REPORT NO. 5.3.2-1

Collision Mortalities at Horseshoe Shoal of Bird Species of Special Concern

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Prepared for Cape Wind Associates

by

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January 2007

FINAL DRAFT – 23 Jan 07

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Executive Summary

1. This report focuses on the Federally-Threatened Roseate Tern, with subsequent comments on the Federally-Threatened Piping Plover, as well as two species of breeding terns that are of State-concern (Common and Least), and the abundant seaducks (of five principal species) which are present in winter. Other reports provide Population Viability Analyses for the two Federally-listed species that address possible significance of the mortalities estimated here.

2. To estimate the numbers of Roseate Terns killed requires information on the numbers expected to be flying past the turbines at rotor height; the number of turbine-rotors encountered and the probability of collision. Input data included field measurements (from aerial surveys reported in the first DEIS and data subsequently obtained) of the numbers and altitudes of terns at the project site through the season (May – mid-September) and their behavior (traveling/fishing). Flight speeds were obtained from the literature. Geometrical modeling was used to estimate encounter rates with rotors in the course of crossings of the project area. Collision-probabilities were also estimated geometrically using, in part, the reported collisions at a windfarm in Zeebrugge, Belgium, where terns nest immediately beside turbines and the numbers killed have been noteworthy.

3. Two sets of mortality estimates have been prepared (see 8 & 9, below): expected values calculated from “simple averages” of the pertinent variables, and uncertainty estimates based on Monte Carlo and bootstrap methods.

4. The project area on Horseshoe Shoal (HSS) was less-used by terns for foraging than other parts of Nantucket Sound, or areas closer to the breeding colonies, and is not crossed by major travel routes. The numbers of terns present on HSS were very low during the nesting season, with larger numbers present in May (before) and in August-September (after).

5. The great majority of the terns using the area (95%) flew below rotor-height, although the numbers at risk have not been precisely established because of the constraints on observing set by weather conditions.

6. For terns traveling at rotor height, no preferred directions have been established: number of crossings was modeled geometrically (Bolker model). This model showed that, while crossing the proposed windfarm circle (the smallest circle that circumscribes the windfarm) at rotor-height, a tern would be expected to encounter, on average, one turbine in 2.3 crossings: this low number principally results from the turbines being widely-spaced. For terns that do encounter a turbine, there is only a small chance of collision; this is for two principal reasons the turbines have only three blades and the rotors have relatively long rotation-periods, and because birds generally avoid these moving objects as well as the stationary turbine towers. The “no avoidance” collision rate with the HSS turbines is estimated from the Band model to be 0.027.

7. From the findings reported from the Zeebrugge windfarm, an avoidance rate of 0.91 was derived for Common Terns: this value is inappropriate for application to HSS because the proximity of the nesting area affects behavior of the birds near the turbines. The avoidance rates used in estimating expected collisions at HSS were 0.953 and 0.983.

8. The **expected mortality of Roseate Terns is 0.8 individuals per year**. Four expected values estimated for collisions ranged from 0.3 to 2.3 Roseates /year, based on 2 values for the number of Roseates present and 2 values for probability of collision.

9. The uncertainty analysis incorporated the documented variability in 8 variables, using a combination of Monte Carlo and data-resampling methods. The results of 5000 simulations indicated a **median mortality of 0.83 Roseates/year with a large uncertainty (5 to 95% probabilities : 0.01 to 8.2 Roseates/year**). Sensitivity analysis compared 8 scenarios which explore the effects on the estimate of kill rate of the lack of knowledge in parameter values needed to obtain that estimate. This analysis shows that the median is robust (i.e. insensitive) to parameter variations, but that the edges of the mortality distribution are very sensitive to assumptions about bird behavior near turbines, and to field count variance.

10. Other species considered briefly include two State-listed terns. The **Common Tern** is more numerous than the Roseate Tern; it uses the project area in generally similar ways and may incur 12 collision-mortalities/year. The Least Tern was seen so rarely in the project area that risk for this species is minimal.

11. The Federally Threatened **Piping Plover** nests around Nantucket Sound and may cross the project area in the course of migratory movements or during dispersal but the numbers, height and course of such flights are unknown, so that no precise collision estimates are possible. However, the numbers of plovers nesting from New England to Atlantic Canada are known. Using estimates from MassWildlife for numbers of annual crossings of the project area and available information on collision probability, plover collisions are estimated at far fewer than one per year.

12. The winter **seaducks** are important components of the avifauna. Local movements in Nantucket Sound generally occur below rotor height. Very recent evidence from operating windfarms off the shores of Denmark and Sweden shows that these waterbirds avoid turbines very effectively in the course of migratory flights, so that the risk to these birds at HSS is expected to be very small but no estimates of mortality have been prepared.

Introduction

Predicting the numbers of Roseate Terns, or of other bird species, that will be killed by wind turbines on Horseshoe Shoal, in Nantucket Sound, is subject to great uncertainty. The magnitudes of some substantial components of any model, most especially avoidance responses, are very poorly known (Chamberlain et al. 2006) so that accurate predictions of collision rates are impossible. Empirical data of direct relevance to terns and other seabirds are limited because the applicability of findings from terrestrial sites and from other regions has yet to be adequately demonstrated. Furthermore, establishing the number of collisions from the results (by counting corpses) is especially difficult at offshore windfarms because collision victims are likely to be quickly taken by scavengers (notably fish and gulls) or will soon sink or drift away. The recent evaluations of collision-risks at offshore windfarms in Danish and Swedish waters, while being important and very informative studies, have focussed principally on seaducks and have little to say directly about terns, which are present at these installations only in small numbers (Petersen et al. 2006, Pettersson 2005).

The following account summarizes how terns use Nantucket Sound, employing information gathered for Cape Wind (CWA) and for Massachusetts Audubon Society (MAS). Much of that information was presented in the DEIS for the Cape Wind Energy Project issued by the U.S. Army Corps of Engineers (USACE) in November 2004 (the first DEIS), while some has been obtained more recently. The principal **study area** for the surveys reported here included most of Nantucket Sound, while the **project area** (see outline of footprint in Fig. 1) on Horseshoe Shoal (HSS) occupied about 8 percent of the study area. (In the remainder of the document, the four terms and acronyms “Horseshoe Shoal”, “HSS”, “project area”, and “project footprint” are used interchangeably.) The account also examines data from the one windfarm, in Zeebrugge, Belgium, where relatively large numbers of collision fatalities of terns have been reported (Everaert & Stienen 2006). These sources are used to develop estimates of the numbers of Roseate Terns that may collide with turbines; in several instances it has been necessary to generalize from other tern species where the particular characteristics of Roseate Terns are unknown. In particular, Common and Arctic Terns are similar to Roseates in size, morphology and flight performance. The principal account is focused on Roseate Terns and is followed by comments on Common Terns, Least Terns, Piping Plovers and seaducks.

