullan, 2002). Thus overall, the ship-lights on a turbine hub would be likely to have little negative impact on birds.

However, aviation lights and other blinking, strobing, and rotating lights, have long been associated with massive mortality events at towers and lighthouses (Kingsley & Whittam, 2001). The reason for this effect is not well studied, but it is understood that birds—mainly nocturnally migrating passerines—somehow become disoriented by the lights and alter their course (Cochran & Graber, 1958). The effect is further amplified during inclement weather (fog, heavy rain), which can increase reflection and refraction of the lights (Seets & Bohlen, 1977; Kemper, 1964). Flocks have been observed to circle around communication towers continually until most or all of the members of the flock have collided (Kemper, 1964). Apparently, lighting on towers is only an issue on really tall structures; one source lists the height where it can become a problem at 90 m (Crawford & Engstrom, 2001). Large offshore wind turbines, consequently, can be expected to place nocturnally migrating birds at risk.

Lastly, the land-based connection of the wind turbines to the power grid may impact terrestrial bird species. In most cases, some kind of infrastructure will have to be built on-shore to regulate the incoming power from the turbines. This construction could impact local populations of birds that breed, roost, or forage in the habitat in or around the new structures.

3. SCIENTIFIC EVIDENCE OF OFFSHORE WIND FARM EFFECTS

Of the nine operational offshore wind farms in the world, only five have been running for three or more years (1: Vindeby, Tunø Knob, Bockstigen, Utgrunden, Blyth). Three years is the minimum amount of time after construction needed to run a study of Before-After/Control-Impact (BACI) design (Anderson et al., 1999)—an impact assessing method that is now a standard for wind farm projects. Furthermore, of those five offshore wind farms, avian impact studies have been undertaken for only three of them (Tunø Knob, Utgrunden, Blyth). For the other three, Environmental Impact Assessments (EIAs) predicted avian impacts to be negligible, therefore not requiring any further research (Percival, 2001). Two of the three operating offshore sites with avian studies, Utgrunden and Blyth, have not released any details of their ongoing avian studies to the public as of the submission of this work. The bulk of our direct knowledge of the impacts of offshore wind farms on birds, consequently, comes from only one primary source—the Tunø Knob wind park in The Netherlands. Therefore, studies of terrestrial wind farms, especially coastal ones, must be used to provide additional key insights.

From a pure data standpoint, the limited direct empirical data present a serious problem to any group trying to accurately predict the impacts of offshore wind farms based on past experience. Fortunately, most currently planned wind farms in Europe are organizing intensive BACI-type bird studies that will provide new results in the coming years. As the next round of offshore wind farm studies (e.g. Horns Rev, Utgrunden, Blyth) are just now ending, we should expect several important studies to become available between the end of 2003 and the middle of 2005. These studies will, no doubt, add much to our limited understanding of offshore wind farm impacts.

3.1. Impacts of the Tunø Knob offshore wind farm, Denmark

The Tunø Knob wind farm (called a “wind park” in the literature) covers 32 hectares (79 acres) of ocean, 3 km west of Tunø Island and 6 km east of the Danish mainland, known as Jylland (Guillemette et al., 1998). The wind farm is located in water 3 to 5 meters deep, approximately 400 m north of a large reef which lends its name—Tunø Knob—to the development site. During low tide this reef is exposed, providing a resting spot for birds. For this reason, as well as for the numerous mollusks that live in the shallow nearby waters, the Tunø Knob area has long been known as a feeding and wintering ground for many bird species.

The Tunø Knob wind farm was constructed during the summer of 1995 and was operational by the end of that year. It is composed of ten 500 kW turbines with tower bases that rise 40.5 m above the water and rotor diameters of 39 m, for a maximum blade height of 60 m above sea-level. The total sweep of each turbine is 1,195 m^2, a vertical area exceeding a quarter of an acre. The turbines are arranged in a rectangle, with two rows 400 m apart, of five turbines each spaced 200 m apart. The turbines were erected on 1,000 tonne (1,102 tons) concrete foundations of the box caisson type, each with a footprint of 100 m^2 (Madsen, 1997, in Guillemette et al., 1998). The turbines are not reported to include any illumination (e.g., red navigation lights), possibly because the area has been closed to the public (military zone) since the 1940s and the turbines are not tall enough to interfere with aviation.

While the Danish waters around Tunø Knob are home to a diverse array of seabirds, all the environmental impact studies have focused only on two species of special concern, the common eider (*Somateria mollissima*) and the black scoter (*Melenitta nigra*, called "common scoter" in Europe). The studies focused only on these two species because they were identified as the two most at-risk by the construction of the wind farm at Tunø Knob (Guillemette et al., 1998). Both duck species use the shallow waters such as those around Tunø Knob as primary wintering and molting grounds, feeding on the nutrient-rich benthic biomass that is both abundant and accessible there (Guillemette et al., 1998). Because these shallow water areas are highly favorable sites for wind farms, present and future, Guillemette et al. (1998) cited that as an extra reason why the eiders and scoters were particularly chosen for their study. Additionally, both species are especially gregarious, commonly forming wintering flocks in the tens of thousands (Goudie et al., 2000). While common eider populations are well studied and monitored internationally, very little is known of the demographics, ecology, or even distribution of black scoters (Fox & Pihl, 2000).

With these two species in mind, researchers set out before the construction to "quantify the potential impact of the Tunø Knob wind park on sea duck abundance and distribution in winter" (Guillemette, 1998: 9). This impact was understood as reflecting a combination of disturbing the birds and an alteration or deterioration of their feeding habitat (Clausager, 2000). Bird collisions were not studied throughout the impact assessment, as a result of difficulties in finding an appropriate methodology. The original impact study was organized into three parts: a Before-After/Control-Impact (BACI) experiment comparing the Tunø Knob wind farm area to a nearby control area, Ringebjerg Sand (see Figure 4a); another BACI experiment just comparing eiders in the construction zone (NW quadrant) of Tunø Knob to three study quadrants adjacent to the south, south-east, and east (see Figure 4b); and three smaller experiments looking at variables of food supply, turbine noise, and flock attraction (Guillemette et al., 1998). The major bird surveys were conducted only during the winter (November through April), since that is when these species were present in the area, and were repeated over three years, 1994-1997. As the turbines were erected during the summer of 1995, the final year, 1996-1997, was more than a full year after completion of the wind farm and thus was used for the "After" comparison. The full results of this study and the Tunø Knob EIA can be found in Guillemette et al. (1998). This report was published by the Danish National Environmental Research Institute and represented a collaboration between the Danish government and the energy consortium ELSAM to better understand the environmental impacts of wind farms.

The initial results of the Tunø Knob experiments did not look very favorable for the ducks (Table 4a). By the second winter after construction (1996-1997), eider numbers had dropped by 75 percent and scoter by more than 90 percent relative to baseline data at Tunø Knob. During the same period of time, eider numbers at the control plot of Ringebjerg Sand remained constant and scoter numbers were only slightly less than in previous years. Total numbers of eiders in the whole of Århus Bay remained constant, implying birds from Tunø Knob had vacated that site and moved elsewhere in the bay. In comparing the four subdivisions within the Tunø Knob area, of which only one (NW) contained the wind farm, all areas showed a marked decrease in eiders after the initial base-line year, except for a large increase in the SW quadrant during the second year (3-5 months after starting turbine operation).

The three manipulative experiments provided added insight. The first experiment controlled for food supply and then turned the turbines on and off, to see the impact of a fully functioning wind farm on the ducks. This experiment found that the noise and movements of the rotors seemingly had no negative effect on eider abundance or distribution. A second experiment manipulatively controlled food supply by pulling out blue mussels around the site, then looked at the proportion of eiders at four distances from the turbines (0, 300, 320, and 600 m). They found that when controlling food supply, eider abundances at these distances were not significantly different. The third experiment used decoys at distances up to 500 m from the wind farm to try to attract flying eiders to land, in order to detect whether the ducks were scared of the turbines when flying or landing. The results showed that eiders generally avoided flying and landing within 100 m of the turbines.

The apparent conclusions of the majority of these results were compromised by the concurrent decline during the 3-year study period of blue mussels (*Mytilus edulis*), a mollusk that is the favorite prey species of the eiders and scoters. Consequently, Guillemette et al. (1998) concluded that the large decline in eiders and scoters in the Tunø Knob area over the course of the study period was not a result of disturbance from the wind farm, but was incidentally a result of declining biomass of a preferred prey species. This conclusion was supported by the fact that during the same period, mussel populations at the control site, Ringebjerg Sand, stayed relatively constant, as did duck abundance of both species. This conclusion is also consistent with the food-controlling experiment, which did not find a disturbance effect. As for the BACI comparison of the four quadrants at the Tunø Knob site that also found a decline in eider abundance, variation among the quadrants was explained as a result of large inter-annual and seasonal fluctuations in eider distribution and numbers. The only negative impact concluded by Guillemette et al. (1998) came from the third smaller experiment, which found eiders to avoid turbines at close distances while flying or landing.

The acceptance of these conclusions was mixed. In a review by Lowther (2000), he described the correlation between mussel declines and duck abundances as "sufficient to account for a high proportion of the overall variation" but stated that the correlation was far from conclusive, especially in terms of explaining scoter declines (Lowther, 2000: 121). Lowther also brought attention to the fact that the study does not examine the potential impacts of the turbines (either their operation or construction) on the mussel populations themselves. He specifically noted that sediment disturbance involved in construction could explain the combined mussel-eider decline.

Due to the slightly ambiguous results of the first three-year study of Tunø Knob, the Danish government decided to continue monitoring duck populations for a fourth year. The results of this study are published in Guillemette et al. (1999; Table 4b). The fourth year of the study (1997-1998) was a good year for mussel settlement, showing large increases in small- and medium-sized mussels (the preferred size for eiders and scoters) as well as all other typically occurring bivalves and eider prey species. Supporting the food supply-duck abundance hypothesis, the fourth year of sampling also witnessed increases in both eider and scoter abundances within Tunø Knob. Common eider numbers peaked even higher than during the 1994-1995 base-line year, while black scoter numbers reached about half of that observed in the base-line year. The study also found that the eiders preferentially exploited only those mussels in the shallowest (0-6 m) water (Larsen & Guillemette, 2000). Consequently, it was hypothesized that in the intermediate years (1995-1997) when the eiders were absent, they had moved on to find mussels in distant shallow-watered areas instead of just moving into nearby deeper waters.

In the Guillemette et al. (1999) analysis of the distribution of eiders within the Tunø Knob study area, they observed that in the fourth year (1997-1998), eider abundances increased in all quadrants from those found in the two previous years. However, they cautiously noted that in the NW quadrant, which contains the actual wind farm turbines, eider numbers increased the least. From their figures we can estimate that in the NW quadrant eiders increased by about 300 birds (300 percent) in the fourth year of the survey, while the other three quadrants increased an average of 950 birds (1900 percent) each. While the authors concluded that these differences were just a result of "natural variation," it is more likely that these data indicate short-distance disturbance effects caused by the wind farm, similar to those found in the original decoy experiment of Guillemette et al. (1998).

One last study at Tunø Knob, reported by Tulp et al. (1999, in van der Winden et al. 2000), looked specifically at the nocturnal flight activity and patterns of wintering common eiders around the wind farm (Table 4c). To estimate numbers of potential collision victims at offshore sites, it is important to know how birds behave around wind turbines in varying weather and light conditions. The results of Tulp et al. add to those reported previously by Guillemette et al. (1998), indicating that the eiders actively avoided the wind farm while flying and that this avoidance effect is found up to 1500 m from the turbines. They also reported that while eiders and scoters were nocturnally active, they flew far less frequently on dark nights than they did when there was substantial moonlight, possibly due to fear of the rotors in the darkness. The study did find that on nights with no moonlight, the eiders tended to avoid the turbines less and many groups flew directly through the wind farm. As the radar was not able to pick up altitudes, it was not certain whether the birds adjusted their flying height when traveling through the wind farm in the dark. The report concludes by commenting that the avoidance effect of wind farms indicates that these structures act as barriers to flight, thus providing important considerations for planning around sites within local migration routes (van der Winden et al., 2000). It should finally be noted that by the time Dirksen et al. completed their study, the ducks were most likely exhibiting habituated responses to the turbines. The study's observed flight behavior of eiders around turbines is consequently best extrapolated to predictions of the behavior of resident birds around turbines, rather than for the behavior of migrating birds, even other eiders.

The results of all studies done at Tunø Knob are summarized in Table 4(a-c). These results, in many ways, are the only primary evidence we have of the impacts of offshore wind farms on birds commonly found in offshore areas. They are especially helpful in indicating the horizontal extent of disturbance effects in offshore areas. Nevertheless, it is critical that we understand the limitations of the Tunø Knob studies in order to better realize their applicability to current offshore wind farm scenarios.

One clear limitation in the study is the paucity of species analyzed. While common eiders and black scoters were of particular concern to the Tunø Knob location, potential negative impacts on birds are obviously not limited to these two species. These two species are also not necessarily the best choices for representative species from which we can extrapolate potential impacts for other species. As Clausager (2000) notes, the common eider is an especially robust bird, with its sensitivity only rising with increasing flock size (raft size). In the Tunø Knob studies, the eiders were generally found in relatively small rafts, less than the tens of thousands of individuals that are more typical of this social species. Environmental impact studies should strive to analyze impacts on both the most sensitive species and those at risk of greatest impact. For Tunø Knob, the black scoter probably satisfies both of these requirements, but the common eider does not.

In addition, the Tunø Knob studies were restricted to only one season of the year (winter) and did not include the molting season, when birds are flightless. Nor did they include migration season, when the wind farm could potentially impact large numbers of other species during a relatively short period of time. They also did not look at flight patterns and disturbance in unfavorable weather conditions (e.g. heavy fog). To do so is especially important in trying to estimate bird collisions, a possibly huge impact about which we know very little in the offshore realm (see next section).

Lastly, it is important to keep in mind the differences between a small-scale wind farm with older turbines such as Tunø Knob and the new, large-scale structures in existence or being planned. Tunø Knob has only ten turbines, while most currently planned offshore farms are ten to twenty times as large. With increased size comes increased barrier effect, increased noise, and increased disturbance caused by both scale and the larger amount of boat traffic necessary to service the wind farm. Furthermore, as opposed to the 500 kW turbines of Tunø Knob, all offshore parks built in the last three years have at least 1.5 MW turbines that are about twice as tall and require flashing aviation lights. All these factors increase the probability of potentially large negative impacts on birds.

3.2. Onshore evidence for potential offshore impacts: Collisions

Given that our direct empirical knowledge of the effects of offshore wind farms on birds is limited to the Tunø Knob study, it is necessary to look to onshore studies in order to understand the processes behind impacts and to help predict potential risks in offshore locations. With over 23,000 MW of installed wind power capacity in the world (Ackermann & Söder, 2002), our knowledge of avian impacts in terrestrial environments is—while far from complete—much more fully rounded.

Those studies that will be of particular use to understanding offshore environments are from coastal and shoreline wind farms, where conditions and species affected begin to approach those found at sea.

The subject of collisions with wind turbines has only been rarely studied, and the results are mixed. Some studies at onshore sites have found very few or no collisions, while others have found such high mortality that the wind farm was forced to close for a period (Kerlinger, 2001). It is unlikely that any wind farm, like any human-made obstacle, will be totally free of collisions during the course of its life. What is important to look at, consequently, is the frequency of collisions and the species affected, to better estimate cumulative impacts.

A number of factors, some involving the structure of the wind turbines, and others involving the planning and location of the wind farm in the surrounding environment, can control collision frequency. Much of the discrepancy in bird collision data comes from two causes, a lack of comparable methodology between studies and trying to compare disparately situated sites. At a very basic level, collisions will be a function of how many birds travel through the wind farm vicinity, the height at which they are flying, and whether or not they actively avoid the turbines or blades (Winkelman, 1992a-b). Collision risks, consequently, will be highly site-specific and species-specific.

In the offshore situation, collision studies are especially difficult to do due to inherent problems in trying to find bird corpses at sea. In all the research done at Tunø Knob, no formal study of bird collisions was undertaken, due to the lack of an effective methodology (Clausager, 2000). Stationing humans in wind parks to monitor offshore collisions has not been successful because of the difficulty of trying to find enough people to observe all the turbines for a long enough period of time to actually get a good measure (Lowther, 2000). Furthermore, human observers cannot accurately document collisions in poor viewing conditions (e.g. dark nights, heavy fog, or rain) when collisions may be heaviest.

An interesting methodology for assessing collision victims in nearshore areas was tested at Blyth Harbor in England, as part of a study looking at the impacts of nine 300 kW turbines located on a breakwater in an area of high local bird movement (peaks around 5000 movements per day; Percival, 2000). At Blyth, researchers combed beaches adjacent to the breakwater for washed-up carcasses of birds that had collided with the turbines a few hundred meters away. They then tested the chance that collision victims that fell into the ocean next to turbines would eventually wash ashore by throwing tagged carcasses into the bay from the breakwater. Their results were reported as inconclusive, but generally they found very few carcasses to ever wash ashore (Lowther, 2000). Despite this unsuccessful attempt, the difficulties of detecting offshore collision victims may soon be solved through the new use of passive surveillance with infrared video-recording techniques (Kahlert & Desholm, 2000). There have yet to be any reports released where this method was used so its potential success is unknown.

The Blyth study did give us evidence, however, that seabirds collide with wind turbines in coastal areas. The turbines at Blyth are relatively small, with the tip of the blade reaching no more than 60 m above sea level. During the first years of study at Blyth, 34 definite turbine-caused deaths were observed, at least 12 of which were common eiders (Lowther, 2000). Other collisions at Blyth included several gulls of three different species (Parkinson, 1999). It was found, however, that bird fatalities from the turbines declined over time—especially for eiders—and this trend continued up to seven years after first operation (Painter et al., 1999, in Percival, 2000). This result suggests that for birds inhabiting the local area around wind farms, habituation is possible, leading to decreasing rates of collision over time. Given that oversea migrants travel in broad fronts and pass a given area only a few times in a lifetime, habituation is a more likely possibility for local species.

The researchers working on the project at Blyth estimated the average mortality rate of a shoreline wind farm to be 0.75-5.2 birds per turbine per year, with the specific rate at Blyth being 1.34 birds per turbine per year (Parkinson, 1999). It is uncertain whether these numbers fully accounted for collision victims lost in the water (as they were on a breakwater, the turbines were bordered on two sides by ocean). These numbers are relatively higher than other onshore estimates in the UK; nevertheless, the collisions represented less than 0.01 percent of all bird flights through the wind farm.

By comparing the results of collision studies at coastal areas, we can observe that most species that could potentially appear at offshore wind farms in the U.S. have been documented to collide in onshore conditions. The only exceptions are strictly pelagic species such the auks (including puffins), gannets, shearwaters and fulmars, and phalaropes. Northern gannets (*Morus bassanus*) may be particularly at risk, as they commonly forage and fly at heights between 10 and 50 m (Nelson, 1978). This behavior would put gannets well within the rotor range of most newly built offshore wind turbines.

At a coastal estuary in the Netherlands, Musters et al. (1996) found nine dead birds that probably collided with one of the five 250 kW turbines installed on a dike. The study found large and medium-sized birds (ducks and gulls) to collide more frequently than smaller birds, although this may have been a consequence of the ease of finding large birds over small ones. Statistically, they only found a direct correlation between the number of victims and the estimated number of visitors to the wind farm of that species (Musters et al., 1996). This result supports the hypothesis that overall frequency of collisions will be a direct function of bird use in the area.

Some of the best known studies of bird collisions come from Winkelman (1989, 1992a-d). At a study of 25 turbines (300 kW, 43 m at highest blade tip) along a dike on Lake IJsselmeer north of Urk in the Netherlands, Winkelman (1989) found 63 dead birds over two years, of which the cause of death of 33 could “certainly to possibly” be attributed to turbine collision. While the proportion of passing birds that collided was unknown, Winkelman estimated 0.5-1.2 bird collisions per day for the entire park, a number corresponding to 7-18 collisions per turbine per year. Collisions accrued across multiple species, passerines and non-passerines alike, although information on the specific species most affected is not available. Collision victims included migrants and local birds, although more collisions were recorded during migration (spring and fall), when more birds were passing through the park than at other times.

A second study of Winkelman's took place near Oosterbierum, the Netherlands, at a farm of 18 300 kW turbines (50 m high at blade tip) located on open land several kilometers in from the coast (Winkelman, 1992a-d). The researchers conducted intense carcass searches during spring and fall migrations, as well as the necessary accuracy experiments (Winkelman, 1992a). Turbines were present at the site starting in 1986 but the park was not fully operational until 1990. Surveys conducted 1986 through 1991 found a total of 76 dead birds, of which most of the obvious collision victims came from the last year of the study when the farm was finally fully running. The majority of collisions occurred after nights with poor flight or visibility conditions (e.g., strong headwinds, fog, rain, new moon), but on average they estimated from collision studies that less than 0.1 percent of the birds passing the wind park during the night collided with a turbine (Winkelman, 1992a).

In a study concurrent to monitoring collisions, Winkelman (1992b) also used radar and image intensifiers to monitor heights and numbers of passing migratory birds. They found most birds to migrate higher than the turbines (> 50 m), but did find significant lower altitude migration around sunrise, sunset, and during nights of large-scale seasonal migration. This work refers mostly to passerine migration, although the collision data were not limited to that group. They also followed birds trying to cross the swept path of turbine blades and found significant amounts of "panic behavior" in these attempts, especially at night. During these limited watches they observed more birds trying to cross the turbines at night than during the day. Of these nocturnal attempts, 28 percent collided. Some of these were actually "wake collisions," where the bird was caught up in the rotor's wake and thrown to the ground—50 percent of wake collisions ended in fatalities. Using these figures, Winkelman estimated that for all birds passing the wind farm at Oosterbierum, 1.1 percent would die from collisions with the turbines. While this specific figure has not been calculated widely for other wind farms, Winkelman's studies at Oosterbierum are acknowledged as exhibiting one of the highest rates of avian collisions and mortality (Kerlinger, 2001). The reason for this high rate is probably a factor of both methodology and site location. Winkelman (1992a) commented that the site experienced heavy songbird migration in spring and fall, and since it was a coastal area, there may have been a higher than normal proportion of low-flying birds (Richardson, 2000). Additionally, Winkelman's methods for detecting collisions using observation and radar, in addition to ground searches, resulted in a more accurate estimate of total collisions, whereas most collision studies only use ground searches (Langston & Pullan, 2002).

The discussion of potential collisions with offshore wind farms is often compromised by the utter lack of useful data on the subject. As a result, sources of information are drawn from extreme studies that often have no relation at all to current offshore wind farm situations. On the positive side, turbine advocates claim that potential deaths of birds from turbines are extremely low (especially when compared to other sources of mortality) and that wind turbines save birds by protecting them from environmental damage occurring either through pollution or global warming (e.g. AWEA, 2003). This position commonly refers to far inland wind parks of fewer than ten turbines that have no documented fatalities, such as one in Garrett, PA (Kerlinger, 2001). On the negative side, opponents of wind farms claim wind farms are “death traps” for birds, causing massive levels of mortality (e.g. Bradley, 2003). This position often relies on now-immortalized wind farm disasters such as the over 400 fatalities—mostly of raptors—at Altamont Pass in California, and the over 100 fatalities at Tarifa, Spain, of which 30 were of the nationally-protected Griffon Vulture (Kerlinger, 2001; Lowther, 2000). Due to differences of location, scale, technology, and at-risk species, however, none of these past experiments, good or bad, tells us much about potential risks in offshore situations.

As has been brought up in numerous disputes over wind farm effects, one part of bird behavior that is necessary to consider is the altitude of migrating birds. It is generally well-known that nocturnally migrating birds fly at very high altitudes of up to several thousand meters—putting them well beyond any risk of collision with turbines (Richardson, 2000). However, migration altitude is highly variable and depends greatly on weather conditions (Richardson, 2000). Birds not only change altitude depending on the strength and direction of predominant winds, but they also avoid flying in clouds or other conditions where visibility is obscured for extended periods of time (Alerstam, 1990). In observations of migrating birds, most species have been observed to fly well within the altitudes of collision risk in various conditions. Dirksen et al. (2000a) found shorebirds, gulls, and passerines to all fly at turbine heights in migration when encountering head winds, even throughout the night. A similar study of coastal birds by Krüger and Garthe (2001) found diurnal migration of seabirds to be concentrated within the range of 1 to 25 m above sea level, with higher altitudes recorded with tailwinds. They concluded that proposed wind farms in coastal areas posed serious threats to migrating seabirds in the North

Sea (Krüger & Garthe, 2001). Consequently, no location will be exempt from collision risks due to presupposed altitudes of nocturnal migrants. However, the predominant flight altitudes of birds in a region may decrease overall risks.

3.3. Onshore evidence for potential offshore impacts: Disturbance

As discussed previously, disturbance can result in two major impacts to bird life: indirect habitat loss and barriers to movement. Indirect habitat loss results when birds purposely avoid wind turbines or the vicinity surrounding them due to the disturbance caused by the turbines. At Tunø Knob, common eiders showed avoidance in flight up to 1500 m away from the nearest turbine (van der Winden et al., 2000). On land, birds have been documented as avoiding wind farms from between 200 m for geese (Larsen & Madsen, 2000) and 500 m for gulls and shorebirds (Winkelman, 1992d). Studies at Blyth Harbour did not find any birds avoiding the turbines there, except for a population of cormorants that was displaced from a roosting area during construction but which returned when the turbines were in full operation (Parkinson, 1999). A similar situation was observed at a small experimental wind farm in the Orkneys, where the only significant impact of the wind farm came when a nesting pair of red-throated loons (*Gavia stellata*) left the area during construction due to human-caused disturbance (Meek et al., 1993).

For evidence of barriers to movement, the studies of flight paths around wind turbines, especially of ducks, has resulted in the suggestion that wind turbines have a high potential to act as barriers to movement (Dirksen et al., 2000b). A number of species from onshore studies have been labeled as ‘sensitive’ to wind farms as barriers. Some of these species include snipe, curlew and thrushes (*Turdus* sp.; Winkelman, 1994d), as well as a variety of duck species (van de Winden et al., 2000). However, just because a wind farm may act as a barrier to movement, it does not necessarily have an associated negative impact. At Tunø Knob for example, the wind farm did appear to act as a barrier to movement, but due to its location in the larger landscape, no significant negative impact was seen (van der Winden, 2000). In truth, no study to date has documented any negative impacts of wind farms to bird populations as a result of acting as a barrier to movement. This lack probably has more to do with the small-scale (2-25 turbines) of most well-studied wind farms, rather than the actual risk of wind farms as barriers. As noted earlier, the risk of negative impacts of barriers to movement will increase substantially as wind farm size grows.

3.4. Onshore evidence for potential offshore impacts: direct habitat loss

As discussed in Chapter 2, direct habitat loss is an impact more typically associated with terrestrial wind farms. Even then, not all locations will show evidence of direct habitat loss. Winkelman (1992d), for instance, did not find breeding populations of shorebirds to decline at Oosterbierum during her study. However, the study did question these results, saying that for species with high breeding-site fidelity, such as shorebirds, reductions in breeding success or population at a wind farm may take many years to document.

In the offshore case, direct habitat loss is rarely documented as presenting a significant impact. As birds do not breed in the open ocean, wind farms cannot affect species in this way. A preliminary environmental impact statement for the Rødsand offshore wind farm in Denmark expresses concern that the specific location of the proposed construction may interfere with the fish species present and thus with the social foraging behavior of a population of cormorants (Kahlert et al., 2002). There is also speculation, as mentioned before, that the construction of the wind farm at Tunø Knob resulted in the decline of mussels and other mollusks, thus leading to the dramatic decline of ducks (Lowther, 2000). These negative impacts, it seems, would most likely be a temporary result of construction, however, and could be subject to mitigation approaches.

Some evidence suggests that wind farms, if planned correctly, could act as artificial reefs for species and thus create better habitat. The placement of a gravity caisson concrete foundation at the base of an offshore turbine can provide considerable benefits to fish stocks around the wind farm—the concrete used as an attachment substrate (Byrne Ó Cléirigh, 2000). However, the negative underwater effects of turbine vibrations, especially on large marine fauna, are still very poorly understood (Dirksen, 2000). In one small experimental turbine in Sweden, lower densities of fish were found near the turbine when it was operating, as well as a disturbance effect on nearby migrating eels (Westerberg, 2000). Consequently, the evidence for habitat augmentation by wind farms still goes both directions.

Nevertheless, with the potential for positive augmentation of habitat by offshore wind farms, it is additionally important to notice the inherent predicament in doing this. If turbines reduce the desirability of an area as habitat, birds will tend not to use that area. The repercussions could be food shortages and declining populations of local species. However, if turbines increase the favorability of habitat, then daily use of the wind farm by foraging birds could increase, enhancing the risk of collisions. While the response to this problem is either to not build or to plan for no change in habitat quality, the possible effects of habituation on bird impacts should also be factored in (Percival, 2000). Habituation of local populations to wind turbines would reduce the drawbacks of positive habitat augmentation, as local populations could exploit the increased resources and not suffer any elevated risk of accidental mortality.

3.5. Scientific evidence: the problem and the solution

From what we can learn from the existing studies conducted at offshore and pertinent onshore locations, we know that collisions are likely to be a problem anywhere, although the frequency and risk of collision will likely show wide variation depending on location and unforeseen factors such as weather. For most offshore wind farm sites, indirect habitat loss will have the second largest impact on birds. While the potential for indirect habitat loss is greatly reduced for offshore sites, impacts will depend on the importance of proposed areas to birds for feeding, wintering, and molting. As for other potential effects of wind farms, such as barriers to movement and direct habitat loss, we know that these effects can occur, but there is an absence of scientific data documenting the precise impacts.

To help alleviate this problem, it is in the best interest of any wind farm developer to implement rigorous bird monitoring studies. Bird studies in the offshore environment should focus around three research components which are now standards in assessment methods in several European countries including Germany (Exo et al., 2002). First, BACI-type impact studies should be conducted including, ideally, a long (3-6 year) “after” period to account for fluctuations in the natural oceanic environment. This approach will also give a better understanding of the possible process of habituation in local populations around the wind farm. Second, in-depth collision studies need to be conducted using infrared video-recording or other inventive techniques (c.f. Kahlert & Desholm, 2000). Third, studies need to include the impacts of wind farms as barriers to movement. For well-planned locations, barriers to movement should not be an issue, but the potential impacts need to be better understood, particularly in terms of songbird migrations.

4. Planning and design of offshore wind farms

Several times in this paper I have purposely qualified judgements on the potential impacts of wind farms by using the statement "if the wind farm is well-planned." The previous chapters have indicated that the effects of wind farms on birds can range widely—from catastrophic to insignificant. No wind farm will have zero impact on birds, so if we decide to build offshore wind farms, we need to be looking at mitigation of impacts rather than eliminating impacts. Some means of mitigation, such as not building wind parks within bird sanctuaries or Important Bird Areas (IBAs), seem obvious, but most are subtler. The purpose of this section is to describe the possible ways to reduce impacts on birds, as well as to evaluate their relative importance to mitigation efforts.

4.1. Mitigation methods: site planning

Of all the ways to reduce cumulative impacts on birds, the location of the wind farm seems to be the most important factor. Location of the wind farm will determine the frequency of use of the wind farm for different species. Heavily used sites could be areas of bird feeding, roosting, mating, staging, daily traveling, molting, or migrating. Wind farm planners can avoid exposing birds to risk by avoiding areas used for these purposes. Different uses of the area will determine to what risks the birds are exposed. An area heavily used for migration would have a greater risk of impacts from collisions, while an area used for roosting or molting may be more susceptible to disturbance and habitat loss. A well-sited wind farm will also avoid areas near known locations of concentrated bird activity. This principle is used in the siting guidelines of several nations and organizations, but how one defines "near" is never fully answered. Sometimes 800 m is given as the minimum distance that a wind farm should be from an important area of avian concern—apparently a guideline first made by English Nature (Dillon Consulting, 2000). Given that van der Winden et al. (2000) found noticeable effects of the Tunø Knob turbines on ducks up to 1500 m, a minimum of 800 m might not be long enough. As this points out, defining a standard minimum distance between wind farms and important bird areas becomes problematic because a minimum distance for "most" species will not protect "all" species. Consequently, the most important part of the siting process is conducting in-depth avian surveys to know beforehand how birds use a given area and, thus, where to place a wind farm in order to minimize impacts.

Site planning does not just involve choosing a location, it also means defining the size, shape, and configuration of the wind farm. Size is going to be a function of how many turbines the farm plans to install. Clearly, the fewer turbines, the less the total risk to any species flying through the wind farm. However, more turbines added within a certain area will cause greater disturbance and consequently decrease the frequency that birds fly through the wind farm at all. While manipulating planning aspects in this way can possibly be effective at deterring birds from entering a wind farm, it should be noted that adjusting configurations of wind farms is not always a proper mitigation strategy. In areas where many birds could end up being forced through the wind farm, the birds would be unable to avoid the wind farm, and so densely packed turbines could result in significant negative impacts.

In most cases, the number of turbines will be fixed by the project's energy goals, so the real flexibility in planning comes from how the turbines are arranged spatially. Most offshore wind farms have taken one of two general shapes—elongated lines of turbines or a solid rectangular grid. Winkelman (1992c) argued that the ideal configuration for a wind farm would depend on the type of bird life most often using the area (i.e., local or migrant). She writes, "to wintering and feeding birds, and maybe also to breeding birds, the best option is a (dense) cluster of wind turbines, to migrating birds this is either a line formation parallel to the main migration direction or an open cluster" (Winkelman, 1992c: 69). Winkelman's justification for this differentiation is because of the opposite planning goals for each group of birds. For local birds, the point is to make the wind farm as undesirable as possible, so they will keep away from it as a way to reduce collision frequency. It is acknowledged that while migrating birds cannot always avoid the wind farm (or even see it until they are within it), migrations will often occur along one directional axis. Therefore, the goal in planning is to minimize the total air space affected by rotors through which the birds have to fly.

To improve upon the "preferred configurations" of Winkelman, it is important to realize that Winkelman's model does not consider the factor of scale. Planned wind farms are using more and more turbines, and a large, dense cluster may not be as ideal for 150 turbines as it would be for 20. For local birds, a very large cluster could act as a barrier to reaching desired resources. In studies of duck flight patterns around wind turbines, van der Winden et al. (2000) found that when confronted with a wind farm, not all birds would fly around it—some would fly through it. The majority that flew through it, however, used routes that maximized the space between them and the turbines (van der Winden et al., 2000). Consequently, breaking one large turbine cluster into several smaller clusters spaced far apart can mitigate the barrier effect of big wind farms.

We can then define new preferred configurations of turbines based on these principles, which present ways to mitigate the possible effects on birds depending on whether the species at highest risk are primarily local or migrants (Figure 5). For a small wind farm with local birds at risk, the ideal configuration is still one dense cluster, but for a large wind farm it is several dense clusters spaced far enough apart. The distance separating clusters should be large enough that there is sufficient undisturbed space in between clusters. Thus, a preferred distance would be over one kilometer, and optimally greater than two. For migrant birds, a line of turbines parallel to migration direction or an open cluster could still be employed, but for large wind farms these should be broken down into two or three lines or clusters. Ideally, the lines should not be placed so as to form funnels, as such a configuration may cause problems for horizontally drifting flight paths, but should be placed in a row with occasional large gaps. Alternately, each line could have some horizontal displacement while keeping the vertical segregation. This approach would decrease the probability that the wind farm would act as a barrier to any birds flying perpendicular to the arrangement.

The importance of breaking up lines is highlighted by examining the way birds migrate at sea and the effects of lateral wind drift. When migrating birds encounter crosswinds, they can either compensate in their headings or slowly move in the direction of the wind; this is called lateral wind drift (Richardson, 2000). It has been found that for various species of birds over oceans, lateral wind drift does occur, and when it happens, birds frequently concentrate along linear features that intersect their flight paths (Richardson, 2000). These linear features can be anything from mountain ridges to coastlines. One long line of turbines would likely create such a feature, increasing the chance that migrating birds would concentrate along the line of turbines rather than avoiding them. By breaking lines apart, the linear concentration would be dispersed by wind drift.

At what point an arrangement should switch from one cluster or line to multiple clusters or lines will depend on the results of experimental evidence. Many questions need to be answered on this subject, such as what density of turbines over what size area is needed to induce the majority of locally moving birds to avoid an array. If there are negative impacts to very large clusters, at what size and in what conditions do these impacts arise? For splitting lines, what is the average rate of horizontal drift of migrating birds of at-risk species? What do typical flight paths look like in a proposed location, and how would one line or multiple lines affect these paths?

Both choice of location and turbine configuration are extremely important measures in mitigating impacts on birds. Location is arguably the easiest and most effective way for a wind farm planner to reduce the overall effects on birds.

However, location and arrangement are typically decided in planning wind farm sites by factors other than bird risks. Wind resources, sea depth, benthic substrate, and proximity to the energy grid will most likely take precedence over effects on birds in deciding what areas to develop for wind farms. Money, shipping lanes, visual effects, zoning permits, and fisheries will most likely determine the size of the area available for development. With a given location, developers will try to fit in as many turbines as possible in order to maximize cost effectiveness. Consequently, the factors that influence bird impacts the most—location and spatial configuration—are the most likely to be decided by extraneous factors. While this necessitates a selection justification for all proposed sites and alternatives in Environmental Impact Assessments, it also means that other ways to mitigate bird impacts need to be considered.

4.2. Mitigation methods: structural choices

When looking at ways to mitigate potential impacts on birds—mostly collisions—it is useful to look at the two general strategies for doing so. The first strategy is change something about the design of the turbines or wind farm so that the risk of collision (and death) to a bird flying through the wind farm decreases. The second strategy is to decrease bird use in and around the wind farm so that the frequency of collisions decreases. The second strategy, although important, has two main problems. Primarily, as Anderson et al. (1999: 72) explains, "changes in behavior could also cause increases in death even if the use around turbines has declined." If a wind farm is designed to scare birds away, then this strategy exacerbates the negative effects of indirect habitat loss such as resource deprivation. Also, scaring birds once they are within the wind farm, may make it likely that they will accidentally collide with a turbine (Anderson et al., 1999). The deterrence strategy is also problematic in that it does not solve any of the risks to birds once they end up inside the wind farm. As Anderson et al. (1999: 73) offers, "If the risk to an individual per visit to a turbine stays the same, then mortality (rate of bird death) has not been reduced even if fewer birds visit." Consequently, when looking at ways to mitigate negative effects on birds, it critical to try to reduce the actual risk of collision in addition to reducing the frequency of collision.

In terms of turbine types and sizes, scientific evidence for the effectiveness of mitigation efforts is ambiguous. There is a current trend among offshore wind farms to use larger, more slowly revolving turbines. Due to their large size, the taller towers could expose either a wider range of birds to impacts, or they could place the rotor too high for most birds, affecting a narrower range of species (Anderson et al., 1999). For certain species that hover close to the ground while foraging, for example, shorter turbines have been correlated with higher mortality levels (Thelander & Rugge, 2000). Nevertheless, the massive rotors of 2 MW or 3 MW turbines (80-100 m diameter) have a much larger swept area than older and smaller turbines, thus presenting more opportunities for collisions with birds in the vicinity. But this risk is also ambiguous, as the larger rotors rotate much more slowly than do smaller rotors. Whether birds are more likely to see the slower moving rotors and thus avoid them, or whether they are more likely to collide due to the large size and very fast moving blade tips is unknown; no studies have been done comparing these factors. As a bottom line, perhaps, given a wind farm with a set total output, a few large, multi-megawatt turbines would hypothetically have a lower impact on birds than many smaller, weaker turbines, since decreasing the density and number of turbines should be more important than decreasing the radius of blades.

A number of mitigation studies have been done to try to improve the visibility of turbines to decrease collision risk. A study in California tried painting rotor blades with ultraviolet (UV) paint to see if it had any effect on mortality levels (Young et al., 2003). Unlike humans, most birds can see in the UV range—an adaptation that has roles in inter-sexual signaling as well as in foraging (Honkavaara et al., 2002). However, whether birds see UV as "just another color" or not, the preliminary tests with UV paint on rotors found no significant effect at all on bird collisions with turbines (Young et al., 2003).

Visibility of rotors may likely have more to do with motion smear—the inability to distinguish quickly moving objects—than with the brightness of rotor blades. Dirksen et al. (2000a) found that ducks could see wind turbines quite well, even while flying on moonless nights. Preliminary research at the National Renewable Energy Laboratories has focused on developing "antimotion smear patterns" that increase the visibility of moving turbine blades at given distances (Sinclair, 2001). Given that trials of this technique have been reported to be successful, motion smear may well be a more useful mitigation tool than changing the brightness or color of turbine blades.

It has also been hypothesized that if birds could hear turbines better, they would avoid them at close range. Modifying rotor blades so that they "whistled" while spinning might help, although no one has tried this yet in the field. Birds' hearing capabilities are actually often worse than those of humans, and in the case with a wind farm, a human is likely to hear a turbine twice as far away as a bird would (Dooling, 2002). It has also been suggested that by the time a bird is able to hear a turbine, it already cannot see it due to the effects of wind smear. Experimenting with blade whistles could very likely increase the distance from which birds are able to hear the blades and thus help birds to avoid turbines (Dooling, 2002).