Redundancy in the following report is intended to facilitate understanding, especially for readers entering the text at different points. Throughout the report many of the calculations yield results with levels of precision that would be meaningless and impede rapid comprehension: to address this difficulty, the precise numbers have been used in calculations while being rounded for use in the text.

To estimate the numbers of terns that may be killed per year by the Cape Wind turbines at HSS requires information on the numbers flying in the windfarm at rotor height, the number of turbines encountered, and the probability of collision. (All collisions are treated as fatalities). Extensive analyses, summarized in the paragraphs that follow, indicate that these several factors each contribute to the outcome and that overall risk is likely to be very small. However, the robustness of the estimated mortality rate is limited by the available data. In the following account, Section **1** describes the presence and behavior of terns in

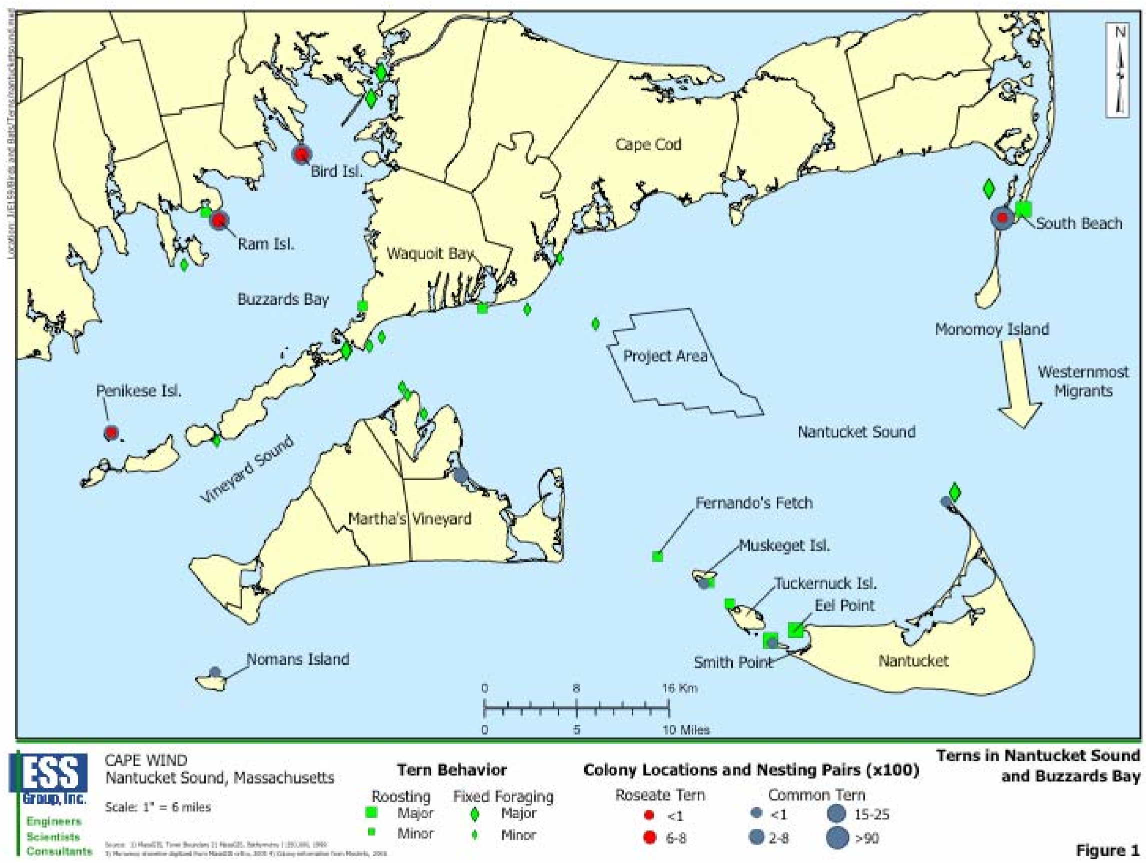
Nantucket Sound and shows from summaries of the fieldwork that the project area on Horseshoe Shoal (HSS) is less-used by terns for foraging than other parts of the Sound, or than areas closer to the breeding colonies, and is not crossed by major travel routes. Estimates of numbers of terns using the whole of the project area (HSS) throughout the season were obtained from these surveys. Section **2** addresses information available on the flight behavior of terns. Information from the first two sections is used in Sections **3** and **4** to estimate the numbers of crossings of the project area at turbine height. Section **5** then examines the grounds for concluding that use of the project area by terns will not be much affected by the windfarm, which is a basis for computing, in Section **6**, using a geometrical model, the probability of encountering a turbine during straight-line crossings of the windfarm. Sections **7** and **8** address the theoretical collision risk, based on further geometrical models. In Section **9**, the empirical evidence from the windfarm in Zeebrugge is used to examine the difficult topic of avoidance rates, which are recognized to be location- and species-specific. Section **10** examines the application of these results (from turbines located beside a tern colony) to the offshore conditions at HSS. In Section **11** several expected values for annual collisions are calculated from simple averages of the variables. Section **12** provides an uncertainty analysis for these kill estimates, employing a mixture of Monte Carlo and data resampling methods and sensitivity analyses. Section **13** and **14** compare these estimates to other estimates and address possible impacts of mortality and relate to Population Viability Analyses for the two Federally listed species. Section **15** considers potential collision risks for other species of special concern.

1. How terns use Horseshoe Shoal

Roseate Terns are summer visitors to Massachusetts waters, with first arrivals about 1st May and only a few stragglers departing after about 20th September (a residency of about 130 days). These dates reflect later arrival and earlier departure than Common Terns. About 98 percent of the 1500 pairs of Massachusetts Roseate Terns nest on Bird, Ram and Penikese Islands in Buzzards Bay, about 38 km northwest of the project area (see Fig.1). These comprise more than half of the population in the northwest Atlantic Ocean. Roseates from these colonies are known to travel by day as far as the western parts of Nantucket Sound to forage (Heinemann 1992). Roseates occur with Common Terns, a more numerous and more widely distributed species, and the two are difficult or impossible to distinguish in the field. The very large tern colony on Monomoy (almost 10 000 pairs, 25 km northeast of the project area), comprised almost entirely of Common Terns with only a handful of Roseates, is the closest large colony to HSS. In 2005, Roseates comprised 22 percent of the terns nesting in Buzzards Bay, 9 percent of those in the Cape Cod region, and 0.25 percent of those nesting around the shores of Nantucket Sound (Mostello 2006).