Not all efforts to increase visibility are necessarily good, however, as lighting of tall structures is strongly associated with massive mortality events of birds. As Richardson (2000: 136) writes, "Under poor visibility conditions, nocturnal migrants tend to be strongly attracted to lights, especially steady lights that continuously illuminate the fog and/or precipitation in the airspace around the light." The general recommendation for wind turbines, consequently, is that lights should be flashing, not steady, and that floodlighting of turbines should be avoided—especially on nights with inclement weather (Richardson, 2000).

Considerable debate also arises about the proper color and blinking frequency for aviation warning lights on towers. The U.S. Fish and Wildlife Service (USFWS) released guidelines in 2000 that all towers that require lighting by the FAA (i.e., >200 ft) should use only the bare minimum of lighting, and preferably a white strobe. The guidelines specifically said that while pulsating and solid lights of all colors were the most dangerous to birds, in strobing lights, white was preferable to red (USFWS, 2000). They described ideal strobe lights as having the largest duration between flashes, in order to give the fewest flashes per minute. The evidence supporting white lights over red lights is mostly anecdotal, and many of the differences have not been thoroughly studied. One study by Gauthreaux (2000) compared lighting at television towers and found increased “non-straight” flights of birds near towers with red lights. Non-straight flight is interpreted as meaning the bird is attracted to the light, thus increasing the chances that it would collide with the tower. Perhaps due to just this one study, the preference for white strobing lights is echoed throughout guidance literature (e.g. Kerlinger, 2000).

The extent to which a wind farm could or would follow the USFWS’s guidelines for lighting is questionable. While the USFWS advocates staying within FAA guidelines for tower lighting, the FAA itself does not recognize the USFWS’s guidelines for lighting (Kerlinger, 2001). A speaker from the FAA said at a government conference in 1999 that the FAA actually did not control the airspace and while they recommended (and in some cases insisted on) proper lighting for towers, they would essentially approve whatever lighting the developer brought to them (Bayley, 2000). Bayley (2000) concluded by saying that since white strobing lights are conspicuous, there is no reason why they should not be approved if developers include them in their plan. The problem, however, is that white strobing systems are expensive—approximately $150,000 a tower (Berland, 2000)—so few developers would willingly use them except for environmental reasons. Consequently, while the possibility exists for offshore wind farms to use bird-friendly lighting and still be approved by the FAA, developers will not be likely to do so unless it is required of them.

Of the other factors influencing the structure of offshore wind turbines, the available literature offers little more in terms of ways to mitigate effects. Some efforts have been made to decrease the ability or desirability of birds to use turbines as perches. The ability of birds to perch on turbines was originally associated with high raptor mortality at sites like Altamont Pass (Orloff & Flannery, 1992). More recent studies comparing fatalities at horizontal-lattice turbines to fatalities at tubular-tower turbines (which have far less available space for perching) found that the ability of birds to perch on a turbine has very little effect on the collision risk for that turbine (Thelander & Rugge, 2000). All currently planned offshore wind farms use tubular-tower turbines anyway, so they cannot be described as a prescriptive mitigation technique.

Once a wind farm is built, several options are available to try to reduce mortality if it has been identified as a problem. If particular turbines are associated with greater collision risks, these turbines can be moved, turned off during high-risk periods (e.g. nights during migration), or even decommissioned. Likewise, if mortality is observed throughout the site, probably the best mitigation technique is to turn off turbines at night, during inclement weather, or during periods of peak migration. Lighting can also be turned off at night to reduce the negative effects of lights on migratory birds, although consideration should be given to the effect of such compromises on aviation and boating safety. If turbines are arranged in clusters, then possibly only towers along the perimeter would need to use lighting, while interior turbines could be unlit. While this would not be as effective at mitigating bird collisions with turbines due to lighting, it would provide at least some level of human safety from collisions.

4.3. Achieving "mitigation"

An important question that needs to be addressed when planning wind farms is how much mitigation is necessary. Every planned wind farm should conduct thorough baseline studies of the use and habits of the area by birds, allowing developers to assess risks in the initial planning stages. If developers only mitigated to a certain governmental standard (e.g., non-significant mortality or disturbance), they would only be doing the bare minimum without actively engaging the problems and analyzing possible solutions. Economically, by adhering to a governmental standard of "non-significance," developers would not be mitigating to an efficient level. For example, for some sites it might cost ten dollars to reduce collisions by 0.5 percent but for others it might cost one million dollars. For poorly-sited wind farms, a governmental standard might make the whole project economically unfeasible, thus protecting the environment. But for developments with very low marginal costs at the point where the standard is reached, the developers could potentially make the wind farm much safer for birds with only a minimal increase in costs. In these latter situations, while developers would be forced to protect birds to the level of the standard, the birds effectively lose nonetheless.

Technology and research will play a major role for future mitigation techniques if the United States continues to explore wind energy as a viable renewable option. As we better understand the complex processes that lead to negative avian impacts from wind farms, we will better be able to either plan around them or develop new ways to combat the impacts. Turbine-bird research, consequently, needs to not only be circumstantial, but experimental. Mitigation techniques are not going to be discovered simply through observation. If we want to build offshore wind farms on a large scale, we need to first build smaller test farms where manipulative experiments can be done. This kind of science will be critical to allowing the development of safe wind farms providing truly environmentally-friendly energy.

5. Case Study:

Cape Wind Offshore Wind Farm

Offshore wind farming has grown steadily in Europe throughout the last decade, but the United States has yet to enter this energy market. That may all soon change, as plans are underway to make the state of Massachusetts an international leader in offshore wind energy. In November of 2001, a Massachusetts-based company, Cape Wind Associates, LLC (Cape Wind), filed an Environmental Notification Form (ENF) with the state, announcing their intent to build a massive offshore wind farm in part of Nantucket Sound (Coleman, 2003). The proposed location is more than three miles from the coast, making it part of the Outer Continental Shelf (OCS) and thereby in federally owned waters. The project is planned to generate up to 420 MW of electricity, and aside from being the first offshore wind farm in the United States, it will be one of the largest wind sites in the world.

While offshore wind farms offer to bring the United States innumerable benefits of affordable, clean, and renewable energy, their direct importation from Europe is impeded by new political and social issues peculiar to this country. Most pertinent to this work, the United States presents new obstacles to the permitting of offshore wind farms because of this nation's federal legislation on birds (Kerlinger, 2001). The two most important bills are the Endangered Species Act (ESA) and the Migratory Bird Treaty Act (MBTA), which together prohibit the unnecessary killing of essentially any single wild bird. In contrast, the legislation protecting birds in most European nations only prevents developments from significantly impacting populations of species (Percival, 2001). Since individual mortalities associated with developments could possibly hinder the permitting process of American development, increased emphasis is placed on possible effects of wind farms such as collisions with turbines. While the ESA as a piece of legislation does have teeth, it is questionable to what extent the MBTA would be able to regulate a proposed or actual wind farm off of Cape Cod. While avian fatalities at wind farms would be prosecutable under the MBTA, to date no such enforcement actions have ever been initiated in response to onshore collisions in the United States (Kerlinger, 2001).

The Cape Wind project consequently represents a decisive point in American wind energy. Possible or realized impacts on birds are being debated throughout the media and permitting process, and these impacts will undoubtedly play a key role in the eventual success or failure of the project. In addition, Cape Wind presents an important opportunity to apply what has been learned about avian impacts at wind farms elsewhere. This case study can be summarized as exploring three questions: where do birds fit into the environmental review and permitting process; what birds use the proposed site in Nantucket Sound and what risks would a wind farm pose; and. from the viewpoint of impacts on birds, how could we make the Cape Wind proposal better through alternative siting, planning, or design?

5.1. Plans, process, and permitting

The Cape Wind offshore wind farm is currently a proposal to build 130 wind turbines in an area of Nantucket Sound known as Horseshoe Shoal (Coleman, 2003). Horseshoe Shoal is an area of shallow water ranging from 8 to 15 ft in depth that lies south of Cape Cod, approximately 6 miles south of Barnstable and 9 miles east of Oak Bluffs, Martha's Vineyard. Horseshoe Shoal has fine- to coarse-grained sands on the bottom that are rich in benthic macroinvertebrates and fishes (Amorello, 2002). The proposed wind farm would consist of an irregularly-shaped grid of turbines covering 24 square miles of the shoal (Figure 6). Cape Wind has recently chosen to use GE's "Offshore 3.6 MW" turbines for the project, which would give a total peak output of 420 MW of energy and an average of 170 MW (Biank Fasig, 2003). The project also includes a 60 m tall data tower that has already been installed. The wind turbines would use two submarine cables to connect to the mainland and underground cables to meet up with existing NSTAR Electric transmission lines on Cape Cod. While the planned wind turbines and Horseshoe Shoal are located in federal waters on the OCS, most of the proposed cable routes are within Massachusetts state boundaries.

Of the GE wind turbines Cape Wind plans to use, each tower has a base diameter of 4.9 meters and rises approximately 77 m above sea level (Figure 7a; GE Wind Energy, 2003). Each turbine has a three-blade rotor with a diameter of 100 meters, so the tip of each blade reaches a maximum of 127 m above sea level. This height is taller than the Statue of Liberty (Figure 7b; APNS, 2003). Rotational speeds vary between 8.5 and 15.3 rotations per minute (GE Wind Energy, 2003). This converts to speeds of 100-180 mph at the blade tip, with a blade passing any fixed point in the swept zone every 1.3 – 2.4 seconds. The rotor normally spins but the turbine only starts to produce electricity during winds of about 8 mph (7 knots) and stops during 5 second gusts of over 56 mph (49 knots). At any time, the rotational speed of the rotor is solely dependent on the wind speed—the turbines cannot be run at "half speed," for instance. Lighting for the proposed turbines is not yet definite, but current plans include two flashing, dual-colored aviation lights at the top of the tower (red for night, white for day) and two amber lights at the tower base ten feet above water level for navigational purposes (Cape Wind, 2002b). The red lights at night are currently planned to be directed vertically, so that they only provide "up lighting." The lights would be visible for up to several miles.

In order the build the wind farm, Cape Wind is involved in a complex multi-year permitting process. To understand the Cape Wind process, it is first necessary to look at how permits are grants for offshore wind farms at the state and national levels. A wind farm built in just federal waters would be subject to the National Environmental Policy Act (NEPA) and would be reviewed by the US Army Corps of Engineers (USACE) under the authority of Section 10 of the Rivers and Harbors Act of 1899 (Environmental Futures, 2001). After the proponents filed an Environmental Assessment (EA) under NEPA, the USACE would then decide whether a full Environmental Impact Statement (EIS) would be necessary. If an EIS were required, the USACE would release a "scoping" document that defined what information and studies needed to be included within the EIS. Based on the EIS, the USACE would decide whether or not to grant the project a section 10 permit for construction (i.e., construction in navigable waters). On the federal level, a wind farm would also need review by the Federal Aviation Administration (FAA) and by several other authorizing departments.

For construction in Massachusetts state waters, the process is similar. Under the Massachusetts Environmental Policy Act (MEPA), after the filing of the ENF giving the details of the study, the Massachusetts Secretary of Environmental Affairs would decide if an Environmental Impact Review (EIR) were necessary and if so, would give the required scope (Environmental Futures, 2001). After completion of the EIR, the Executive Office of Environmental Affairs (EOEA) would make a decision on the granting of a MEPA certificate. This certificate is just one of numerous required checkpoints before the Massachusetts Department of Environmental Protection (DEP) grants a construction permit. For an offshore wind farm, the DEP requires the approval of other organizations such as the Energy Facilities Siting Board, Massachusetts Office of Coastal Zone Management, Massachusetts Natural Heritage Program, and Massachusetts Historical Commission. For a location near Cape Cod, any development also requires an independent review by the Cape Cod Commission (CCC) as a Development of Regional Impact (DRI; Durand, 2002). It should be noted that throughout the MEPA and NEPA processes, public commentary is amply included. Public and outside comments are especially critical to the EOEA and USACE in defining the scope of an EIR/EIS as well as in the final decision.

The Cape Wind proposal on Horseshoe Shoal is undergoing an especially complicated permitting process because it crosses the boundary between federal and state waters. The actual wind turbine array is in federal waters, while the connecting cables and other structures on land are in state territory. However, for the sake of simplicity and public relations, Cape Wind has voluntarily agreed to complete a full review of the entire project under NEPA, MEPA, and the CCC (Durand, 2001). To satisfy these reviews, it will submit one joint EIS/EIR/DRI to be reviewed separately by the CCC, the EOEA, and the USACE. For this joint report, scoping of the transmission cables has been defined by the EOEA, while scoping of the wind farm has been defined by the USACE with additional recommendations from the EOEA. While all three organizations will review the report, due to the limits of jurisdiction, the CCC and EOEA can only grant a certificate to those parts of the project lying within state boundaries. The USACE will have the final, and only, decision on the permitting of the wind turbines themselves.[2]

The Cape Wind project is progressing slowly relative to most developments in Massachusetts, but the timeframe is typical of most large developments. Most MEPA projects are complete in less than three years, while the permitting process of offshore oil platforms through the Department of the Interior usually takes from five to ten years (Environmental Futures, 2001; Griscom, 2002). Cape Wind filed their ENF in the fall of 2001, and scoping documents were released the following spring, following an extensive comment period. Cape Wind is currently in the middle of its intensive environmental review, for which they are conducting numerous original studies as

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[2] It has been predicted that in the next three years, jurisdiction of permitting wind farms in offshore waters will be transferred to the Department of the Interior, which already permits offshore oil

well as collaborating with outside organizations. In August of 2002, Cape Wind received a permit from the USACE to construct a data tower in Horseshoe Shoal to collect measurements on wind, waves, and weather, as well as other factors. The tower was built in November of 2002. According to a Cape Wind spokesman, the EIS/EIR/DRI could be finished and submitted as soon as November of 2003, allowing construction to be completed in 2004 (Biank Fasig, 2003). However, given the high emphasis in the scoping statements placed on solid ecological data, especially with regard to birds, it is more likely that the environmental review will be completed in 2004, potentially allowing a fully operational wind farm by 2005.

In both of the scope of work documents provided by the EOEA and USACE, birds play a central and critical role in the evaluation of the environmental impacts of the proposed wind farm (Durand, 2002; USACE, 2002). In the EOEA scope, for example, the comments and instructions on necessary information on avian impacts constitutes the largest part of the environmental impacts section. The EOEA scope is also very clear that the state government places a high value on bird life and that due to the proposed development's large size and uniqueness to this country, caution is greatly needed in relation to impacts on birds (Durand, 2002). The EOEA also criticizes Cape Wind's ENF document that claimed that potential bird impacts were minimal and that bird use of Horseshoe Shoal was low to begin with. The EOEA responds to the ENF by saying, "these conclusions seem premature, and the EIR should contain much greater analysis to support the conclusions" (Durand, 2002: 7). To help support the ENF claims in addition to allowing strong predictions of potential

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platforms.

impacts, the EOEA also asks that Cape Wind "present as much pre-construction data as possible on the spatial and temporal characteristics of avian activity in the Horseshoe Shoal area" (Durand, 2002: 7). Although the USACE scope elaborates much less than does the EOEA scope, both documents are clear in defining well-studied avian impacts as highly significant to the success of the Cape Wind environmental review process.

Part of the reason such emphasis is placed on birds in the scopes is that Nantucket Sound includes breeding grounds of two federally-endangered species, the piping plover (*Charadrius melodus*) and the roseate tern (*Sterna dougallii*). In addition, a Massachusetts state "Species of Special Concern"—the common tern (*Sterna hirundo*)—is a known breeder around Horseshoe Shoal. In order to meet compliance under Section 7 of the Endangered Species Act, the EIS/EIR will have to undergo thorough Biological Assessment of the piping plover and roseate tern, documenting their full reliance on and abundance in the area. Additionally, the EOEA scope has requested that a comparable biological assessment be conducted for the common tern within the study area (Durand, 2002).

The USACE scope requires that Cape Wind look at avian impacts from a number of perspectives. The Corps asks that Cape Wind provide detailed baseline data on all bird species that frequent Nantucket Sound, including spatial and temporal information (USACE, 2002). The scope allows some of this information to come from the work of others, published or unpublished, but also requires Cape Wind to conduct new field studies on their own. Cape Wind has suggested that they will conduct their own studies over a two-year period and the USACE scope hopes that information from other studies will allow them to present a three-year baseline data set. Interest groups such as the Massachusetts Audubon Society have claimed that Cape Wind needs to conduct at the very least a three-year baseline study in order to begin to understand bird use of Nantucket Sound in all weather and seasonal conditions, regardless of annual fluctuations (Clarke, 2001). The USACE stipulates that all data gathered should be copious enough to allow a "statistically rigorous analysis of results" (USACE, 2002: 4).

The USACE scope also requires specific topics to be studied, as well as methodological requirements. Five issues the EIS/EIR must address include: "bird migration, bird flight during storms, foul weather, and/or fog conditions, food availability, predation, and benthic habitat and benthic food sources" (USACE, 2002: 4). The three main ways to assess use and behavior of birds in Nantucket Sound suggested by the USACE are through aerial surveys, boat surveys, and radar studies with ground truthing (USACE, 2002). These are the main field techniques used to gather baseline data for wind farm impact studies in Europe.

Where the USACE is rather implicit on its demands for the EIS/EIR, the EOEA is explicit. The USACE scope generally covers ways to predict impacts of indirect and direct habitat loss, but does not go into much detail, nor does it address the issue of collisions. The EOEA, in contrast, states that the impact report should focus on effects on three main groups of birds: migratory songbirds, wintering seaducks, and rare and endangered birds (Durand, 2002). Since collision risk is difficult to quantify beforehand other than through analyzing migration distributions, abundances and flight height, the EOEA scope suggests that Cape Wind "develop potential methods for assessing impacts from [unusual weather events associated with high mortality], and consider a range of management responses to reduce bird mortality" (Durand, 2002: 7). The scope asks that the collision risk assessment also incorporate lighting impacts into the analysis. Finally, the EOEA scope also asks for a post-construction monitoring plan and impact thresholds and appropriate responses if significant impacts are discovered. All of these factors are critical to the proper assessment of the Horseshoe Shoal wind farm, and while Cape Wind is not required to follow the scope stipulated by the EOEA in order to be granted its required permits, it would be inadvisable to ignore the EOEA scope completely.

One final part of both the USACE and EOEA scopes is that Cape Wind is required to choose and conduct full impact reviews of three alternative sites. Cape Wind is currently evaluating the possibility of building at 14 alternative sites from a list provided to them by the USACE (Leaning, 2003a), after Cape Wind initially proposed two alternative locations in Nantucket Sound (Figure 6). This "long list" includes onshore sites like brownfields, as well as other offshore locations. After reviewing Cape Wind's initial assessments of these alternatives, the USACE will decide whether any of the alternatives require thorough environmental assessments similar to that being done at Horseshoe Shoal. Given the available wind resources off the coast of Massachusetts (Figure 2a), several other offshore areas are available to build outside of Nantucket Sound, and indeed companies such as Winergy have looked into building in these areas (Figure 3). What criteria Cape Wind chooses to differentiate between the alternative sites in its EIS/EIR remains to be seen.

5.2. Bird use of Nantucket Sound and possible wind farm impacts

The Massachusetts coast essentially defines the bird life found in the state. Of the 350 bird species seen annually in the Massachusetts, 313 of them are found in the coastal region, with many species restricted just to that area (Bird Observer, 1994). This high coastal diversity means an offshore wind farm in Massachusetts could potentially impact numerous groups of birds (Table 5). Climate conditions play an important—if not solely deterministic—role in the presence, distribution, and abundance of species along the coastal zone (Forster, 1994). Passerine migration along the coast can be pronounced in both spring and fall, with common "migrant traps" occurring at areas such as Parker River National Wildlife Refuge, Marblehead Neck Sanctuary, and several areas along Cape Cod from Chatham to Provincetown (Forster, 1994). Seabirds are incredibly numerous along the Massachusetts coast, with groups of wintering birds, breeding birds, and traveling and staging migrants. Sea watches along the coast can sometimes give clues to just how many seabirds use Massachusetts waters, although results are highly dependent on weather conditions (Heil, 2001).

Just how many seabirds live in and migrate through Massachusetts's waters can only be estimated. At Andrews Point on Cape Ann, north of Boston, Rick Heil has been conducting detailed sea watches since 1975 (Heil, 2001). Of these watches, peak fall migrations average 10,000 to 15,000 seabirds passing Andrews Point per day, with numerous days with counts that exceeded 30,000 seabirds. Heil estimates that several hundred thousand seabirds pass Andrews Point each fall (Heil, 2001), and these are just the ones visible from shore. Elsewhere along the coast, seabird counts are just as high. At First Encounter Beach in Eastham, the total number of seabirds counted over 12 days in 2002 exceeded 70,000, with about 54,000 of those being migrating northern gannets (B. Nikula, unpublished data).