Both species rest on the beaches of the Sound and the islands and forage by day in nearby waters, including over HSS in small numbers. The latter area is beyond the foraging range used by most terns traveling from the principal colonies. Travel time for a Roseate Tern from the colonies on Bird Island or Ram Island, in Buzzards Bay, would be about one hour, depending on the route taken (as well as wind and weather). The larger numbers of terns seen over HSS in May are likely to include many that are in the early stages of the breeding cycle (before incubation). This pattern might change in future if Muskeget Island

20 km south of the center of HSS) once more became the site of a major tern colony. Daytime aggregations on islands and beaches, especially before and after the breeding season, have been noted on the south shore of Cape Cod as well as from South Beach, Chatham, to Muskeget (to the east and south of the project area) but rarely on the eastern



shores of Martha's Vineyard (the western edge of the Sound). During the summer of 2002 the terns in this western area were examined during two flights and seven boat trips. No concentrations of terns were found and few terns were seen, indicating that very few commuters from this area cross HSS (first DEIS, Appendix 5.7-F).

Terns are opportunistic foragers: they respond very rapidly to the changing availability of prey and to the movements of other terns. The numbers of terns in an area can vary substantially from minute to minute and from hour to hour, as well as by the seasons. Some locations are favored because the bottom-topography makes prey available, but much foraging is not so obviously explicable. Roseates have a less-diverse diet than Commons: this difference results, in part, from restricting their foraging to a lower diversity of habitats and a smaller range of sites.

The principal staging area for terns from Cape Cod and wider areas before migration in fall is in the NE corner of the Sound, at South Beach, Chatham, near to the colony-site on South Monomoy; large numbers of post-breeding terns also gather at the western end of

Nantucket and the nearby islands. It is likely that the post-breeding movements are complex, with possible back-and forth travels and annual variation reflecting prey availability. It has been suggested that most of the Roseate Terns in the Northwest Atlantic may join these aggregations (Trull et al.1999) and depart during a short period in mid-September. If terns did travel on direct routes between the principal colonies and staging areas in Massachusetts, or thence over the ocean to wintering areas in the Caribbean or South America (as they are thought to do), **they would not pass over HSS**. Wintering areas (in South America) lie to the east of Cape Cod: the arrow on the map (Fig. 1) points toward the locations of the westernmost recoveries of Roseate Terns banded in New England (I. Nisbet, pers. comm.).

Also shown on the map are major and minor sites for nesting, and for resting or staging, as well as some localized areas where foraging Roseates may concentrate in Massachusetts (Heinemann 1992; CWA fieldwork). The terns at these (“fixed”) feeding concentrations are often exploiting particular topographic features that make prey available. Terns also feed near the resting/staging sites marked: to increase clarity, overlapping symbols for feeding and resting are not both shown on the map. The smaller resting and foraging areas are not used consistently. The spatial distribution of foraging effort is not well represented by the symbols for these fixed foraging concentrations because other types of foraging are not similarly constrained; these locations should be interpreted in conjunction with the maps of tern numbers in the first DEIS and in the reports from MAS. These two datasets are combined and summarized in two seasonal maps in (ESS Group 2006a).

Terns in Massachusetts are active throughout daylight hours and apparently do not travel far at night. Observations on four days in late August 2006 of terns traveling towards and away from the major roost on South Beach, Chatham (ESS Group 2006b), illustrate a pattern that is probably general but has not been explicitly documented (no mention by Nisbet 2002). The first outward-flying terns in the morning passed the boat-based observers 4 to 10 minutes before sunrise (n = 3 days), and the last inward-flying terns passed 10 to 20 minutes after sunset (n = 3). These are outliers: most traffic occurred after sunrise and before sunset. Movements in the opposite direction were consistent with this pattern: the numbers of outward movements away from the roost in the afternoon declined strongly an hour earlier, about 50 minutes before sunset. Thus, daylength (sunrise to sunset) provides a conservative measure of the period during which terns are active, and this period, less the travel time to and from the windfarm, is the time potentially spent amongst the turbines.

At night, terns in Massachusetts roost onshore, at the colony or at other sites safe from ground-predators. This is thought to be a general pattern but the behavior has not been studied in detail. Before and after the breeding season terns are known to roost on remote headlands and islands, such as Eel Point and Smith Point on Nantucket, Muskeget Island, and Fernando’s Fetch, a transient sandbar northwest of Muskeget (used by terns from about 1998 to 2004), as well as the favored site at South Beach, near to the Monomoy colony. The shifting sands of the area provide an array of safe roosting sites that may change as years pass. Observations suggested that some of these sites were used only for daytime resting (e.g., the Waquoit jetties), while others were also used at night (e.g., Fernando’s Fetch). As the time of migration approaches the terns increasingly concentrate at night on South Beach. A few anecdotal observations in support of these conclusions follow; on 15 May 2006 all terns had left the Waquoit jetties by 20 minutes before sunset, most heading west towards Buzzards Bay (D. Oakley, pers. comm.); on 1 and 15 August 2002, hundreds of terns were observed flying towards Fernando's Fetch near nightfall (first DEIS, Appendix 5.7-F); during a visit in late August 2006 no terns were present at night in the day-time roosting area on Eel Point, Nantucket (T. White, pers. comm., fide R.Veit). When a colony is disturbed by arrival of a nocturnal avian predator, such as a Great Horned Owl, many terns leave but they appear to stay near the colony site (JJHatch, pers. Obs.) and would not be likely fly from Buzzards Bay to HSS. No reports of similar disturbances of roosting sites have been found. Unexplained early-season nocturnal departures of terns from the Monomoy colony have been reported: the movements of these birds are not known and no systematic nocturnal surveys have been conducted.

Shortly after their arrival in spring, terns are sometimes seen resting on the open water, generally in flocks. This behavior is almost unknown near colonies during the breeding season but reappears during pre-migratory staging. Terns in the project area are either foraging or traveling, most of which occurs below the height of the turbine rotors (see below).

During the (daytime) aerial surveys (2002 – 2004) by Cape Wind and by MAS, Common Terns were seen from mid April to mid November, and Roseates were recorded over HSS from early May to mid-September. Numbers of terns over HSS were greater in May, before the nesting season, then declined to near zero during incubation and chick-rearing, then were sometimes higher again in August after the chicks fledged. Annual variations in the numbers of terns using Nantucket Sound were large, but the great majority of terns were reported near the shores of the Sound, especially to the west of Monomoy, and relatively few were seen in the project area in any year. For more detail, see the first DEIS and several reports on the Mass Audubon website (http://www.massaudubon.org/news/). These findings have been combined in (ESS Group 2006a).

1.1 Numbers of terns Substantial numbers of the terns observed were not identified to species (about 57 percent, see first DEIS). For those that were so identified, the range of estimates for the fraction that were Roseates is large and there is substantial opportunity for error; two median values have been used for compiling the totals below. This species-ratio was assumed to be the same for all the observations during those periods when Roseates were present (May through mid-September). From the Cape Wind aerial surveys in 2002 and 2003 Roseates comprised 10 and 20 percent, respectively, of the sightings identified to species; for the combined boat surveys and ground-truthing for Cape Wind in 2002 the percentage of Roseates was 14.5. For the MAS boat surveys the percentage of Roseates in the identified sightings was 3.9 in 2003 and 2.4 in 2004. The median of these five datasets is 10.0 percent. To address the wide and unexplained variation of estimates a second value of 3.2 percent, the mean of the two MAS estimates, will also be used and the topic is examined in the Uncertainty assessment (Section 12).

To estimate use of the project area (on HSS) by terns, the numbers recorded on narrow transects during aerial surveys were converted to the numbers estimated for the entire project area. (Calculated as: area of HSS x number seen within transects of HSS/ area of those transects). These numbers were then averaged for three periods during which use was similar: May (as early May to early June) for pre- and early breeding, June & July for feeding young at the nest, August & first half September for post-fledging. Table 1 summarizes data from CWA and MAS: the conversions for calculating the totals present on HSS differ because of the different protocols used, especially transect widths and spacing. The numbers reflect the revised footprint for the project and therefore differ slightly from the numbers presented in the first DEIS. The CWA surveys were conducted in 2002 and 2003, and the MAS surveys were conducted in 2002, 2003 and 2004.

In May, two aerial surveys for CWA reported an estimated average of 392 terns on HSS (within the project footprint). There were no completed flights for MAS in May (because of weather), but the number of terns reported from 25 systematic boat surveys of HSS were higher in May (mean 68.3 per survey) than later in the breeding season (4.5 per survey) and indicated a peak mid-month. Conversion of these boat-based observations in

Table 1. Numbers of terns observed within Wind Park footprint (HSS) during aerial surveys, May to mid-September, and estimated totals present. (Cape Wind surveys in 2002, 2003; MAS surveys in 2002, 2003, 2004).

Month	Year	Source	N surveys	Terns observed	HSS Av. totals	Mean	Comb.
MAY	2002	CWA	1	21	104	392	392
	2003		1	137	680		
	2003	MAS	0	-	-		
	2004		0	-	-		
JUNE & JULY	2002	CWA	2	0,0	0	5.5	21
	2003		5	0,1,8,1,1	10.9		
	2003	MAS	3	4,4,1	37	37	
	2004		0	-	-		
AUGUST & SEPTEMBER	2002	CWA	3	7,30,8	74.3	39	86
	2003		3	0,1,1	3.3		
	2002	MAS	3	2,11,18	128	133	
	2003		5	1,52,10,10,6	196		
	2004		3	13,2,3	74		

- Individual surveys separated by ",". MAS data include 2 surveys after mid-September.
- **Totals**, estimated for HSS: obtained by extrapolating survey results to entire windfarm area
- **Mean**, calculated from annual mean totals in preceding column. See Section 13 for uncertainty analysis.
- **Comb.**: combined means of CWA and MAS observations.

May to numbers for the whole of HSS yields a total of 116 terns. The disparity between the aerial and boat datasets cannot be completely resolved but one simple explanation would be that the boat-transects were effectively narrower than the one-mile (1.6 km) suggested to be the range. Therefore, the (higher) aerial estimates will be used as the principal basis for subsequent (conservative) projections. These are equal to 392 terns/day x 31 days = about 12 000 tern-equivalents at risk during the month of May. (A **tern-equivalent**, a measure of use of the area by terns, represents one tern in the area continuously for one day).

In June – July, when many terns are feeding young at the colonies, the numbers at HSS were low: the mean totals estimated present on HSS from CWA and MAS aerial surveys were 5.5 and 37, respectively. Together, these are equal to 21.2 x 61 = about 1300 tern-equivalents.

Similarly, after the breeding season, in August – September, when numbers build at South Beach, HSS was used by variable numbers of terns. This use is equal to 86 x 46 = about 4000 tern-equivalents, and the annual total was nearly 18 000 tern-equivalents.

The estimated proportions of Roseates among these terns was 0.032 or 0.10 (see above, at beginning of 1.1). Thus, the total Roseate-equivalents were 17 728 x 0.032 = nearly 600, or, 17,728 x 0.1 = about 1800 Roseate-equivalents per year.

2. Altitudes and speeds of tern flight

Foraging terns, generally recognizable by flight pattern and head position, fly close to the water surface and below the height of the proposed rotors (23 - 134 m, or 75 – 440 ft, above sealevel (asl)). Roseates often dive from greater heights than Commons (Gochfeld et al. 1998) but this foraging behavior does not extend to the height of the rotors. On the other hand, **traveling** terns are seen at a wider range of altitudes, sometimes as high as the rotor-swept zone when flying downwind (see below, Section 4). When traveling into headwinds, terns generally fly closer to the water surface to avoid stronger adverse winds.

The **fraction of travelers** recorded during the boat-based surveys for MAS ranged from 0.33 to 0.81 (median 0.53 for 5 season/year sets of observations) and similar results were found during the CWA fieldwork. Findings of the aerial surveys were systematically lower by a small amount (median fraction travelling 0.39, for both CWA and MAS datasets); these data have been disregarded as potentially less reliable, because of the uncertainty of characterizing the behavior from the airplane.

The flight speed of traveling Roseate Terns has received little study; they clearly often fly faster than Common Terns (JJHatch, personal observations) which have been measured at 8.4 m/sec (airspeed) down- or cross-wind and 12.2 m/sec upwind (Nisbet 2002). Roseates, flying at 11 m/sec, or 40 km/hr in still air, would cross the proposed turbine field in 13 - 22 minutes (minimum and maximum straight-line distances), but no preferred route is reported. However, as described in Section 4, terns at rotor height are flying downwind so that crossing times are shorter. For subsequent estimates we use 8.6 minutes crossing time

(Bolker et al. 2007) using a groundspeed of 42 km/hr, based on mean wind speed of about 22 km/hr(see Table 2).   Such travelers are at risk of collision when at rotor height.