For migrating birds, Nantucket Sound is a critical pathway and food source. It is estimated that tens of millions of landbirds migrate through the Cape Cod area every year, mostly between August and November (Nisbet & Drury, 1967). Detailed radar studies in autumn have categorized landbirds migrating over Nantucket Sound as belonging to one of two groups (Table 5, Figure 8). The first group, traveling generally Southward, consists of small passerines departing in the evening from southeast Massachusetts, New Hampshire, and Maine over the Atlantic for winter grounds in South America and the West Indies (Drury & Nisbet, 1964). This group includes thrushes, cuckoos, swallows, and long-distance migrant wood warblers, especially the blackpoll warbler (*Dendroica straita*). The second group, traveling WSW and consisting of mostly thrushes and sparrows, passes over Nantucket Sound starting in the middle of the night after flying directly from Nova Scotia (Drury & Nisbet, 1964). The former group has been observed to travel en masse and quickly ascend to heights of several thousand feet, while the latter group passes through in a dispersed front at lower altitudes (Nisbet, 2002). These landbirds, especially the low-flying ones of the latter group, are particularly at risk to collisions with illuminated wind turbines at night in inclement weather.

There are also substantial groups of seabird migrants, as the seawatch data indicate (Table 5). Seabird migration generally follows three main pathways that are used throughout the year, from April to November (Figure 9; Nisbet, 2002). The first pathway is used by large numbers of waterfowl such as long-tailed ducks, scoters, and loons, that arrive in the fall from the Great Lakes and fly through Nantucket Sound at night toward the Southeast (Nisbet, 2002). These birds are generally observed migrating at low altitudes. The second large group of birds is made up of flocks of shorebirds (e.g., sandpipers) migrating to South America that leave staging grounds in Massachusetts in late summer and early fall (Drury & Keith, 1962). These birds generally take off in late afternoon, ascend rapidly to altitudes between 2,000 and 5,000 m, and then fly rapidly toward the Southeast (Nisbet, 1963; Nisbet & Drury, 1967). This category includes both the semipalmated plover (*Ercunetes pusillus*) and the black-bellied plover (*Squatarola sqatarola*), but probably does not include the federally-endangered piping plover (Nisbet, 1963; c.f. following discussion on piping plovers).

The final group is made up of gulls, terns, gannets, sea ducks, and loons that make variable seasonal migrations through Massachusetts in the spring and fall. Their migration path generally follows the coastline (WSW in fall, NE or NNE in spring), but individual flock paths exhibit great variation depending on weather, winds, and geography (Nisbet, 2002). Most species of this group migrate during both day and night at variable low altitudes (from 10 m for eiders to 50 m for gannets; Nisbet, 2002; Nelson, 1978). Of migrating seabirds, the first and last groups are most at risk of collisions or barrier effects from a wind farm, since the shorebirds generally migrate at extremely high altitudes.

While available migration studies have not looked particularly at birds passing over Horseshoe Shoal, all the birds mentioned follow migration routes that would take them over the general vicinity of Horseshoe Shoal. Whether birds pass directly through the shoal depends on wind, weather, and from where they are migrating. Migration through the shoal will consequently vary from year to year, as well as from species to species. Multi-year monitoring with radar and visual surveys will be critical in documenting migration routes through Horseshoe Shoal and the Cape Wind alternative sites.

Nantucket Sound is also an especially important area for birds that can be seen as "local," in that they spend half the year in Massachusetts' waters (Table 5). For waterfowl, Nantucket Sound is an important wintering ground, holding a quarter- to half-a-million birds each winter—one of the largest waterfowl concentrations anywhere on the East Coast (Clarke, 2001). It is especially critical for wintering scoters and long-tailed ducks (*Clangula hyemalis*). The long-tailed duck wintering flock constitutes a population of national importance, numbering in the hundreds of thousands. The estimate from the 2003 Christmas Bird Count on Nantucket counted over half-a-million in this flock (A. Jones, pers. comm.). Each day the ducks commute at low altitudes from their night roosts in Nantucket Sound out to their day-time feeding spots southeast of Nantucket (Nisbet, 2002). While estimates of scoter wintering populations are unavailable, a transect survey from Hyannis to Nantucket in January of 2001 counted about 30,000 surf scoters (*Melanitta perspicillata*) and 9,000 black scoters (R. Heil, pers. comm.). Assessing the impact risks that the Cape Wind project poses to these sea duck populations will depend on the location of roosting and feeding grounds, their variability among years, and the pathways of daily movement. From the perspective of cumulative impacts, the combination of wind farms in Nantucket Sound and the proposed Winergy sites to the east and southeast of Nantucket could be quite destructive to these large and important populations of birds.

In the summer and early fall, the use of Nantucket Sound is defined mostly by breeding colonies of seabirds along the south coast of Cape Cod. One breeding species of special concern is the federally-endangered piping plover. Unlike seabirds, the piping plover's breeding habitat in Massachusetts is limited to nesting and foraging on "undisturbed" sandy beaches (USFWS, 1996). The only risks to piping plovers from an offshore wind farm would arise from possible collisions in migration. Very little is known about the details of piping plovers in migration, however. From what has been observed, piping plovers typically migrate in small flocks of less than ten individuals (Haig, 1992). While piping plovers of the Northeast population are known to stop at beaches and coastal mudflats to feed during migration, it is likely that many groups fly non-stop from New England to the Gulf of Mexico (Haig, 1992; USFWS, 1996). Long-distance migratory shorebirds typically fly at altitudes above 1500 m (Richardson, 1979), which would put piping plovers well out of the reach of wind turbines. But whether piping plovers fly at this altitude, and specifically if they do when migrating over Nantucket Sound, has yet to be determined. In comparison to many long-distance migratory shorebirds that fly directly from New England to the east coast of South America, the piping plover has a relatively short distance to fly (Drury & Keith, 1962). Essentially, the risks to piping plovers from a wind farm on

Horseshoe Shoal are unknown at present. Due to the small population remaining in New England and the difficulty of monitoring flight paths and altitudes, our knowledge is not likely to be increased by studies for this project (A. Jones, pers. comm.).

Two other species of concern that breed around Nantucket Sound are common and roseate terns. Common terns are listed as a Massachusetts State Species of Special Concern, while the roseate tern is considered a federally-endangered species. The roseate terns that nest in the Northeast are an endangered temperate-zone sub-population of a species that is otherwise primarily tropical in its occurrence (Nisbet & Spendelow, 1999). The Northeast population has two main breeding grounds, one between Long Island and Cape Cod, and the other in the upper Gulf of Maine (Nisbet & Spendelow, 1999). About half of the entire Northeast population of roseate terns breeds in Buzzard's Bay, Massachusetts, and nearly the entire Northeast population congregates in the late summer around Chatham, Massachusetts for pre-migratory staging (Perkins et al., 2003; Trull et al., 1999). Consequently, Nantucket Sound is a critical location for the roseate tern, as a significant proportion of the North American population of this species relies directly on the Sound for one or more resources. Furthermore, since such a high percentage of the regional population gathers in one place (South Beach) during staging, it also means that the roseate tern population is extremely vulnerable to human disturbance (Trull et al., 1999).

How the proposed wind farm would affect roseate terns (and common terns) is still unclear. It has been found that the northeastern roseate tern population is highly sensitive to changes in the adult survival rate, as opposed to changes in productivity or food resources (Nisbet & Spendelow, 1999). From this fact we can hypothesize that indirect habitat loss to terns from the wind farm would have little impact, as they can always forage elsewhere with little or no effect on population stability. However, we can also hypothesize that even a small level of mortality (at the scale of individuals) resulting from the wind turbines could have a significant impact on breeding colonies. This is regardless of the fact that the killing, even accidentally, of even one individual of an endangered species is federally prohibited.

How roseate terns use Horseshoe Shoal will determine their risk of collisions with wind turbines. Roseate terns are specialized predators on small schooling fish and prefer sandy banks where they can engage in "shoal feeding"—the trapping of fish on a shoal or sandbar when the tide runs out (Nisbet & Spendelow, 1999). Such feeding likely occurs on Horseshoe Shoal, where parts of the shoal are nearly exposed at low tide (Cape Wind, 2002a). While feeding or traveling, roseate terns typically fly at altitudes less than 60 m, although they will fly higher under certain conditions such as approaching a night roost or when flying downwind (Nisbet, 2002). At 60 m, a flying tern would be within the bottom of the swept area of a blade used by the turbines proposed by Cape Wind (Figure 7a). Tern use of Horseshoe Shoal is expected to include foraging during the breeding period of July and August, and the area may also be a part of daily routes used by terns in the pre-migratory staging period in September (Nisbet, 2002).

Massachusetts Audubon began a study of tern use of Horseshoe Shoal in 2002, surveying for common and roseate terns in Nantucket Sound from August 19 to September 19 using both aerial and boat surveys (Perkins et al., 2003). By the end of the survey, almost all of the terns had left their staging ground around South Beach in Chatham to begin their trans-hemispherical migration. The study by Perkins et al. found fewer terns in and around Horseshoe Shoal than in other parts of Nantucket Sound during the survey window. For roseate terns, they found only one individual directly over Horseshoe Shoal during the course of four days of transects from a boat. While this evidence does suggest that Horseshoe Shoal may not be a primary feeding location for terns, at least in late summer, it is important to keep in mind that the surveys started late in the year, possibly after most terns had already moved west toward Chatham to begin staging (Perkins et al., 2003). It has also been noted that the total number of staging terns recorded near Chatham were lower in 2002 than in previous years, possibly attributable to an earlier migration (Perkins et al., 2003). The water temperature of Nantucket Sound also reached record-breaking highs in 2002, which very likely could have had a negative effect on fish populations in the area, resulting in the low usage of the Sound for tern foraging and staging (A. Jones, pers. comm.). In other years, greater numbers of terns may result in a greater dispersion of use of the entire Sound for foraging and movement during staging.

As with any large survey of bird distribution and abundance, medium to large differences in annual occurrence are going to occur. Perkins et al. plan to continue their tern surveys through 2004 and intend to expand the time period of the surveys to include the period from April to mid-September (Perkins et al., 2003). A three-year study period would thus allow the study to detect and account for annual variations in tern abundance and distribution. Without completion of at least a three-year study, any baseline understanding of bird use of Nantucket Sound, with respect to roseate and common terns, may be deficient.

5.3. Analysis of possible avian impacts from the Cape Wind project

The impacts I have described above are based on the limited information currently known and available concerning bird use of Nantucket Sound. Specific knowledge for Horseshoe Shoal is anecdotal at best, and we will only truly know after multi-year surveys and monitoring. Nevertheless, we can posit several types of possible impacts on birds that a wind farm on Horseshoe Shoal might impose, and with these impacts we can look at elements of planning and design of the wind farm.

As explained in the previous section, most possible impacts of the proposed wind farm are a direct result of collisions with the turbines. For direct and indirect habitat loss, we do not know yet of any birds that rely specifically on Horseshoe Shoal for food or any other site-specific resource. The only possible exception to this information may be wintering sea ducks—such as scoters and eiders—which may gather on the shoal to feed during the winter. No one has published data on winter use of the shoal to date, although Mass Audubon is planning to expand their survey of the Sound to include wintering ducks during the coming winter of 2003-2004 (A. Jones, pers. comm.). Even if wintering ducks do rely on Horseshoe Shoal to feed in the winter, it is questionable whether the habitat will really be "lost" to them. The studies from Tunø Knob showed common eiders were not affected significantly by wind turbines in terms of habitat loss (Guillemette et al., 1999), nor were they deterred by turbines spaced at least 400 m apart (Van der Winden, 2000). Current designs for the Cape Wind site have turbines spaced in a grid 800 m by 540 m. Additionally, the study from Blyth Harbour showed that eiders can become habituated to wind turbines near wintering grounds (Lowther, 2000). Depending on the type of foundation used to secure the turbines into the sea floor, habitat for fish may be augmented. This augmentation could either work to make the habitat more desirable to birds by increasing food resources, or, if for instance, the turbines disrupted the life cycle of sand eels on Horseshoe Shoal, the shoal could become less desirable for feeding. The most significant risk of impact to birds, however, lies with collisions.

As described previously, collisions are most likely to occur among three main groups of birds: local birds (breeding terns, wintering ducks), migrating land birds (mostly passerines), and migrating seabirds (loons, ducks, gannets, and gulls). Each group is at risk during different parts of the year, at different times of day, and under different weather conditions. It should not be entirely surprising, consequently, that the ways we can think of planning for and reducing these risks are different for each group.

For local birds, we must ask whether this is the correct location for the wind farm. Collisions from local birds will not be as dependent on weather or freak accidents—they will be a matter of probability. If a wind farm is sited in the middle of an area that is used by birds, collisions will eventually occur. That is true whether we are discussing terns, ducks, or pelagic species like shearwaters. For the future of the roseate tern, whether Horseshoe Shoal is frequently used by the species for daily movements or foraging will play a large part in how many collisions occur. For a species with a total breeding population in the northwest Atlantic of around 4,000 pairs, what risk of mortality is "acceptable" or "negligible" in regards to background mortality, and what risk of mortality is too high? It has been argued that even one death of a roseate tern is unacceptable (Clarke, 2002), and this position is supported at least by the wording of the Endangered Species Act. Consequently, if roseate terns are shown to use the area even on an infrequent basis, then perhaps Horseshoe Shoal is not the correct location for the wind farm. The choice of what standard to hold in terms of acceptable risks will be decided partly by the USACE and partly by the enforcement of the Endangered Species Act.

It has been hypothesized that the risk of impacts to wintering sea ducks is minimal at wind farms due the combination of habituation and avoidance of turbines. However, neither of these factors will matter if birds are trapped in the middle of one of the strong winter storms that frequent the coastal Northeast. Mass Audubon has expressed concern over the possibility of large flocks of sea ducks being pushed into the vicinity of the wind farm during a large storm and suffering collisions on a large scale (Clarke, 2001). During these winter storms, it has been observed that populations of sea ducks that typically cover Nantucket Sound up to 15 miles from the coast are pushed North toward Cape Cod by the winds and waves of the storms (A. Jones, pers. comm.). Large populations of sea ducks could then be forced through the wind farm during the course of one storm. The behavior of ducks during these storms—whether they try to fly, or whether they ride it out—is unfortunately little known.

For migrating land birds, little can be done in terms of placement. Most offshore areas in the Northeast have some sort of heavy migration in the fall, and the migrants usually fly on a broad front, without noticeable gaps (Nisbet, 2002). Consequently, lowering passerine collision risk is not affected by either proper siting of a wind farm or by the strategic arrangement of turbines. Since collisions of this kind will be largely unavoidable no matter where a wind farm is built, the proper focus of efforts should be on preventing major mortality events associated with migration at night in bad weather. As stated previously, collision risks are highest when migrants en route to a stopover encounter sudden inclement weather, especially over the ocean where they cannot seek shelter (Richardson, 2000). Risk reduction can start by switching from the nighttime red flashing lights proposed by Cape Wind to white lights that strobe as infrequently as the FAA allows. Cape Wind has also mentioned the possibility having these red lights "uplit" on turbines to make the towers more visible from above but not from shore (Cape Wind, 2002a). It is unknown how this directional illumination would affect migrating passerines.

After the wind farm is operational, there are several ways to practice preemptive mitigation. For instance, during peak nocturnal fall migration, all lights could be turned off and the rotors could stop spinning. Alternatively, if an experienced avian ecologist were on hand, nights of high passerine migration could be predicted several hours or days in advance, and lights turned off only when thus warned. Predicting high-risk conditions, however, requires specific data on the number of birds migrating at low altitudes under various weather conditions (Richardson, 2000). Stopping the rotors from spinning would help reduce risks of collisions, but as communication towers have shown, even stationary towers are not immune to high mortality events.

The final group, migrating seabirds, are difficult to predict and plan for due to their lack of a unifying migration pathway or timing of migration. Each species will be slightly different from the next. Better studies of what species pass through Horseshoe Shoal will allow risk reduction planning to be more specific. One factor that will partly determine collisions from migrating seabirds is the degree of visibility of the turbines. Nisbet (2002) described seabird migration through Nantucket Sound as being both a nocturnal and diurnal phenomenon. Studies from the Netherlands found ducks to be able to see and avoid unlit wind turbines even on nights without moonlight (Van der Winden, 2000), thus improving the chances of turbine visibility and avoidance under most conditions. While heavy fog or bad weather could impede visibility, most seabirds migrate either directly preceding or on the tailwinds of a large front, typically "Nor-easters" in the fall in Massachusetts (Heil, 2001). This predicts that the majority of migrating seabirds would not be passing through a wind farm on Horseshoe Shoal during conditions most likely to produce significant mortality. During heavy fall storms, however, seabirds will often seek shelter in bays and other protected bodies of water (Heil, 2001). If a wind farm were located in one of these areas, collision risks would be extremely high. While it is unlikely that Horseshoe Shoal provides the needed shelter for seabirds in migration, the full use of Horseshoe Shoal by migrating seabirds in various weather conditions will only be discovered through extensive monitoring in all meteorological conditions.

A proactive strategy can also be adopted when looking at mitigation of collisions from seabirds—whether local or migrating. As various groups of seabirds, particularly ducks and gulls, have been shown to actively avoid wind turbines and wind farms, an optimally designed wind farm at Horseshoe Shoal will maximize the ability of seabirds to see turbines and find alternative ways around them (Van der Winden et al., 2000; Winkelman, 1992c). Furthermore, due to the variety of species and migration routes through Nantucket Sound, especially those that are dependent on variable weather conditions, there is likely to be no major axis of migration on which to orient an arrangement of turbines. Consequently, if we were to optimize the arrangement of turbines on Horseshoe Shoal so as to minimize collision risks from migrating or local seabirds, we would want dispersed clumps of five to 20 turbines (e.g., Figure 10). Within a set boundary, the clumps would be arranged to maximize distance between clumps and to allow multiple routes of passage through the wind farm. Turbines within clumps would be arranged to maximize density while keeping a minimum distance between towers. It should be noted that this type of spatial planning of wind farms is purely experimental and the effects of such planning—positive or negative—have not been shown in studies of existing wind farms. Based on what we know from bird behavior around existing wind farms, however, creativity with turbine arrangements could possibly be a very positive way to plan for and mitigate expected bird impacts.

5.4. The bottom line

In summary, there are numerous ways that we can analyze potential impacts on birds from the proposed Cape Wind wind farm and use planning to lower the risks. The tools directly available to the developers are choices on site location, turbine arrangement, and lighting. As a further measure post-construction, the activity of lights and turbines can be manipulated (i.e., turned off) to correspond to periods of high collision risk. What risk-reducing measures Cape Wind might actually employ will depend a lot on the results of the numerous field studies currently undertaken to assess bird use of and distribution in Horseshoe Shoal and Nantucket Sound. These surveys will determine, for instance, whether Horseshoe Shoal is even a viable option for a place to build a wind farm without severely impacting bird populations such as the endangered roseate tern.

While the results of Massachusetts Audubon's one-month study indicated low tern usage of the area, it is up to the federal regulating institutions to determine what levels of risk are acceptable and what levels are not. This can be said for all final decisions on risks to birds, whether local or migratory, songbird or seabird. However, it is not up to just the federal regulatory institutions alone to make these decisions; their decisions are assisted by input from federal and state environmental agencies, with room for public opinion at many stages. Even if the Cape Wind project does get permitted but environmental agencies or citizens groups with standing believe the USACE made a mistake, they can take the project to court (Griscom, 2002). The Natural Resources Defense Council (NRDC), for instance, is waiting until the full

EIS is released by Cape Wind before they take a stand on the issue (Griscom, 2002). It is clear that the policy debate of offshore wind farms in the United States is just beginning, and it will probably be several years before regulation and permitting issues start to be solved.

Until this happens, however, we are faced in potentially as little as two years with the full construction of one of the largest offshore wind farms in the world. For those concerned about the environment and wildlife of Nantucket Sound, much will depend on the findings released by Cape Wind, Mass Audubon, and other groups in the next year or two. The longer the period of study, the better we will know what the risks are. For this reason, it is in the best interest of the state to require at least a three-year baseline study of avian use and presence in Nantucket Sound. From the information currently available, Horseshoe Shoal does not seem to be an improper place to build a wind farm from an avian conservation perspective, but the scale of Cape Wind's proposal does seem entirely improper given our limited knowledge of offshore wind farms' impacts on birds. Any initial offshore wind farm project in the United States should be of a small scale (<50 turbines) in order to better assess and understand impacts while limiting the risk of causing significant harms. This is the more prudent approach.

6. CONCLUSION

In-depth understanding of human-nature conflicts can take a long time to mature. The offshore wind industry has only existed for 13 years; thus it should be of little surprise that our knowledge of the effects of offshore turbines on birds is far from conclusive. We have a large list of potential impacts on birds from wind farms, and very few complete studies have looked at even a portion of these impacts. Those studies that are available provide little material for researchers to use to predict impacts elsewhere, due to the high variability of geography, weather, and a whole host of localized factors involving bird species and habits.