Terns are exceptionally agile flyers: they hover and rapidly change course repeatedly while foraging. This means that they are most unlikely to collide with the monopole towers that support the turbine rotors, or with other stationary structures in the windfarm, as discussed in Appendix 5.7-H of the first DEIS. Very severe storms may be an exception to this generalization but these are very rare and no relevant data exist for bird behavior in such storms. However, it seems possible that terns flying near turbines in high winds might be driven through the rotors and thus experience higher risk than during milder conditions. During storms, most coastal birds rest on beaches but they may be displaced from these by storm tides. In such storms, the turbine rotors would be stationary (they are designed to shut down in winds above about 89 km/hr, the cut-out wind speed) and thus would presumably present a lower risk to traveling birds than would moving rotors. To describe the occurrence of severe weather during the terns' presence, here defined as wind speeds well above the flight speed of terns (which is about 40 km/hr), we examined the 16-17 year record (8/1985-12/2001) for the months May-September from the Buzzards Bay Tower, about 60 km west of Horseshoe Shoal (http://www.ndbc.noaa.gov/data/climatic/BUZM3.pdf). At this site the wind speeds are recorded at 24.8 m above mean sealevel (msl). Data from this source are summarized in Table 2, which indicates the frequency of observations of hourly-average winds >50 km/hr and >100 km/hr, by month.

Table 2. Hourly average windspeed by month, Buzzards Bay Tower (1985–2001). Cumulative percent frequency of high winds; mean wind speed.

Wind speed (km/hr)	May	June	July	August	September
Freq. > 50	2.4	0.8	0.8	0.9	2.6
Freq. > 100	0	0	0	0.2	0.2
Mean	25.7	24.4	22.3	22.2	24.4

These years included Hurricane Bob, which passed over Nantucket Sound on 19 August 1991, and Hurricane Gloria which crossed the coast of Connecticut on 27 September 1985 (after the Roseates had left Nantucket Sound). This information suggests that only rarely are winds likely to be of sufficient strength to drive terns uncontrollably through the rotors or past the monopoles; we have no estimate of the chance that terns would be flying at the times and places that would put them at this potentially higher risk.

Migrating terns fly at a wider range of heights than residents: some are known to fly overland at night at heights of several thousand meters (Alerstam 1985), and along coastlines by day below 25 m asl, in both headwinds and tailwinds (Kruger & Garthe 2001). They may also forage en route (JJHatch, personal observations). At the operating windfarm at Horns Rev, off the Danish coast, nine percent of the Common/Arctic Terns (which are present there only during the migration season) were recorded at turbine height (30 – 110 m). Terns departing from South Beach in fall, probably both Roseate and Common Terns apparently starting on their southward migration, have been observed climbing rapidly to hundreds of meters (Veit & Petersen 1993, S. Perkins pers. comm. 2002). Some departures of terns from a colony/staging area on migration begin as conspicuous flights in late afternoon until sunset; loose flocks climb until almost lost to sight (Cullen 1956). The circling, climbing (or "kettling") flocks reported by MAS in August 2002 and September 2003 are likely to have been of this type. Also, near sunset on 29 August 2006, shipboard observers (for CWA) located 1.6 km (1 mile) NW of the old lighthouse on South Monomoy watched three groups of terns that appeared to have come from the principal staging area of South Beach drifting downwind (200 deg), about SSW, while circling and climbing to altitudes of at least 129 m, or 400ft, where the highest visible birds disappeared into low clouds. These flocks are likely to have been migrating or preparing to do so. Such flights would not cross the project area, which lies approximately WSW from South Beach. No such flocks were seen the following evening (ESS Group 2006b). It is most likely that all Roseate Terns on Cape Cod depart from South Beach on fall migration in the manner described. For spring arrivals, the height and hour at which they cross Nantucket Sound are unknown. Relevant observations during CWA's fieldwork are limited to six Common Terns observed flying singly northward near the water surface during an aerial survey south of Martha's Vineyard on 14 April 2003 (first DEIS, Appendix 5.7-K, Table 6; not included in (ESS Group 2006a)).

3. Crossings of the project area

Although the principal goals of the aerial surveys were to characterize patterns of seabird distribution and abundance, they also contribute to predictions of collision risk. The survey numbers represent "snapshots" of tern activity as opposed to counts of transits across HSS. If we assume that travelers continue across the windfarm and are replaced by others we can estimate the number of crossings and potential encounters with turbines. In practice, travelers may have local destinations, so this approach is likely to overestimate risk substantially. Classifying individuals as traveler or forager is sometimes difficult; however, this difficulty applies most often to low-flying birds because high-flying birds are traveling.

Traveling terns may cross a windfarm and thereby risk encountering turbines. The numbers of such crossings can be estimated from the numbers of terns present and the fraction of terns traveling. This fraction was variously estimated as 0.53 (Section 2). We suppose that Roseate travelers at rotor height cross the windfarm, on average, in 8.6 minutes, flying downwind (in any direction) at 42 km/hr. These birds are replaced by other travelers for the duration of the day, less the travel time to and from colony or overnight roost because most travelers leave after sunrise and return before sunset. To simplify calculations we use a single mean daylength of 14.5 h and round-trip travel-time of 2 h. Total Roseate crossings per year is estimated as the number of Roseate tern-equivalents x number of crossings per day. That is: 567 (or 1773) tern-equivalents x 12.5 hours x 6.97 crossings per hour (i.e. 87 per day); that is about 50 000 (or 150 000) crossings per year.

The following section addresses the (small) fraction of travelers that fly at the height of the rotors where they are at some risk of collision.

4. Numbers at rotor height

The CWA and MAS data include eight samples of flight altitudes that are described below and summarized in Table 3: the median of these 8 values for the fraction at rotor height was 0.044 (mean for all values 0.062). During boat surveys reported in the first DEIS (Appendices 5.7-D, -F, -L, -M, -N), terns were identified as foraging or traveling and it was frequently impossible to identify species so observations of all terns are combined. The flying heights of traveling terns in or near HSS were estimated visually: of these, 30/1717, or 0.017, were at rotor-height. These data include boat-based observations for radar ground-truthing in 2002 that may have incorporated disproportionate numbers of low-flying terns. Similar data from HSS were reported by MAS; from 25 boat surveys during the breeding season in 2003 and 2004, 17/293 traveling terns (= 0.06) were at rotor height (Sadoti et al. 2005a, Fig. 4, and Table 3)). For 14 boat surveys during the pre-migratory staging period in 2002-2004, 1/60 (= 0.017) traveling terns were at rotor height (Sadoti et al. 2005b, Table 7). These data are separated by year in Table 3.

Additional boat-based data on heights of flying terns were gathered for CWA in 2006: during 7 days in May (5 – 31) on HSS for radar ground-truthing (in conjunction with GMI), and during 4 days in late August to document flight behavior of terns traveling to/from the staging area at South Beach. These observations were designed to include early and late hours that were not adequately examined during the fieldwork reported in the first DEIS. (A minority of these heights were measured with instruments rather than estimated visually). In May 2006, 39/126 traveling terns (0.31) observed from the boat were at rotor height, the highest at 200 ft (60 m) (ESS Group, unpublished observations). Some of these terns were also detected by GMI's vertical radar: these included heights of nine Common Tern targets, totaling 33 individual terns counted by boat-based observers. At rotor height were 5/33 terns (0.15), max. height 35 m (120 ft).

In August 2006, the heights of terns flying between the large roost at South Beach and foraging areas west of the southern tip of Monomoy were visually estimated and some were measured with a laser rangefinder and clinometer. These data from a different part of Nantucket Sound are included here because the behavior at HSS is expected to be similar under comparable conditions. During these observations, on all four days, the wind direction was consistently between N and E (thus, blowing away from the staging area) and windspeeds varied from 1 to 5 m/sec (2 - 10 knots). This provided an opportunity to examine flight-height in relation to wind speed and direction. All but one of the upwind fliers were below rotor height (n = 357), while 70/177 (0.40) of downwind fliers were at the height of the rotors. There was a tendency for more terns flying downwind to be at rotor height at higher windspeeds. Over all, 110/958 (0.11) of non-foraging terns, including those flying cross-wind as well as up- and down-wind, were at rotor height, only 29 of these were above 80 m (250 ft), with the highest measured at 106 m (350 ft). Presumed benefits of flying high downwind include better chances of locating flocks of feeding terns to join; this would not apply to terns flying toward the roost and away from the feeding areas. It would be interesting to know if downwind over-water flights towards the staging area have a similar height-distribution to those described here.

Table 3. Estimated fractions of traveling terns at rotor height (23-134 m asl) from boat-based observations.

Location	Year	Season	N terns	n at rotor ht	n/N	Source
HSS + surrounds	2002	Both	1717	30	0.017	First DEIS Appendix 5.7-F
HSS	2003	Breeding	130	8	0.062	Sadoti et al 2005a
HSS	2004	Breeding	163	9	0.054	Sadoti et al 2005a
HSS	2002	Post-br.	23	0	0	Sadoti et al 2005b
HSS	2003	Post-br	8	0	0	Sadoti et al 2005b
HSS	2004	Post-br	29	1	0.034	Sadoti et al 2005b
HSS	2006	Breeding	126	39	0.31	ESS Group, 2006 unpubl.
Monomoy	2006	Post-br.	958	110	0.11	ESS Group, 2006b
TOTAL			3154	197	0.062	

Median for 8 values for n/N is 0.044

Of the 110 terns at rotor height, most (73%) were in the lower half of the rotor-swept zone. Additional observations of terns apparently departing from the staging area on migration are mentioned in an earlier paragraph: these included birds in the rotor-swept zone but they are excluded from the present summaries because, as noted above (at end of section 2), it is unlikely that terns in the project area behave in this way

Observations of the height at which terns were flying were recorded during aerial surveys and these can be used to support the boat-based conclusions. For assessing tern performance we use the boat-based data; results from the aerial surveys are included for completeness while recognizing that relevant height estimates are likely to be subject to greater errors. Results of Cape Wind's aerial surveys suggested that few terns were flying at rotor-height: this conclusion was criticized in comments on the first DEIS because the observers were alleged to be observing only within a cone below the aircraft and thus not sampling all heights adequately. This is a valid concern for quantitative conclusions when many birds are present at or near the water surface, however this was not the case for most occasions when terns were present in Nantucket Sound: during these surveys the transects included all birds for the complete width to the height of the plane. Terns are relatively conspicuous and were detected over a wide area: the presence of substantial numbers of high-flyers would have been evident. The sightings of terns estimated to be at rotor height totaled 53 during 3974 km of aerial transect in the study area during the breeding season and 0 during 3938 km of transect during the post-breeding/staging period (CWA aerial survey data).

Similarly, during survey flights for MassAudubon during the breeding season a single tern at 400 ft was noted by Sadoti et al 2005. The flights for Cape Wind during the same time of year encountered three terns above 90 ft asl. During the staging period there were more observations of terns near rotor height, 25 records (of 93 terns) in all; most of these were in the north-eastern quadrant of the study area where MAS transects were close to South Beach because of the layout of their study area; there were four recorded over HSS (MAS unpublished data). Limitations of all these height data are that observations did not cover all hours of the day equally and were confined to relatively good weather, without storms or fog.

The general conclusions from the boat-based observations are that most traveling terns, as well as all foragers, were observed below the height of the proposed rotors. About five percent (4 to 6) of travelers were reported at rotor height. This number combines the median of 8 diverse samples and the mean of the numbers observed. Most of these were within the lower half of the rotor-swept zone (23- 90 m or 75-295 ft) and flying downwind. The observations during the aerial surveys were consistent with these conclusions.

5. Expected effects of the windfarm on use of the area by terns

Terns forage readily close to bridges, ships, oil-rigs and other large offshore structures so that it is unlikely that they would avoid, or be displaced from, Horseshoe Shoal after installation of wind turbines (as was shown for migrating eiders, for example, in Danish waters (Desholm & Kahlert 2005)). The underwater bases of monopoles and service platform would add very small areas of new habitat that may provide food for small numbers of low-flying foraging terns, principally Common Terns. Preliminary empirical evidence about the slight responses of terns to turbines is available from surveys at the operating Horns Rev offshore windfarm (Denmark), where Common/Arctic Terns during the migration season were observed entering the windfarm, generally below rotor height, and were not seen to react to turbines; however, some of these terns later flew out of the windfarm (Christensen et al. 2004) and were interpreted as possibly avoiding the turbines. Additionally, 3 species of terns nest within 30 to 250 m of coastal turbines in Zeebrugge, Belgium, with no evidence of a barrier effect or displacement (Everaert & Stienen 2006, see below). Thus, it is reasonable to suppose that terns will continue to use HSS in similar ways to those summarized in the previous paragraphs (and in more detail in the first DEIS); barrier effects, displacement, and disturbance for these species are expected to be slight or non-existent, although this conclusion requires verification. (In this context it is appropriate to repeat the earlier conclusion that HSS is not a major or critical foraging area for terns.)