Given the sudden worldwide rush to offshore wind projects, citizens, scientists, and planners are left with a dilemma: what do we actually know and how do we proceed? To start, we know that bird collisions do occur—no location is immune. No matter the base-line conditions or known bird behaviors, the variable conditions of nature will always put birds in the same vicinity as turbines. Some locations, however, are far worse than others. We know from onshore studies that impacts such as habitat loss and barriers to flight can occur. For offshore wind farms, the risk of observing these impacts at significant levels will be site-specific. Consequently, the first priority is trying to foresee problems before a wind farm is built. The second priority is monitoring bird activities around built wind farms in order to define impacts that arise after construction. Both of these options require constant and rigorous scientific study.

Some will argue that the need to understand the impacts of wind farms on birds puts too strenuous a burden on developers. This view is also expressed by the sentiment, “Why do we need to study impacts here when other locations are studying the same thing?” Regardless of the site-specificity of impacts, it is imperative to appreciate the precautionary approach necessary to evaluate such huge changes to the natural landscape. The trend in offshore developments is for larger wind farms generating more power. Tiny impacts that may have been insignificant or unnoticed at 5 or 20 turbine experiments may be magnified to disastrous levels in 100 or 200 turbine industrial zones. Since the knowledge that we do have comprises an insufficient pool, any risk added needs to be accompanied by a full analysis of preconditions as well as an extensive post-construction monitoring program. That is the only effective way to protect the marine environment until we know for certain the full consequences of our actions.

The Cape Wind project is an important test that will undoubtedly direct the fate—at least in the immediate future—of the United States’ offshore wind energy potential. This study is not intended to be a comprehensive analysis of the impacts on birds from the Cape Wind project, nor is it intended to be a balanced look at all the benefits and disadvantages that the wind farm might offer Massachusetts and the United States. Its purpose is to take a background look at what information is available to us from past experience and to apply this knowledge so as to best understand the process and possible risks associated with building a wind farm on Horseshoe Shoal. What the actual impacts on birds are, or how Cape Wind deals with these impacts, still remains to be seen.

It is hard to deny that the United States needs to increase its sources of renewable energy, and harnessing offshore wind energy provides one demonstrated way for the U.S. to do so. Rushing ahead with a pioneering project of mammoth proportions may not be the wisest way for the U.S. to enter into this market, however. Given the need to begin with careful and calculated steps, a better prescription for the environment, consequently, involves two consecutive parts. The first part is building more small experimental offshore sites in areas with varying degrees of avian activity. These sites should be intensively monitored and, as experiments, disassembled when finished. Smaller wind farms will also allow experimentation with turbine configurations, different species and behaviors, and various mitigation measures. The second part involves building one or two medium to large wind farms in areas carefully located to minimize avian impacts. These locations may or may not coincide with the places with the most favorable wind resources, but by carefully monitoring the impacts of large wind farms, we can better formulate, modify, or reject future developments. In the last chapter, I suggested that Horseshoe Shoal may serve as a proper site for a trial wind farm of this type, but now is not the right time to build a very large wind farm there without prior offshore wind experience.

We already live in a world where humanity's developments have redefined the natural world in ways that are now beyond our control. This is not the wisest way to do things. Without knowing the future of offshore wind farms in the United States, we must do our best to carefully plan and monitor each step we take. To do otherwise is simply reckless.

Table 1. Site characteristics of the nine offshore and two nearshore (<1 km from shore) wind farms operational in 2003.

Site	Country	Distance to shore (km)	Year operational	Bird studies	No. turbines	Turbine power (MW)	Tower height (m)	Rotor diameter (m)
Vindeby [a, b]	Denmark	1.5 to 3	1991	none	11	0.45	38	34
Lely [b, e]	Netherlands	0.8	1994	1994-1996	4	0.50	42	40
Tunø Knob [b, c]	Denmark	6	1995	1994-1998	10	0.50	43	39
Dronten [b, e, f]	Netherlands	0.3	1996	none	28	0.60	50	43
Bockstigen [b, f]	Sweden	4	1998	none	5	0.55	42	37
Utgrunden [b, e, f]	Sweden	12	2000	2000-present	7	1.45	65	70
Blyth Offshore [b, d]	U.K.	1	2000	2000-present	2	2.00	58	80
Middelgrunden [b, e, f]	Denmark	2 to 3	2001	none	20	2.00	60	76
Yttre Stengrund [b]	Sweden	5	2001	2000-present	5	2.00	60	72
Horns Rev [b]	Denmark	14 to 20	2002	1999-present	80	2.00	70	80
Samsø [b, f]	Denmark	3.5	2002	unknown	10	2.30	61	76?

References:
(a) Henderson et al., 2001
(b) Wind Service Holland, 2003
(c) Guillemette et al., 1999
(d) Parkinson, 1999
(e) Percival, 2001
(f) Ackerman & Söder, 2002

Table 2. Planned offshore wind farm developments in New England. All sites could possibly begin operating by 2005.

Site	Company	Water ownership	Size (sq. mi.)	No. turbines	Turbine power (MW)	Total Power (MW)
Horseshoe Shoal	Cape Wind [a]	Federal	26	130	3.6	420
Nantucket 1	Winergy [b]	Federal	62	231	3.5	832
Nantucket 2	Winergy	Federal	44	212	3.5	763
Nantucket 3	Winergy	Federal	33	169	3.6	608
Davis Bank	Winergy	Federal	47	208	3.5	749
Provincetown	Winergy	State	1.63	10	1.8	18
Buzzards Bay	Winergy	State	1.0	10	1.8	18
Essex	Winergy	State	<2.0	10	1.8	18

References:
(a) www.capewind.org
(b) www.winergyllc.com/sites.shtml

Table 3. Potential effects of offshore wind turbines on birds, separated by turbine element and groups impacted.

	Underwater life/ecosystem	**Resident (or local) seabirds**	**Migratory passerines**	**Migratory seabird**
Construction	Trenching, digging. Disruption of habitat, breeding cycles, and natural communities.	Temporary displacement from roosting, feeding, or molting grounds.	Negligible.	Negligible.
Turbine structure	Direct loss of sea floor. Can change processes of sedimentation and water flow. Also possible reef effect, increasing habitat for certain marine species.	Possible collision. Potential for perching. Direct habitat loss of seafloor built on. Possible increased food due to reef effect.	Possible collision.	Possible collision.
Rotating blades, operational system	Vibrations could disrupt marine life. Electromagnetic currents could affect fish and marine mammals. Chemical cleaners and leakages could poison surrounding water.	Greater chance of collision. Possible disturbance and avoidance of turbine due to blade motion and noise.	Greater chance of collision, especially if tower is lit.	Greater chance of collision.
Entire wind farm system	Possibly disrupt processes integral to survival of an ecosystem. Possibly increase diversity and abundance of marine life.	Disturbance and avoidance of entire system. Possible indirect habitat loss of molting or feeding areas. Possible barrier to flight of daily movments. Ability to habituate in long term? Increased food within system from reef effect, or less food due to disturbance of benthic community?	Barriers to movement unlikely.	Disturbance could cause indirect habitat loss if wind farm includes important staging area. Migrating seabirds could possibly exploit increased food at wind farm, if present.

Table 4a. Summary of results of the first Tunø Knob study (Guillemette et al., 1998), based on table in Guillemette (1998). TK = Tunø Knob wind farm site, RS = control site.

Investigation	Spatial scale (ha)	Design characteristics	Conclusion
1a. Aerial surveys of the whole of Århus Bay comparing the abundance of eiders at TK and RS before and after the construction of the wind farm.	88,000 to 5000	BACI controlling for the abundance of eiders in the whole of Århus Bay.	Tendency to have fewer eiders at TK after the construction while it remained stable at RS. The results are suggestive of an impact (see ground surveys below).
1b. Ground surveys comparing the abundance of eiders at TK and RS before and after the construction of the wind park.	700 to 800	BACI 'controlling' for the abundance of food at both study sites.	Much lower number of eiders at TK after the construction while it was almost stable at RS. This was associated with qualitative and quantitative differences in the biomass of blue mussels between the two sites. The results suggest that the decrease in eider abundance was caused by food supplies and not by the wind farm This interpretation probably also applies to the results of aerial surveys.
2. Ground surveys comparing the abundance and distribution of eiders within TK.	160 to 245	BACI with three sister areas (quadrants).	Much lower number of eiders in the presumed impact sub-area (NW) after the construction of the wind farm and similar fluctuations in the sister sub-areas. Large inter-annual and seasonal variations in the distribution of the eiders. The results suggest that fluctations in the eider numbers were caused by natural variation and not by the wind farm This interpretation also applies to their spatial distribution.
3. On-off experiment comparing the abundance and distribution of eiders.	40 to 230	Experiment randomizing the effect of food supply.	Similar numbers of eiders when controls and treatments are compared. The noise and the movements of the rotor do not affect negatively the abundance and the distribution of eiders.
4. Exploitation experiment comparing the proportion of eiders at different distances from the wind farm on a winter basis.	40 to 230	Manipulative experiment controlling for the influence of food supply.	Similar proportion of eiders (corrected for food supply) at different distances of the wind farm. Neither the standing towers nor the revolving rotors influenced the abundance of eiders on a winter basis.
5. The decoy experiment testing the impact of the wind park on flying eiders	40 to 230	Manipulative experiment 'attracting' eiders to land at different distances from the wind farm.	Eiders avoided flying and landing within 100 m of the wind farm. This should decrease the probability of collision with the standing towers (in good weather collisions). Note: these behaviors are from habituated local birds.

Table 4b. Summary of results of the second Tunø Knob study (Guillemette et al., 1999). TK = Tunø Knob wind farm site, RS = control site.

Investigation	Spatial scale (ha)	Design characteristics	Conclusion
1. Ground surveys comparing the abundance and distribution of eiders and scoters within TK.	160 to 245	BACI with three sister areas (quadrants).	Based on the suggested impact of the previous study (Guillemette et al., 1998), an extra year of data was added to the ground survey (previously investigation 3). This fourth year of data collection saw huge increases in eider abundances, accompanied by similar increases in blue mussel populations—a favored prey of eiders—as well as other benthic food supplies. The spatial distribution of eiders around the wind farm vicinity was also similar to the distribution observed in the baseline year. Scoter populations in the fourth year also increased from previous years, but did not exceed baseline numbers. This fourth year indicated that the decline in sea ducks observed in the two years post-construction was not caused by the wind farm, but was caused (through high correlation) by a simultaneous decline in preferred food sources.

Table 4c. Summary of results of the third Tunø Knob study (Tulp et al., 1999, in van der Winde et al., 2000). TK = Tunø Knob wind farm site, RS = control site.

Investigation	Spatial scale (ha)	Design characteristics	Conclusion
1. Radar and visual survey of nature and intensity of nocturnal flight activity of eiders in vicinity of TK.	200 to 800	Looked at flight direction, duration, distance, and proximity to turbines. Compared nights with varying amounts of ambient moonlight.	Eiders actively avoided the wind farm at night, with the distance of disturbance detectable up to 1,500 m. Avoidance was greatest on moonlit nights, when nocturnal flight was high. On nights without moonlight, eiders flew 3 to 6 times less often, and did not avoid the turbines as much. The avoidance of the turbines at night suggested that turbines can act as barriers to movement.

Table 5. Important avian species groups potentially impacted by an offshore wind farm in Nantucket Sound. General groupings based on Nisbet (2002). Many of the numbers for altitude and population are estimates and remain to be scientifically validated.

	Characteristic species	**Typical flying altitude**	**Estimated numbers arounc Cape Cod**
Migrant landbirds from MA NH	Thrushes, cuckoos, swallows, long-distance wood-warblers, such as blackpoll warbler	Typically around 1,000 m	Tens of millions (total over Cape Cod each fall)
Migrant Landbirds from Nova Scotia	Thrushes and sparrows	< 1,000 m	Tens of millions (total over Cape Cod each fall)
Migrant seabirds from Gre Lakes	Long-tailed ducks, scoters, loons	Variable, several thousand meters over land to 10 m over water	Several hundred thousand
Migrant shorebirds to Sout America	Sandpipers, red knots, dowtichers	Up to 7,000 m	Several hundred thousand
Spring and fall seabird seasonal movements	Gulls, terns, gannnets, sea ducks, loons	Variable (1 - 60 m)	Several million
Wintering sea ducks	Long-tailed ducks, eiders, scoters	< 20 m, but possibly higher in different conditions	500,000 to a million
Piping plover	——	Unknown	150 to 500, possibly more.
Roseate tern	——	Usually < 60 m	Typically 4,000 breeding, up to 10,000 staging
Common tern	——	Usually < 60 m	Probably around 4,000 breeding, up to 20,000 staging

Figure 1. Map of the nine offshore and two nearshore wind farms operational in 2003. Lely and Dronton are the nearshore wind farms, defined as being less than one kilometer from the shore.

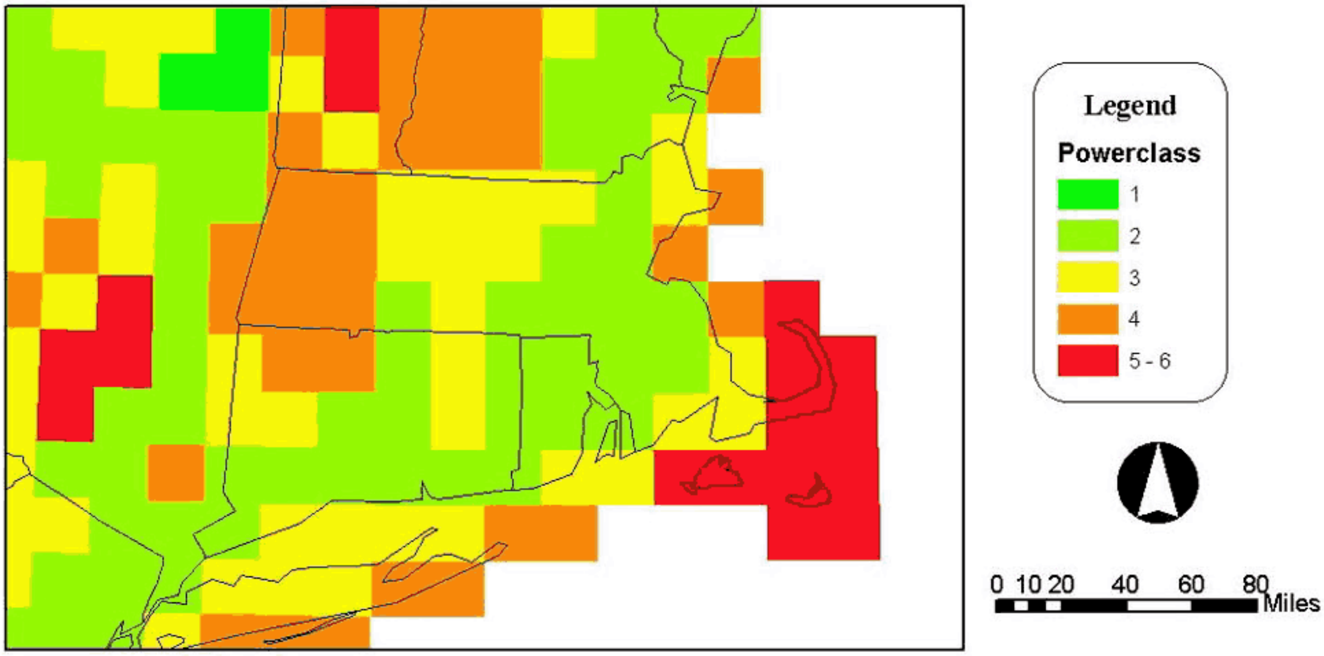

Figure 2a. Map of wind resources for southern New England. Areas designated class 3 or greater are suitable for most utility-scale wind turbine applications, whereas class 2 areas are marginal for utility-scale applications but may be suitable for rural applications. Wind data from National Renewable Energy Laboratory GIS database.

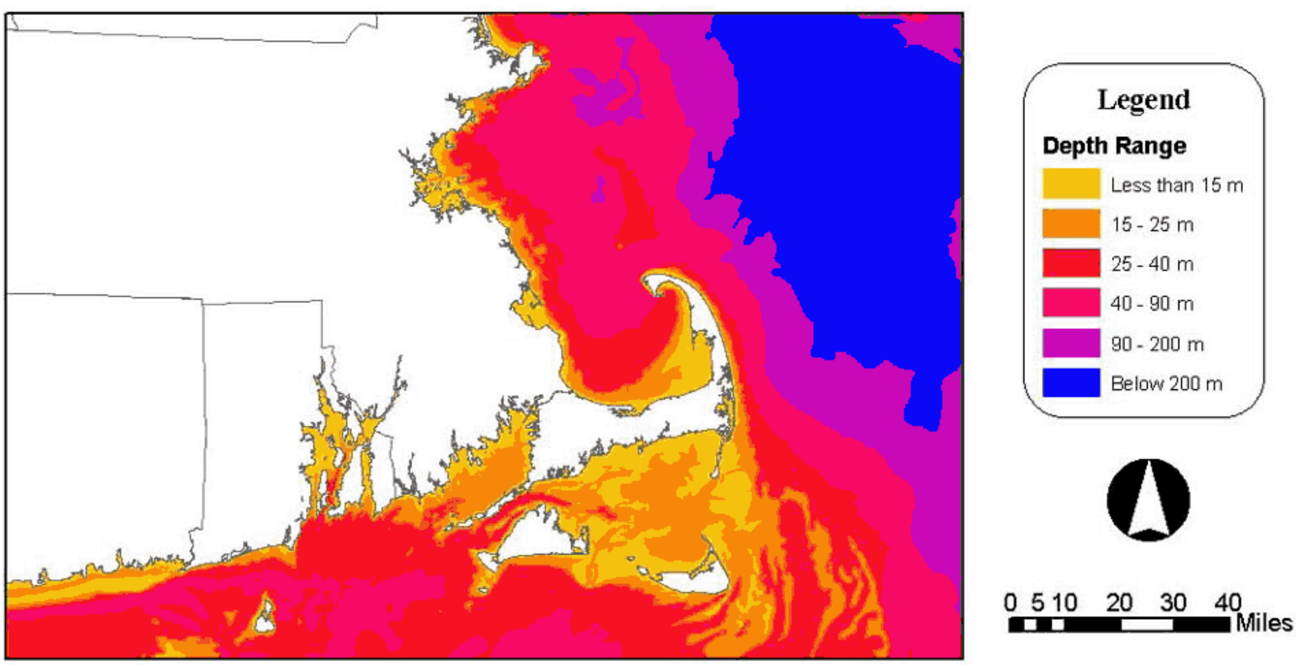

Figure 2b. Map of water depth in southern New England. Data from MassGIS.

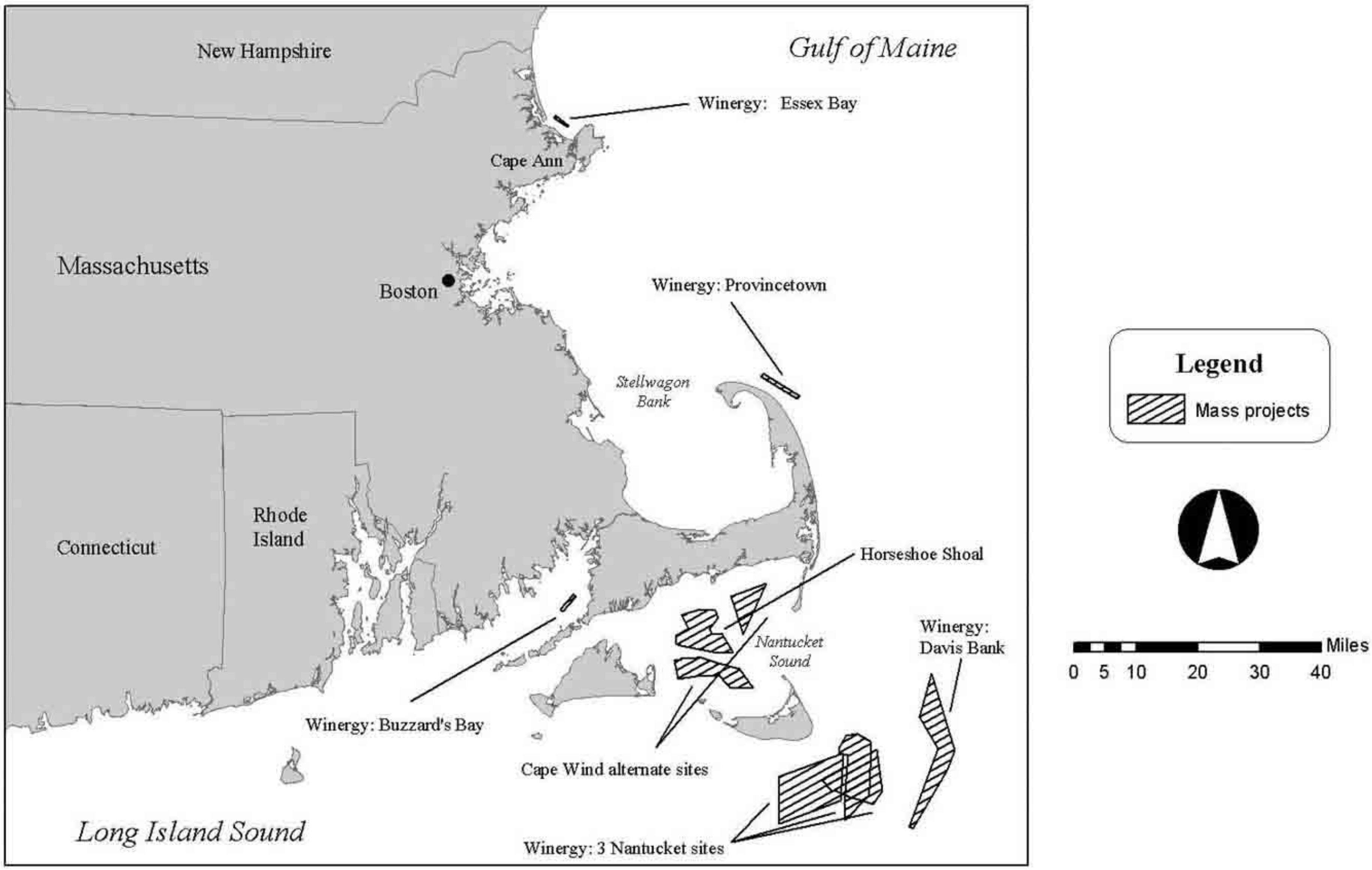

Figure 3. Map of planned offshore wind farm developments in Massachusetts. Current plans only seek to build at five locations. Cape Wind would only build at one of the three Nantucket Sound sites, and Winergy would only build at one of the three sites SE of Nantucket or Davis Bank. Data based on maps provided by *Cape Cod Times* and Winergy LLC.