At present there are no resting places for terns on Horseshoe Shoal; construction of turbines and a service platform could change this, if terns are permitted to rest on them. From such places close to the turbines terns would be expected to engage in risky behavior in the form of high courtship flights and other social behavior during which they could drift downwind at turbine height. However, these structures will incorporate bird-proofing features (see first DEIS, section 5.7.4) and Cape Wind will be committing to a monitoring and mitigation plan based on adaptive management to ensure that this bird-proofing meets the needs.

6. Probability of encountering rotor(s)

Terns cross HSS in many directions and no dominant movement patterns were recognized for travelers at rotor height. (Thus the modeling of crossings differs from studies of migrating birds, such as the seaducks passing Danish offshore windfarms (Desholm and

Kahlert 2006)). The 130 turbines of the proposed windfarm (with rotors at 23 – 134 m asl) will be installed on a grid of approximately 630 x 1000 m, so that they will be separated by about five to nine rotor-diameters. For estimating the numbers of rotors encountered while crossing the windfarm, we initially considered a geometrical model (the Bolker model; Bolker et al. 2007) without including important biological parameters. This model treats the rotors as vertically-mounted discs, without thickness, that may be oriented in any direction (in response to wind). Details of the model can be down-loaded from (http://www.cs.umb.edu/~eb/windfarm/). There is also, on the same site, an "open source" spreadsheet that includes details of the proposed windfarm on HSS and visitors are encouraged to enter their own values for key variables (including locations and size of turbines (for other windfarms), flight and wind directions, height of flight; also probability of not colliding, used for estimating mortality). The model assumes that travelers fly in horizontal straight lines and cross the windfarm at all angles, initially with all turbines at right-angles to the bird's track(s). This "worst-case" analysis shows that the expected number of turbines encountered during such a crossing of the smallest circle containing the windfarm over the full range of rotor height is about 0.67. More realistically, for turbines oriented in a single direction (as they would be during a single crossing) and with terns distributed evenly in the rotor-swept zone and flying in every direction, the expected number of turbines encountered during a crossing at rotor height (over all angles) is 0.43. This is for crossings of the circular region containing the windfarm with wind direction SW; for the actual region of the windfarm the expected number is 0.61, or 0.71 for wind direction SE. This number is probably an overestimate of actual encounters because the suggested distribution at turbine height is likely to be conservative, as is the assumption of flying in straight lines. The probability of a bird surviving an encounter with a turbine rotor is very high (see next Section) so that, in calculating encounters for those crossings with >1 encounters, the probability of mortality in prior collisions is assumed to be zero.

Birds flying below the height of the rotors may encounter the turbine towers (monopoles) and the probability of doing so can be modeled in the same way as encountering rotors, substituting in the spreadsheet the radius of the monopole for the length of the blade. (Such an encounter is not expected to lead to collision, see below.) For crossings of the HSS windfarm circle below rotor height, the expected number of monopoles encountered is 0.04 (or one in 25 crossings).

7. Theoretical collision risk

Calculating a collision risk entails estimating the number of birds expected to encounter the rotors (part 1), and the probability of a bird that passes through a rotor being hit (part 2). The preceding section addresses the theoretical probability of a bird encountering turbine rotor(s) while crossing HSS at rotor height.

Birds that fail to survive an encounter with a turbine may be hit by a blade or damaged by turbulence downwind, after passing the rotor (Winkelman 1992); these are not distinguished in subsequent usage. For estimating the probability of being hit, one model (Tucker 1996) is useful for understanding the underlying principles. Tucker's model incorporates complete avoidance of all parts of the blades moving at speeds below a threshold (25 m/sec in the examples developed in that paper: this speed was selected after watching birds avoid cars moving at various speeds (V. Tucker, personal comm.)). By modeling geometrically the probability that a bird and a blade coincide, the model shows the relative importance, for risk to birds, of various parameters including bird size and aspect ratio, size and shape of rotor blade, velocity of wind and bird. Such modeling makes it clear that flying downwind through a rotor is relatively safe because of the bird's high groundspeed. Flying upwind, however, is riskier. As speed of headwind increases, collision (in the absence of avoidance behavior) becomes more certain as groundspeed of the bird declines to nearly zero. The characteristics of avoidance behavior have not been adequately established and some empirical estimates have been based on birds flying both up- and down-wind. There may be a trade-off, for collisions, between "no avoidance" collision risk and potential for avoidance behavior. However, for obvious energetic reasons, birds (and especially terns) usually do not fly upwind at rotor height (and probably never at groundspeeds <5 m/sec, where theoretical collision probability starts to increase steeply); instead, in such conditions most fly close to the water surface where the contrary wind-velocity is reduced. The data summarized in Section 4 indicate that terns at rotor height in Nantucket Sound are flying downwind. (This does not apply to all birds in all places: some storm-driven migrants may even be blown backwards.)

At very high wind speeds (above 25 m/sec (55 mph or 89 km/hr) for 600 sec, the cut-out wind speed) the turbines shut down and the blades become stationary (information from GE for 3.6 MW turbine); this is expected to reduce but not eliminate risk of collision in severe storms.

A second model, of collision risk, was developed by Band et al. (in press) for Scottish Natural Heritage and is named the SNHWB model by Chamberlain et al. (2005) who evaluated it for English Nature and concluded that, although it is mathematically sound, it is particularly sensitive to aspects of bird behavior that are largely unknown. One part of this model considers the probability of collision, from geometric considerations, without initially including any avoidance responses on the part of the bird. For HSS, this model can be used to estimate collisions with the turbines encountered. For the proposed turbines, the no-avoidance collision probability for Roseate Terns passing through a rotor, estimated from the Band/SNHWB model, is 0.027.