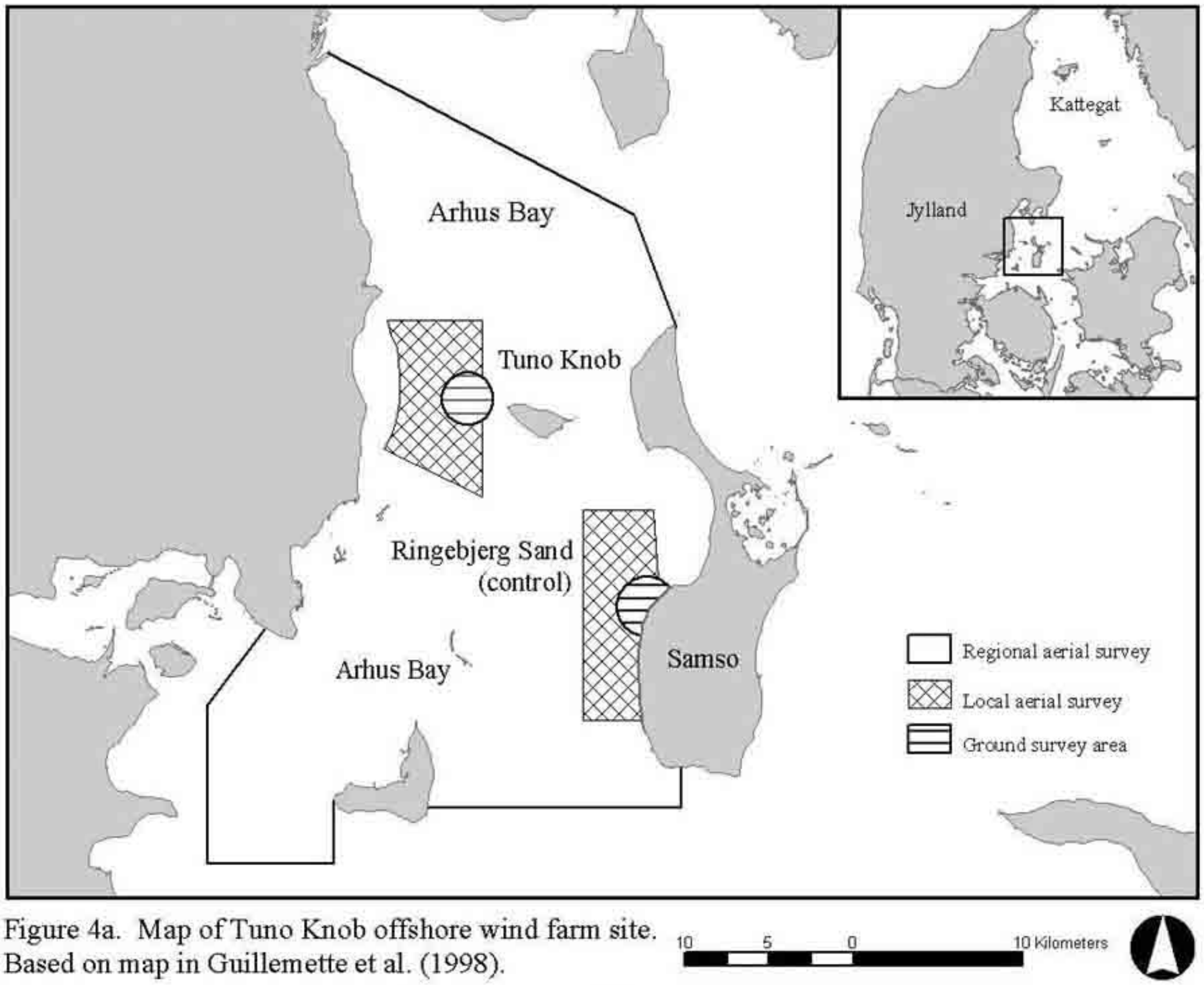

Figure 4a. Map of Tuno Knob offshore wind farm site. Based on map in Guillemette et al. (1998).

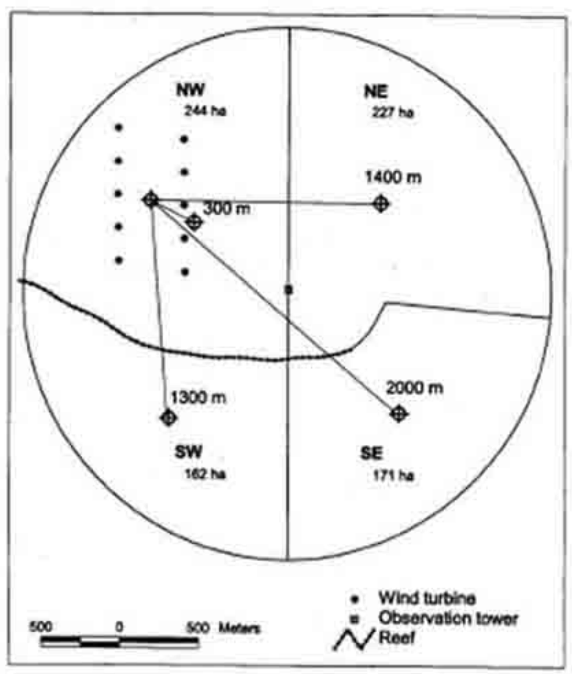

Figure 4b. Map of Tunø Knob wind farm study area, subdivided into four quadrants. The wind farm is located in the NW quadrant. From Guillemette et al. (1998: 36).

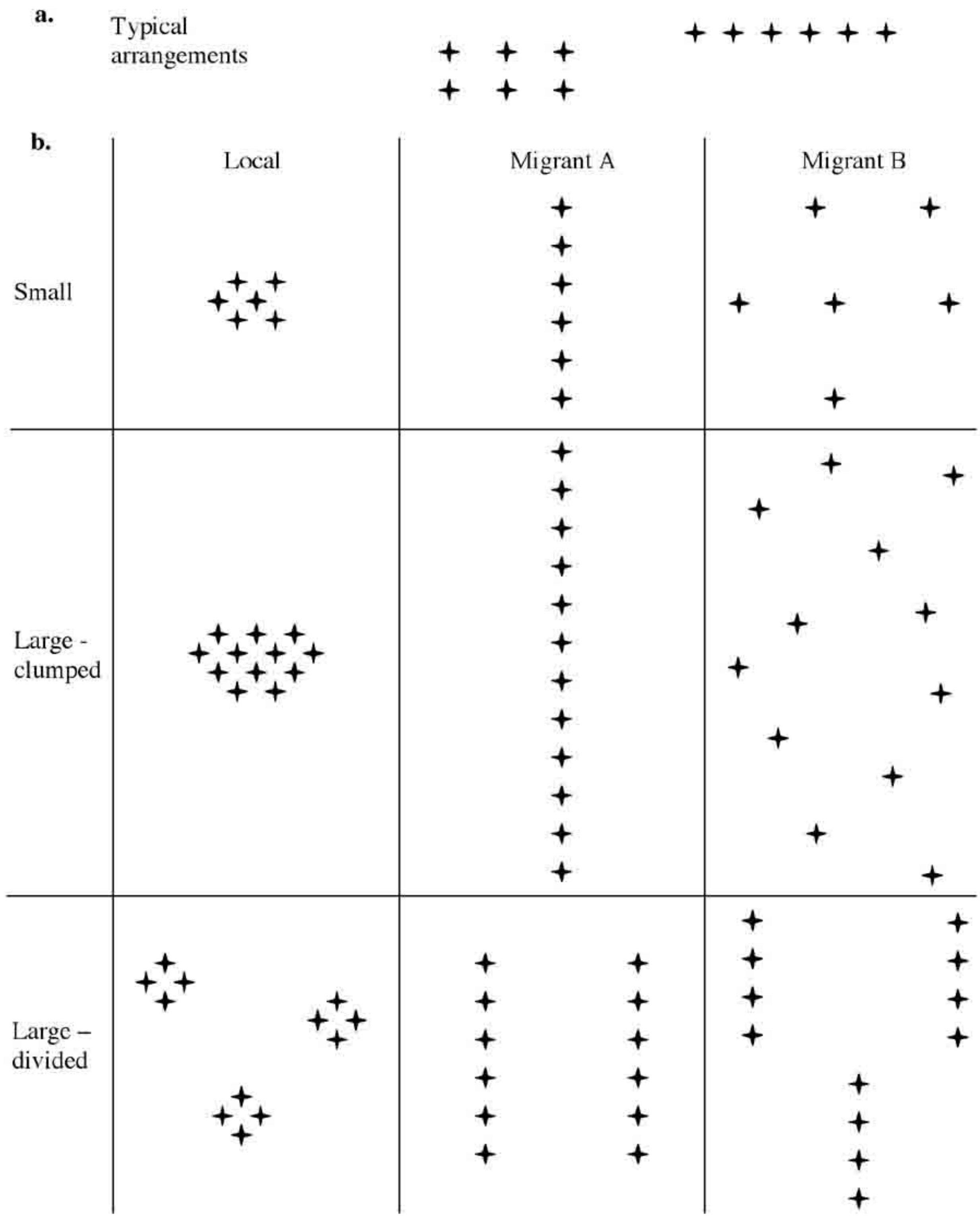

Figure 5. Possible spatial arrangements of offshore wind farm turbines. a. Typical arrangements of current wind farms. b. Hypothetical arrangements based on number of turbines (for example, n=6 for small, n=12 for large) and presumed dominant usage by birds (local birds or migrants). Two migrant strategies (line and dispersed) are depicted.

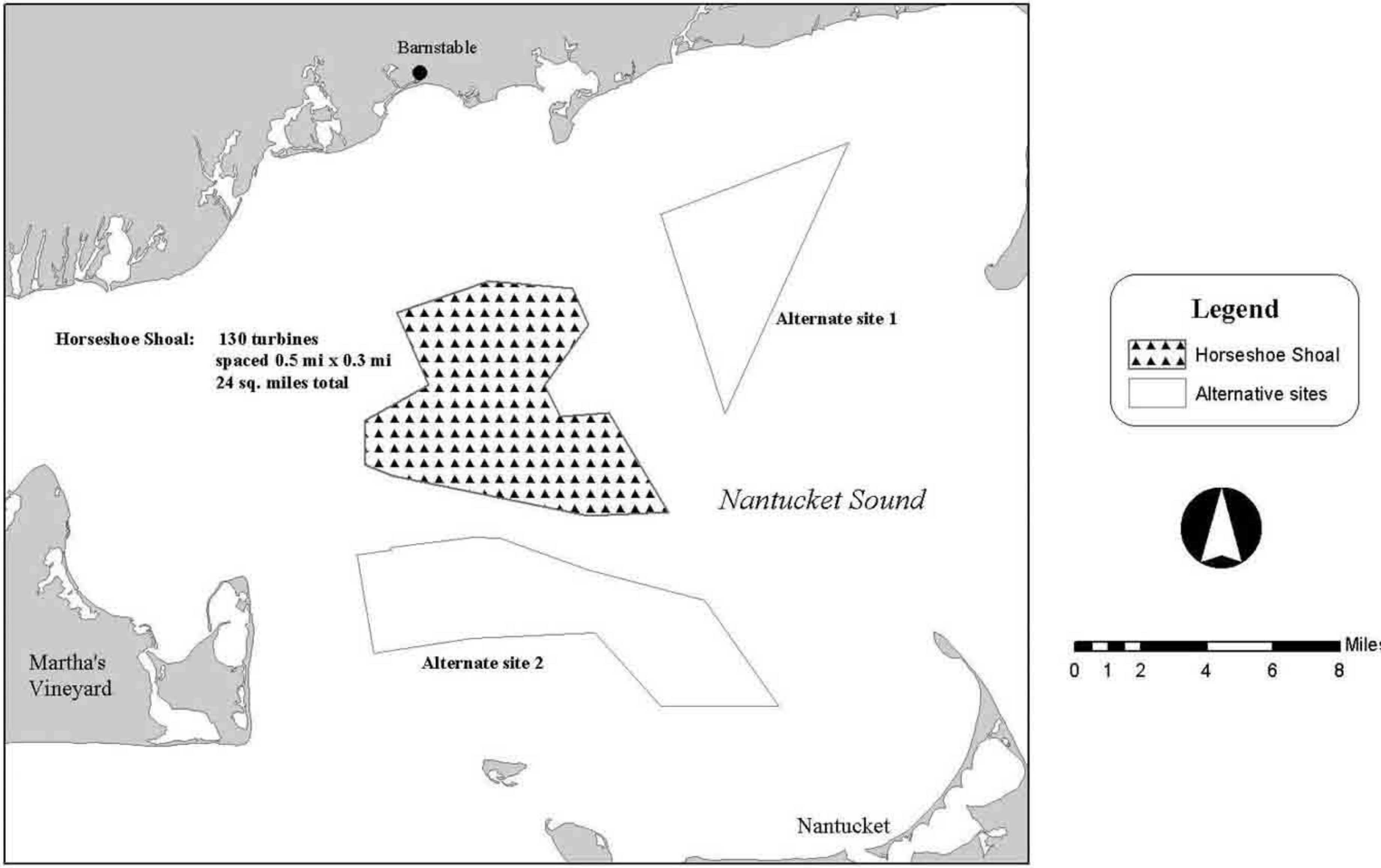

Figure 6. Map of planned configuration of Cape Wind offshore turbines in Nantucket Sound. Shown includes the planned site on Horseshoe Shoal and two selected alternate sites. It should be noted that the alternate sites are proposed by Cape Wind, but are still under consideration by the USACE. Data based on maps provided by *Cape Cod Times*.

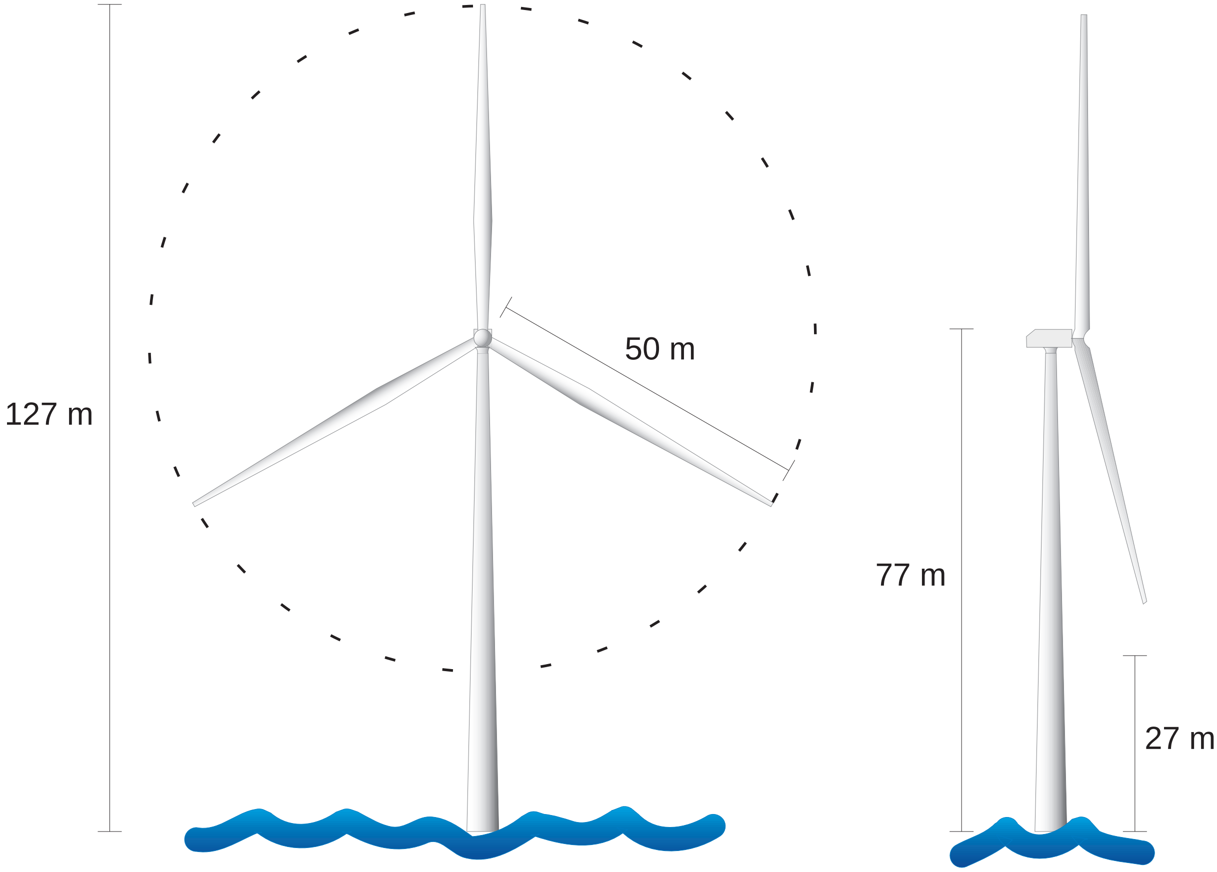

Figure 7a. Dimension diagram of GE Offshore 3.6 MW wind turbines. Blade revolves between 8.5 and 15.3 rpms. All dimensions from GE Wind Energy (2003).

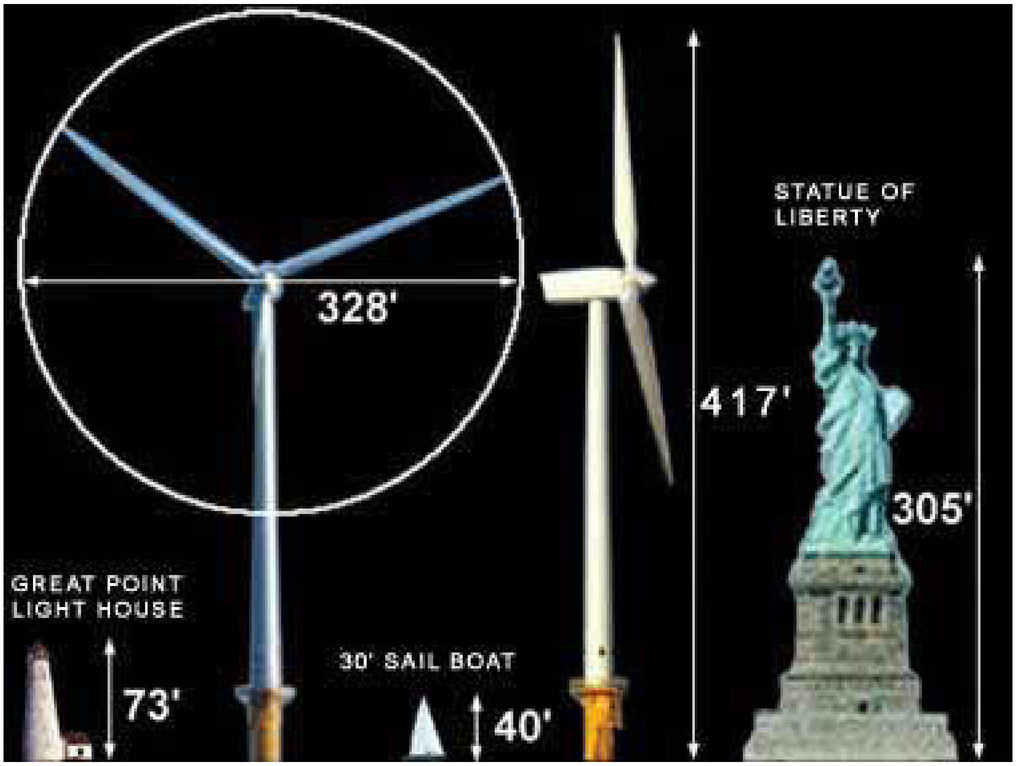

Figure 7b. Height comparison of GE offshore turbines and other objects. Note heights are not metric. Graphic © 2003 Alliance to Protect Nantucket Sound, Inc.

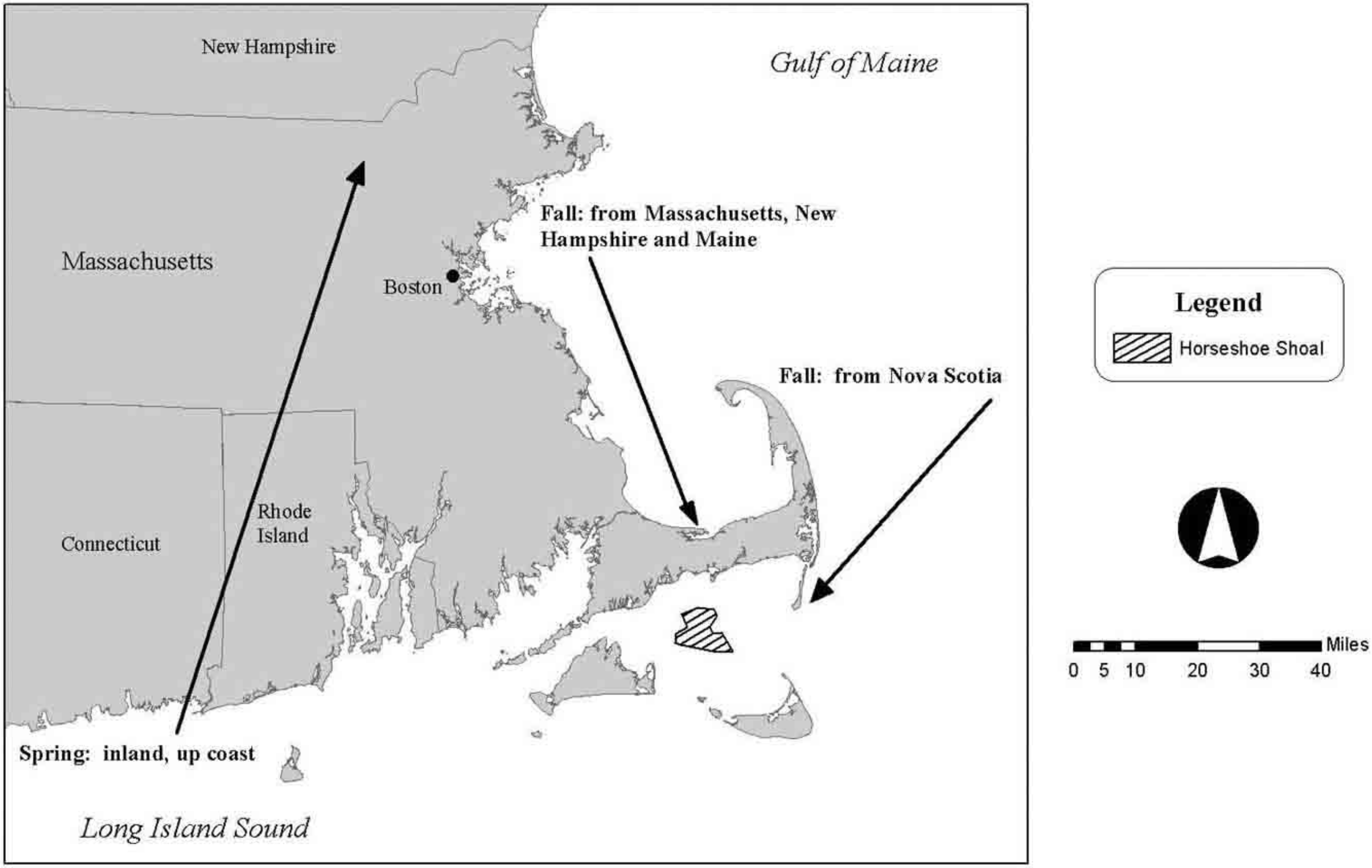

Figure 8. Map of main landbird migrations around Cape Cod in spring and fall. Based on data from Drury & Nisbet (1964) and Nisbet (2002).

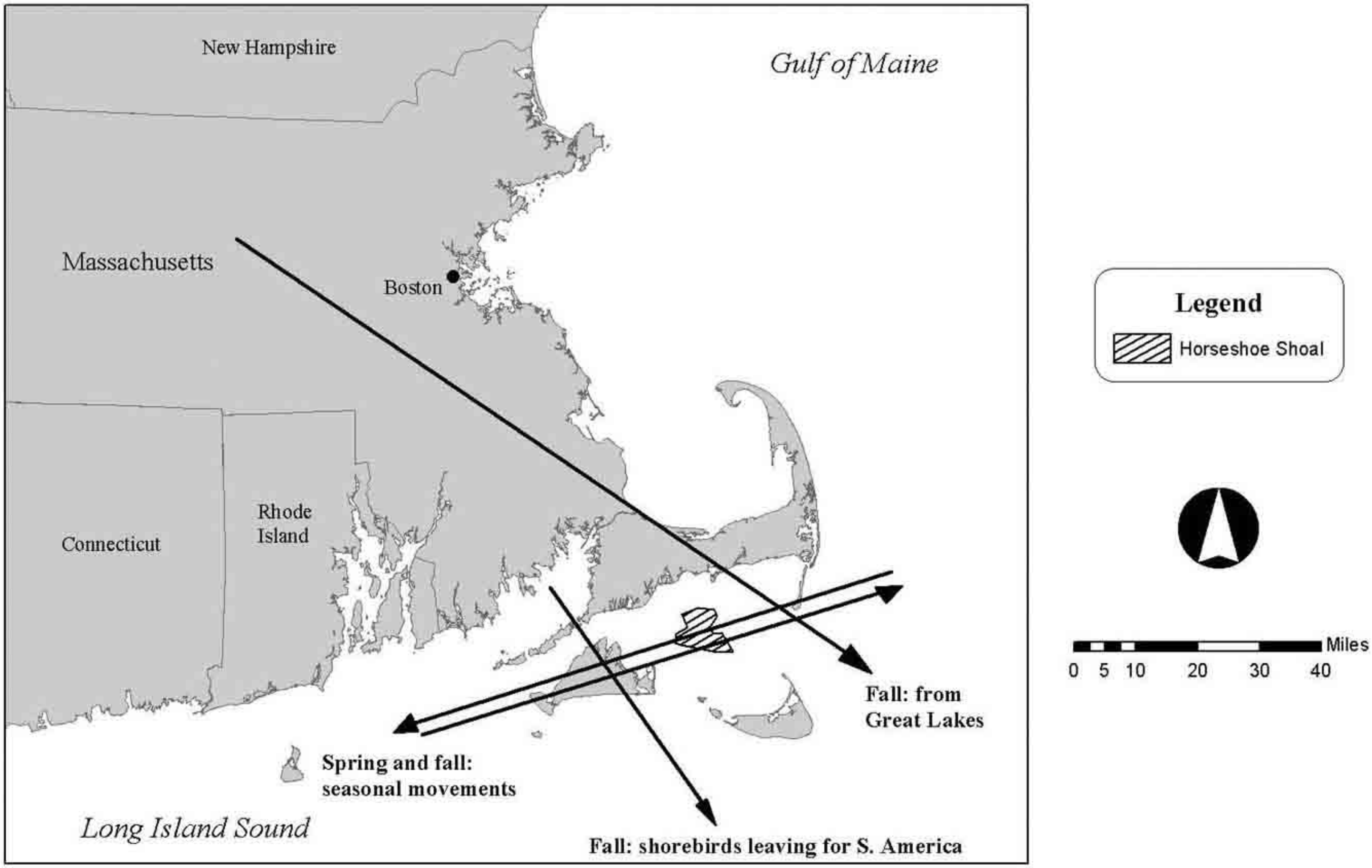

Figure 9. Map of main seabird migrations around Cape Cod in spring and fall. Based on comments by Nisbet (2002).

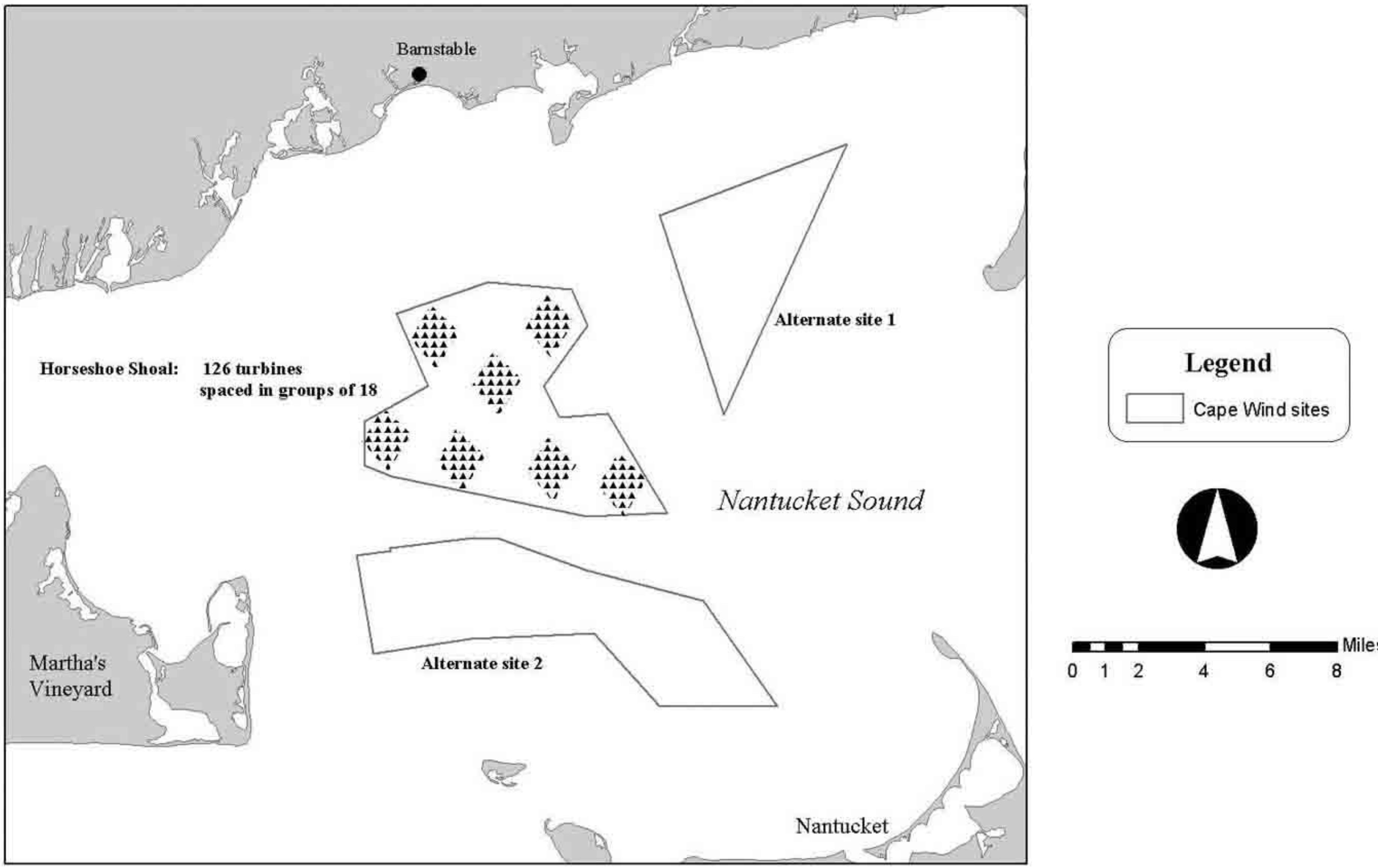

Figure 10. Possible optimal arrangement of turbines on Horseshoe Shoal. Spacing designed so as to maximize large gaps between clumps, within boundaries of the shoal. Design is purely theoretical. Outlines based on maps from *Cape Cod Times*.

REFERENCES

Ackermann, T. & Soder, L. (2000). Wind energy technology and current status: a review. *Renewable and Sustainable Energy Reviews, 4*, 315-374.

Ackermann, T. & Söder, L. (2002). An overview of wind energy-status 2002. *Renewable and Sustainable Energy Reviews, 6,* 67-128.

Alerstam, T. (1990). *Bird Migration.* (D. A. Christie, Trans.). Cambridge: Cambridge University Press.

Alliance to Protect Nantucket Sound (APNS). (2003). Visualize 130 Turbines. <http://www.saveoursound.org/visual.html> (cited 16 March, 2003).

American Wind Energy Association (AWEA). (2003). Wind energy fact sheet: facts about wind energy and birds. <http://www.awea.org/pubs/factsheets/ WEandBirds.pdf>.

Amorello, M. (2002). "Mark Amorello, Chair, Massachusetts Marine Fisheries Commision, to Colonel Thomas L. Konig, US Army Corp of Engineers," 15 August, 2002. <http://www.saveoursound.org/environmental.html>.

Anderson, R., Morrison, M., Sinclair, K., & Strickland, D. (1999). Studying wind energy/bird interactions: a guidance document. Prepared for the Avian Subcommittee and NWCC. Washington, D.C.: NWCC c/o RESOLVE.

Bayley, D. (2000). Obstruction marking (lights)—recommendations from the FAA. In Avian mortality at communication towers (ed. Evans, W. R., and Manville, A. M.). Transcripts of Proceedings of the Workshop on Avian Mortality at Communication Towers, August 11, 1999, Cornell University, Ithaca, NY. <http://migratorybirds.fws.gov/issues/towers/ agenda.html>.

Berland, H. (2000). Licensing concerns, NEPA, sitings, Telecommunication Act mandates—the FCC perspective. In Avian mortality at communication towers (ed. Evans, W. R., and Manville, A. M.). Transcripts of Proceedings of the Workshop on Avian Mortality at Communication Towers, August 11, 1999, Cornell University, Ithaca, NY. <http://migratorybirds.fws.gov/issues/towers/ agenda.html>.

Berthold, P. (2001). *Bird Migration: a general survey.* (H. Bauer & V. Westhead, Trans.). Oxford: Oxford University Press.

Biank Fasig, L. (2003, January 22). Wind farmers plow ahead – Developers choose manufacturer, reduce number of planned turbines. *The Providence Journal-Bulletin*, pp. E01.

Bird Observer. (1994). *A Birder's Guide to Eastern Massachusetts*. Colorado Springs, CO: American Birding Association.

Bradley, R. L. (2003). Why renewable energy is not cheep and is not green: problems of windpower. National Center for Policy Analsyis study. >http://www.ncpa.org/ studies/renew/renew2d.html> (cited March 10, 2003).

Byrne Ó Cléirigh, Ltd. (2000). Assessment of impact of offshore wind energy structures on the marine environment. Byrne Ó Cléirigh, Ltd., EcoServe, and School of Ocean and Earth Sciences, University of Southampton, UK.

Cape Wind. (2002a). Project at a glance. <http://www.capewind.org/learning/ pglan02.htm> (cited 16 March, 2003).

Cape Wind. (2002b). Project siting and visual impacts. <http://www.capewind.org/ benefiting/sitev02.htm> (cited 16 March, 2003).

Clarke, J. J. (2001). "John J. Clarke to Bob Durand, Re: Cape Wind Project, Nantucket Sound," 13 December, 2001. Massachusetts Audubon Society. <http:// www.massaudubon.org/PDF/News/MEPA.windfarm.pdf>.

Clausager, I. (2000). Impact assessment studies of offshore wind parks on seabirds with special reference to the Tunø Knob wind park. In *Technische eingriffe in marine lebensrume* (ed. Merck, T. and von Nordheim, H.), pp. 120-125. Workshop des Bundesamtes für Naturschutz Internationale Naturschutzakademie Insel Vilm 27.-29. Oktober 1999 . Bundesamt fr Naturschutz . - BfN-Skripten.

Cochran, W. W., & Graber, R. R. (1958). Attraction of nocturnal migrants by lights on a television tower. *The Wilson Bulletin, 70*, 378-380.

Coleman, J. (2003 January 22). Wind turbine proposal cut by 40. *Cape Cod Times*. <http://www.capecodonline.com/special/windfarm/windturbine22.htm>.

Crawford, R. L., & Engstrom, R. T. (2001). Characteristics of avian mortality at a North Florida television tower: a 29-year study. *Journal of Field Ornithology, 72*, 380-388.

Dillon Consulting Ltd. (2000). Wind turbine environmental assessment: draft screening document. Toronto Renewable Energy Co-operative and Toronto Hydro Energy Services, Inc. <http://www.torontohydro.com/energyservices/green_power/ ea_approval/index.cfm>.

Dirksen, S. (2000). Considerations on environmental issues in the planning of offshore wind farms in the Netherlands. Presented at Worskshop Offshore-Windenergienutzung Technik, Naturschutz, Planung. Deutsches

Windenergie-Institut GmbH, Wilhemshafen, 27 Juni 2000. < http://www.dewi.de/ dewi/download/sonstiges/workshop/04.pdf>.

Dirksen, S., Spaans, A. L., & van der Winden, J. (2000a). Studies on nocturnal flight paths and altitudes of waterbirds in relation to wind turbines: a review of current research in the Netherlands. Proceedings of the National Avian-Wind Power Planning Meeting III, San Diego, CA, May 1998, pp. 97-109. Washington, D.C.: NWCC c/o RESOLVE Inc., and LGL Ltd., King City, Ontatio.

Dirksen, S., Tulp, I., Schekkerman, H., Larsen, J. K., van der Winden, J., van de Haterd, R. J. W., van Horssen, P., & Spaans, A. L. (2000b). Nocturnal flight activity of sea ducks near the windfarm Tunø Knob in the Kattegat. Abstracts of presentations to the Wetlands International Seaduck Specialist Group Meeting Workshop on scoters, 29 Nov. – 3 Dec., 2000. <http://www.dmu.dk/ 1_Om_DMU/2_afdelinger/3_kyst/4_international/5_seaduck/ AbstractScoter.htm>.

Dooling, R. (2002). Avian hearing and avoidance of wind turbines. NREL/TP-500-30844. Golden, CO: National Renewable Energy Laboratory.

Durand, B. (2002). *Certificate of the Secretary of Environmental Affairs on the Environmental Notification Form, EOEA#12643.* Boston, MA: Executive Office of Environmental Affairs. <http://www.capewind.org/reporting/ MEPA12643cert.pdf>.

Delft University Wind Energy Research Institute (Duwind) (2001) *Final Report: Concerted Action on Offshore Energy in Europe*. <http://owe.starforze.net/ca-owee/indexpages/downloads/ CAOWEE_Complete.pdf>.

Drury, W. H., & Keith, J. A. (1962). Radar studies of songbird migration in coastal New England. *Ibis, 104,* 449-489.

Drury, W. H., & Nisbet, I. C. T. (1964). Radar studies of orientation of songbird migrants in southeastern New England. *Bird-Banding, 35,* 69-119.

Environmental Futures, Inc. (2001). *A developers guide to regulations, policies and programs that affect renewable energy and distributed generation facilities in Massachusetts.* Massachusetts Division of Energy Resources, Boston, MA. <http://www.state.ma.us/doer/pub_info/guidebook.pdf>.

Erikson, W. P., Johnson, G. D., Strickland, M. D., Young, D. P., Sernka, K. J., & Good, R. E. (2001). Avian collisions with wind turbines: a summary of existing studies and comparisons to other sources of avian collision mortality in the United States. National Wind Coordinating Committee Resource Document. Washington, D.C.: NWCC c/o RESOLVE Inc., and Western Ecosystems Technology, Inc., Chayenne, WY.

Evans, W. R. (2000). Avian mortality at communication towers: background and overview. In *Avian mortality at communication towers* (ed. Evans, W. R., and Manville, A. M.). Transcripts of Proceedings of the Workshop on Avian Mortality at Communication Towers, August 11, 1999, Cornell University, Ithaca, NY. <http://migratorybirds.fws.gov/issues/towers/ agenda.html>.

Exo, K. Hüppop, O., & Garthe, S. (2002). Offshore-windenergieanlagen und vogelschutz. *Seevögel, 23*, 83-95.

Forman, R. T. T., Reinekine, B., & Hersperger, A. M. (2002). Road traffic and nearby grassland bird patterns in a suburbanizing landscape. *Environmental Management, 29,* 782-800.

Forster, R. A. (1994). Introduction. In Bird Observer (Ed.), *A Birder's Guide to Eastern Massachusetts* (pp. 1-13). Colorado Springs, CO: American Birding Association.

Fox, T. & Pihl, S. (2000). Seaduck specialist group scoter workshop 2000. Abstracts of presentations to the Wetlands International Seaduck Specialist Group Meeting Workshop on scoters, 29 Nov. – 3 Dec., 2000. <http://www.dmu.dk/ 1_Om_DMU/2_afdelinger/3_kyst/4_international/5_seaduck/ AbstractScoter.htm>.

Gauthraux, S. (2000). The behavioral responses of migrating birds to different lighting systems on tall towers. In Avian mortality at communication towers (ed. Evans, W. R., and Manville, A. M.). Transcripts of Proceedings of the Workshop on Avian Mortality at Communication Towers, August 11, 1999, Cornell University, Ithaca, NY. <http://migratorybirds.fws.gov/issues/towers/ agenda.html>.

GE Wind Energy (2003). Multi-megawatt 3.2s and 3.6 offshore turbine technical specifications. <http://www.gepower.com/dhtml/wind/en_us/products/ mmw/mmwspecs.jsp> (cited February 7, 2003).

Goudie, R. I., Robertson, G. J., & Reed, A. (2000). Common Eider (*Somateria molissima*). In *The Birds of North America, No. 546* (ed. Poole, A., and Gill, F.). Philadelphia: The Birds of North America, Inc.

Griscom, A. (2002 December 19). Tilting at windmills: activists are split on proposed wind project off Cape Cod. Grist Magazine. <http://www.gristmagazine.com/ powers/powers121902.asp>.

Guillemette, M., Larsen, J. K., & Clausager, I. (1998). Impact assessment of an off-shore wind park on sea ducks. NERI Technical Report No. 227. Denmark: Ministry of Environment and Energy and NERI.

Guillemette, M., Larsen, J. K., & Clausager, I. (1999). Assessing the impact of the Tunø Knob wind park on sea ducks: the influence of food resources. NERI

Technical Report No. 263. Denmark: Ministry of Environment and Energy and NERI.

Haig, S. M. (1992). Piping Plover. In A. Poole, P. Stettenheim, and F. Gill (Eds.), *The Birds of North America, No. 2*. Philadelphia: The Academy of Natural Sciences; Washington, D.C.: The American Ornithologists' Union.

Heil, R. (2001). Seabirds of Andrew's Point, Rockport, Massachusetts. *Bird Observer, 29.5,* 359-380.

Henderson, A. R., Morgan, C., & Smith, B. (2001). Offshore wind energy in Europe – from the Concerted Action Project. Paper presented at British Wind Energy Association Conference 2001, Brighton, 16-18 October. <http://www.geocities.com/biblioteca_eolica/offshore.pdf>.

Honkavaara, J., Koivula, M., Korpimäki, E., Siitari, H., & Viitala, J. (2002). Ultraviolet vision and foraging in terrestrial vertebrates. *Oikos, 98*, 505-511.

Hunt, W. G., Jackman, R. E., Hunt, T. L., Driscoll, D. E., & Culp, L. (1998). A population study of golden eagles in the Altamont Pass Wind Resource Area: population trend analysis 1997. Report to National Renewable Energy Laboratory, Subcontract XAT-6-16459-01. Santa Cruz: Predatory Bird Research Group, University of California, Santa Cruz.

Kahlert, J., & Desholm, M. (2000). Methods for assessing the effects on birds of wind turbines built in the seas. Abstracts of presentations to the Wetlands International Seaduck Specialist Group Meeting Workshop on scoters, 29 Nov. – 3 Dec., 2000. <http://www.dmu.dk/1_Om_DMU/2_afdelinger/3_kyst/4_international/5_seaduck/AbstractScoter.htm>.

Kahlert, J., Desholm, Petersen, I. K., & Clausager, I. (2002). Base-line investigations of birds in relation to an offshore wind farm at Rødsand: results and conclusions, 2001. NERI report. Denmark: Ministry of Environment and Energy and NERI.

Kemper, C. A. (1964). A tower for Tv: 30,000 dead birds. *Audubon Magazine, 66.1*, 86-90.

Kerlinger, P. (2000). Avian mortality at communication towers: a review of recent literature, research and methodology. Cape May, NJ: Curry & Kerlinger, L.L.C.

Kerlinger, P. (2001). Avian issues and potential impacts associated with wind power development in the nearshore waters of Long Island, New York Cape May, NJ: Curry & Kerlinger, L.L.C.

Krüger, T., & Garthe, S. (2001). Flight altitudes of coastal birds in relation to wind direction and speed. *Atlantic Seabirds, 3*, 203-216.

Kingsley, A. & Whittam, B. (2001). Potential impacts of wind turbines on birds at North Cape, Prince Edward Island. A report for the Prince Edward Island Energy Corporation. Sackville, NB: Bird Studies Canada, Atlantic Region.

Langston, R. H. W., & Pullan, J. D. (2002). Windfarms and birds: An analysis of the effects of windfarms on birds, and guidance on environmental assessment criteria and site selection issues. Presented at Convention on the Conservation of European Wildlife and Natural Habitats, December 2002, Strasbourg. T-PVS/Inf (2002) 30 revised. Council of Europe.

Larsen, J. K., & Guillemette, M. (2000). Influence of annual variation in food supply on abundance of wintering common eiders *Somateria mollissima*. *Marine Ecology-Progress Series, 201*, 301-309.

Larsen, J. K., & Madsen, J. (2000). Effects of wind turbines and other physical elements on field utilization by pink-footed geese (*Anser brachyrhynchus*): A landscape perspective. *Landscape Ecology, 15*, 755-764.

Leaning, J. (2003a January 26). Where else can the wind farm go? Army Corps takes up an assessment of 14 alternative sites. *Cape Cod Times*. <http://www.capecodonline.com/special/windfarm/whereelse26.htm>.

Leaning, J. (2003b March 5). Winergy files for wind farms in state waters. *Cape Cod Times*. <http://www.capecodonline.com/special/windfarm/winergyfiles5.htm>.

Lowther, S. (2000). The European perspective: some lessons from case studies. Proceedings of the National Avian-Wind Power Planning Meeting III, San Diego, CA, May 1998, pp. 115-124. Washington, D.C.: NWCC c/o RESOLVE Inc., and LGL Ltd., King City, Ontatio.

Madsen, P. S. (1997). Tunø Knob off-shore wind park. Proceedings of the European Union Wind Energy Conference, Gøteborg, 20-24 May, 1996, pp. 4-7.

Massachusetts Division of Energy Resources. (MA DOER) (2003). Renewable Energy Programs. <http://www.state.ma.us/doer/programs/renew/renew.htm> (cited 26 Feb. 2003).

Meek, E. R., Ribbands, J. B., Christer, W. G., Davy, P. R., & Higginson, I. (1993). The effects of aero-generators on moorland bird populations in the Orkney Islands, Scotland. *Bird Study, 40*, 140-143.

Morrison, M. (2002). Searcher bias and scavenging rates in bird/wind energy studies. NREL/SR-500-30876. Golden, CO: National Renewable Energy Laboratory.

Morrison, M.. L., Pollack, K. H., Oberg, A. L., & Sinclair, K. C. (1998). Predicting the response of bird populations to wind energy-related deaths. Presented at 1998 ASME/AIAA Wind Energy Sumposium, Reno, NV. NREL/CP-500-25009. Golden, CO: National Renewable Energy Laboratory..

Musters, C. J. M., Noordervliet, M. A. W., & Ter Keurs, W. J. (1996). Bird casualties caused by a wind energy project in an estuary. *Bird Study, 43*, 124-146.

Myers, J. P., Morrison, R. I. G., Antas, P. Z., Harrington, B. A., Lovejoy, T. E., Sallaberry, M., Senner, S.E., & Tarak, A. (1987). Conservation strategy for migratory species. *American Scientist, 75*, 19-26.

Nelson, B. (1978). *The Sulidae: Gannets and Boobies*. Oxford: Oxford University Press.

Nelson, B. (1980). *Seabirds: their biology and ecology*. London: Hamlyn Publishing Group Limited.

Nisbet, I. C. T. (1963). Measurements with radar of the height of nocturnal migration over Cape Cod, Massachusetts. *Bird-Banding, 2*, 57-67.

Nisbet, I. C. T. (2002). "Ian C. T. Nisbet to Karen Adams, Re: File No. 200102913," 26 March 2002. I. C. T. Nisbet & Company Scientific Consulting. <http://www.saveoursound.org/pdfs/nisbet.pdf>.

Nisbet, I. C. T. & Drury, W. H. (1967). Scanning the sky – birds on radar. *Massachusetts Audubon, 51,* 166-174.

Nisbet, I. C. T., & Spendelow, J. A. (1999). Contribution of research to management and recovery of the roseate tern: Review of a twelve-year project. *Waterbirds, 22,* 239-252.

Nyden, P. J. (2002 November 3). Wind farm should have few wildlife risks, studies show. *Sunday Gazette-Mail*. <http://sundaygazettemail.com/news/Other+News/ 2002110212/>.

Offshore Wind Energy Europe (OWEE) (2003). Map of existing and planned windfarms in North-West Europe. <http://owe.starforze.net/windfarms/North-West_Europe. php> (cited 10 March 2003).

Orloff, S., & Flannery, A. (1992). Wind turbine effects on avian activity, habitat use, and mortality in Altamont Pass and Solano County Wind Resource Areas. P700-92-001. Report from BioSystems Analysis Inc., Tiburon, CA, for Planning Department, Alameda, Contra Costa and Solano Counties, CA, and California Energy Commission, Sacramento, CA.

Parkinson, K. (1999). *Environmental consequences of offshore wind power generation*. Unpublished M.Sc. dissertation, Institute of Estuarine and Coastal Studies, University of Hull.

Pepper, L. (2001). *Monitoring and Evaluation of Blyth Offshore Wind Farm: Navaid requirements for UK offshore wind farms*. ETSU W/35/00563/REP/2 and DTI/Pub URN 01/787. <http://www.dti.gov.uk/renewable/pdf/W3500563R2.pdf>.

Percival, S. M. (2001). Assessment of the effects of offshore wind farms on birds. DTI/Pub URN 01/1434. London: Crown Estate.

Perkins, S., Jones, A., & Allison, T. (2003). Survey of tern activity within Nantucket Sound, Massachusetts, during pre-migratory fall staging. Final Report for Massachusetts Technology Collaborative. Lincoln: Massachusetts Audubon Society. < http://wind.raabassociates.org/events.asp?type=eid&event=35>.

Richardson, W. J. (1979). Southeastward shorebird migration over Nova-Scotia and New-Brunswick in Autumn – Radar Study. *Canadian Journal of Zoology, 57,* 107-124.

Richardson, W. J. (2000). Bird migration and wind turbines: migration timing, flight behavior, and collision risk. Proceedings of the National Avian-Wind Power Planning Meeting III, San Diego, CA, May 1998, pp. 132-140. Washington, D.C.: NWCC c/o RESOLVE Inc., and LGL Ltd., King City, Ontatio.

Rogers, A. L., Manwell, J. F., & McGowan, J. G. (2003). A year 2000 summary of offshore wind development in the United States. *Energy Conservation and Management, 44*, 215-229.

Seets, J. W., & Bohlen, H. D. (1977). Comparative mortality of birds at television towers in Central Illinois. *The Wilson Bulletin*, 89*,* 422-433.

Sinclair, K. (2001). Status of avian research at the National Renewable Energy Laboratory. Presented at AWEA's WINDPOWER 2001 Conference, Washington D.C. NREL/CP-500-30546. Golden, CO: National Renewable Energy Laboratory.

Thelander, C. G., & Rugge, L. (2000). Avian risk behavior and fatalities at the Altamont Wind Resource Area. Golden, CO: National Renewable Energy Laboratory.

Therkelsen, B. Grant, B., Bain, D., Davis, A., Gray, T., MacIntyre, D., & Ugoretz, S. (1998). *Permitting of wind energy facilities: a handbook*. Washington, D.C: National Wind Coordinating Committee, c/o Resolve.

TranStats (2003). Motor Vehicle Registration, 2000, Bureau of Transportation Statistics. < http://www.transtats.bts.gov>.

Treweek, J. (1996). Ecology and environmental impact assessment. *Journal of Applied Ecology, 33*, 191-199.

Trull, P., Hecker, S., Watson, M. J., & Nisbet, I. C. T. (1999). Staging of roseate terns *Sterna Dougallii* in the post-breeding period around Cape Cod, Massachusetts, USA. *Atlantic Seabirds, 1*: 145-158.

U.S. Army Corp of Engineers (USACE). (2002). Environmental Impact Statement, Scope of Work, Wind Power Facility Proposed by Cape Wind Associates, LLC. <http:// www.nae.usace.army.mil/projects/ma/ccwf/windscope.pdf> (cited 23 February, 2003).

U.S. Fish and Wildlife Service (USFWS). (1996). *Piping Plover (*Charadrius melodus*), Atlantic Coast Population, Revised Recovery Plan.* Hadley, MA.

United States Fish and Wildlife Service (USFWS) (2000). Service interim guidelines for recommendations on communications tower siting, construction, operation, and decommissioning. Unpublished memo to Regional Directors. <http:// migratorybirds.fws.gov/issues/towers/comtow.html>.

Van der Winden, J., Schekkerman, H., Tulp, I., & Dirsken, S. (2000). The effects of offshore windfarms on birds. In *Technische eingriffe in marine lebensrume* (ed. Merck, T. and von Nordheim, H.), pp. 126-135. Workshop des Bundesamtes für Naturschutz Internationale Naturschutzakademie Insel Vilm 27.-29. Oktober 1999 . Bundesamt fr Naturschutz . - BfN-Skripten.

Westerberg, H. (2000). Impact studies of sea-based windpower in Sweden. In *Technische eingriffe in marine lebensrume* (ed. Merck, T. and von Nordheim, H.), pp. 163-168. Workshop des Bundesamtes für Naturschutz Internationale Naturschutzakademie Insel Vilm 27.-29. Oktober 1999 . Bundesamt fr Naturschutz . - BfN-Skripten.

Winergy, LLC. (2003). Wind farm status. <http://www.winergyllc.com/sites.shtml> (cited 26 Feb. 2003).

Wind Service Holland. (2003, February 14). Offshore wind energy. <http:// home.planet.nl/~windsh/offshore.html> (cited 11 March 2003).

Winkelman, J. E. (1989). Birds at a windpark near Urk: bird victims and disturbance of wintering and roosting ducks, geese, and swans. RIN-Rapport 89/15. Arnhem: Rijksinstituut voor Natuurbeheer.

Winkelman, J. E. (1990). Impact of the wind park near Urk, Netherlands, on birds: bird collision victims and disturbance of wintering waterfowl. Supplement to ACTA XX Congressus Internationalis Ornithologici, Christchurch, New Zealand, December 1990, pp. 402-403.

Winkelman, J. E. (1992a). The impact of the Sep wind park near Oosterbierum (Fr.), The Netherlands, on birds, 1: collision victims. RIN-rapport 92/2. Arnhem: DLO-Instituut voor Bos-en Natuuronderzoek.

Winkelman, J. E. (1992b). The impact of the Sep wind park near Oosterbierum (Fr.), The Netherlands, on birds, 2: nocturnal collision risks. RIN-rapport 92/3. Arnhem: DLO-Instituut voor Bos-en Natuuronderzoek.

Winkelman, J. E. (1992c). The impact of the Sep wind park near Oosterbierum (Fr.), The Netherlands, on birds, 3: flight behaviour during daylight. RIN-rapport 92/4. Arnhem: DLO-Instituut voor Bos-en Natuuronderzoek.

Winkelman, J. E. (1992d). The impact of the Sep wind park near Oosterbierum (Fr.), The Netherlands, on birds, 4: disturbance. RIN-rapport 92/5. Arnhem: DLO-Instituut voor Bos-en Natuuronderzoek.

Young, D. P., Erickson, W. P., Strickland, M. D., Good, R. E., & Sernka, K. J. (2003). Comparison of avian responses to UV-light-reflective paint on wind turbines. Subcontract report NREL/SR-500-32840. Golden, CO: National Renewable Energy Laboratory.

APPENDIX A. ACRONYMS

BACI: Before-After/Control-Impact

CCC: Cape Cod Commission

DEP: Department of Environmental Protection (MA state)

DRI: Development of Regional Impact

EA: Environmental Assessment (US federal)

EIA: Environmental Impact Assessment (European nations)

EIR: Environmental Impact Review (MA state)

EIS: Environmental Impact Statement (US federal)

ENF: Environmental Notification Form (MA state)

EOEA: Executive Office of Environmental Affairs

ESA: Endangered Species Act

FAA: Federal Aviation Authority

IBA: Important Bird Area

MBTA: Migratory Bird Treaty Act

MEPA: Massachusetts Environmental Policy Act

NEPA: National Environmental Policy Act

NRDC: Natural Resources Defense Council

OCS: Outer Continental Shelf

USACE: United States Army Corps of Engineers

USFWS: United States Fish & Wildlife Service

Appendix B. Research methods

My academic entry into the world of offshore wind farms began relatively late for most thesis writers. Having started researching for several months on road disturbance and fragmentation effects on wildlife, it was not until mid-November that I first heard about offshore wind farms and birds. It was then that the topic was broached on MASSBIRD, an online forum for birders in Massachusetts. An initial posting expressed concern over the Cape Wind project and cited rumors of wind farms off of Plum Island (the Winergy "Essex Bay" site). In the ensuing electronic melee, few people provided any real evidence to support the copious amounts of purely imaginary conjectures. It was only after spending an entire weekend researching the subject on the Internet to satisfy my own curiosity, that I realized I should make the topic my thesis. What follows is a general account of the methods by which I researched this topic, so that the reader will have a better sense of the tools I used to inform my writing.

Despite the wonders of Harvard's library system, more than half of my research was conducted on the World Wide Web. Most of this online research consisted of materials that had not been published in peer-reviewed journals. A general web search for "offshore wind and birds" was an easy start. My strategy was to find sources on the topic, see what studies they referenced, and then try to track down as many of these studies as possible. Not surprisingly, many of my most important resources were studies conducted by governmental or national agencies in different countries. Many of these documents are freely downloadable in .pdf format from national databases. Two of the most useful publication resources for this study were:

The Danish National Environmental Research Institute (NERI)
http://www.dmu.dk/1_viden/2_Publikationer/default_en.asp
U.S. National Renewable Energy Laboratory
http://www.nrel.gov/publications/

Clearly not all the information necessary could be found on the Internet. For certain Danish publications I contacted NERI, which put me in touch with Ib Clausager. Mr. Clausager kindly sent me a package with many of the sources I needed. I had a similar experience attaining the studies of Jan Winkelman. Her studies from the 1990s were not available online, so I inquired after her to Alterra in the Netherlands. Alterra kindly forwarded my request onto Ms. Winkelman who promptly sent me English versions of the most pertinent Dutch studies.

In order for me to better understand the Cape Wind position and developmental framework, I attended an evening seminar at Harvard co-sponsored by the Center for the Environment and the Graduate School of Design. The event was on December 5th, 2002, and was titled "Public and Private Power, Issues, Challenges, and Future Applications." The evening featured a talk by Jim Gordon and Chris Sherman, President and Manager of Project Development, respectively, of Cape Wind Associates. I asked Jim Gordon during the presentation about birds and permitting, and was able to talk extensively to Chris Sherman afterward about Cape Wind's role in and plans for environmental studies.

To learn about the subject from another perspective, I consulted with Andrea Jones, Bird Conservation Biologist for Mass Audubon, who is overseeing the avian surveys in Nantucket Sound. She told me about bird distribution in Nantucket Sound, the role that Mass Audubon is playing in studies of the Sound, and possible impacts of Cape Wind's project. I was able to discuss these topics with her extensively at an informal gathering of the Nuttall Ornithological Society in early March.

To supplement the studies of bird migrations through Cape Cod done by Ian Nisbet and others in the 1960s, I contacted two longtime local seabird watchers, Rick Heil and Blair Nikula. Rick has been observing seabird migrations from Andrews Point on Cape Ann for over 25 years. Similarly, Blair has been recording data from seabird watches by him and others at various points along Cape Cod for 15 years and has amassed a database with over 1200 species entries. Both Rick and Blair were generous enough to allow me full access to their extensive records on seabird occurrences along the Massachusetts coast. While little of this went directly into my final work, being able to look at the data and discuss it with both Rick and Blair was a great help.

Finally, throughout the many months I worked on this project, I regularly met and conferred with my advisor, Professor Richard Forman. While not intimately familiar with my topic, Richard brought to meetings years of experience with human-nature interactions, as well as all the wisdom of a scientist and professor. Above all else, these meetings let us examine and solve problems I had reached, and generate strategies for the next steps in my work.