This is the downwind estimate only, using the tern speed in still air of 11 m/sec. Based on observations summarized in Section 4, it is assumed that Roseate Terns fly below rotor height when flying into headwinds exceeding 3.5 m/sec, the wind speed at which the rotors will be permitted to start rotation to generate electricity. Input bird speed in the model was determined by combining the wind speed with the tern speed in still air. Since this was a downwind calculation, the speeds were added. Turbine rotation period was specific to the wind speed modeled, with a maximum period of 7.06 seconds from the cut-in wind speed of 3.5 m/sec to a wind speed of 5.8 m/sec, and a minimum period of 3.92 seconds from a wind speed of 9.6 m/sec to the cut-out wind speed of 25 m/sec, with a linear interpolation for the remaining intermediate wind speeds. Above wind speeds of 25 m/sec, the blades are feathered in order to halt their rotation. Modeling was conducted at a series of ten wind speed ranges between 3.5 and 25 m/sec for which there were known frequency-of-occurrence data over a continuous period of over 16 years (7/1985 - 12/2001) at the nearby Buzzards

Bay Tower (see Section 2, above), using data from the months of May through September. The wind speed frequencies were multiplied by the collision risk probabilities and the results summed across all wind speeds to determine the overall risk for birds flying downwind. To estimate actual collisions, the no-avoidance collision probability must be multiplied by a non-avoidance rate (that is, 1 minus the avoidance rate) to incorporate the behavior of the birds. Recent assessment has shown that the output of this model is particularly sensitive to small variations in avoidance rates, a topic that needs urgent attention (Chamberlain et al. 2005, 2006).

For encounters with monopoles, the no-avoidance collision probability is expected to be offset by complete avoidance by almost all birds under all but the most extreme conditions.

8. Avoidance

Although many birds pass through the rotor area unscathed, mortality can occur from collision with the blades or from the downwind turbulence. Many birds take effective avoiding action, some when they detect an array of turbines, others when they approach an individual turbine, or an oncoming blade: avoidance may occur at any point in this range (Winkelman 1992). For estimating actual collisions, an avoidance factor is required: it represents the proportion of the birds that could be hit but take effective avoiding action. For most studies, the value used has been >0.95, indicating almost all individuals, but the topic is poorly understood. For terns, the first level of avoidance (of an entire windfarm, termed “deflection” by Band) probably does not apply (see above, Section 5). The data available for establishing an appropriate “avoidance factor” for closer approaches are limited and likely to be strongly species- and location-specific. As noted earlier, terns generally avoid collision with stationary structures but the ranges of extreme conditions that might place them at risk of colliding with the monopoles are not known, but see Section 2 above. Direct observations with thermal-imaging devices etc. show promise for exploring this issue (Desholm et al. 2006). An alternative approach is to use data for known passage rates and kills for comparison to predicted collision rates and thereby derive estimates of avoidance rates:

= 1- (observed deaths/ predicted deaths assuming no avoidance).

One such example is available for terns, from a windfarm in Belgium.

9. Empirical evidence from Zeebrugge

To understand and estimate collision mortality of terns in Nantucket Sound it is necessary to examine the available empirical information about collisions of terns at other windfarms. These data may shed light on possible mortality rates and rates of avoidance of terns at the Cape Wind project. Terns are rarely reported as colliding with lighthouses or other coastal structures (see Jones and Francis 2003 and other evidence reported in Appendix 5.7 H of the first DEIS, section 4.2.4). They have only rarely collided with guy-wires, electrical lines, or other types of structure (Shire et al. 2000). Chamberlain et al. (2005, 2006) emphasize that rates of collision or avoidance should only be applied to other sites (or different species) with caution. A single case study of mortality has been described for terns. Collision mortalities of 3 species have been reported from a coastal windfarm adjacent to a tern colony in Zeebrugge, Belgium (Everaert 2004, Everaert & Stienen 2006). The terns nest on an artificial peninsula (area to 6.5 hectares) constructed, as a nesting site, adjacent to a row of 25 medium-sized wind-turbines installed on a harbor breakwater. Varying numbers of terns have nested at this site since 2001. The close proximity of the nesting colony means that the findings at this windfarm site are much more adverse than those expected in the middle of Nantucket Sound, and therefore may not be directly applicable to the Cape Wind project.

At this windfarm, as many as 18 killed terns/year were found below a turbine very near the colony and the highest estimated annual mortality at a turbine was 56 terns/year. However, a much more useful variable to establish for possibly relating to the Cape Wind project is the collision-probability for birds passing the turbines. In 2004, the nesting terns comprised 1832 pairs of Common Terns *Sterna hirundo*, 4067 pairs of Sandwich Terns *S. sandvicensis*, and 138 pairs of Little Terns *Sterna albifrons*. Somewhat lower numbers were present in 2005 (and one turbine distant from the tern colony was not operating that year). Some Common Terns nested as close as **30 m** from the turbines but most of the terns nested at distances of 100 – 250 m and additional terns nested elsewhere in the harbor. No evidence was found that the presence of the turbines adversely affected use of the area by terns. Of these three species, the Common Tern is slightly larger than the Roseate Tern; the Little and Sandwich Terns are, respectively smaller and larger. The following summary and analyses focus principally on 2004, to convey the important points: the additional corroborative information on 2005 can be found in the cited references.

In 2004 and 2005, dead terns were collected systematically from the vicinity of the turbines throughout the year. The numbers of terns found apparently killed by the turbines (all of them adults) were 50 and 52, respectively. These numbers were corrected, for each turbine, for accessible search area (to account for corpses lost in adjacent water etc.), searcher efficiency, and scavenging to yield **estimated collision mortalities** of 168 and 161 terns for the entire windfarm. To better understand collisions, attention was paid to the six turbines immediately adjacent to the colony, where most of the tern-deaths were concentrated. Additional turbines (19) of various sizes are located up to about 1 km from the colony. In the entire 2004 breeding season, 47 dead terns were found at these six turbines, and the estimated collision mortality in June 2004 was 23 Common Terns (also 25 Sandwich Terns).

The turbines in question are 400kW units with the hub at 33 m, blades 17 m in length, and a rotor-swept zone of 16 – 50 m (52 – 164 ft), placed at intervals of about 120 m along the breakwater. (These turbines are substantially smaller, lower, and closer together than those proposed for Nantucket Sound, see below). The terns principally cross this line of turbines, approximately at right-angles, in the course of daily foraging flights. Crossings, and heights, were counted for two complete days in June 2004 (also in 2005) at the six turbines closest to the nesting colony. Two collisions of Common Terns were witnessed during these four days. No crossings were observed during two nocturnal observation periods with “generation 3” night-vision equipment, and no dead birds have been found beneath the disabled turbine, which had no blades (Everaert pers. comm.).

The turbines present the maximum area to the flying terns when oriented across the line of flight (and parallel to the breakwater): in this orientation the area swept by the blades occupies about 22 percent of the rectangle crossed by terns flying at turbine-height. At other orientations of the turbines a lower percentage of the area is occupied, but the terns that traverse the rotors are at greater risk of collision because they take longer to pass through the area swept by the blades. Terns were more likely to be killed when winds oriented the turbines across their flight path than at other directions. Most of the crossings by Common Terns recorded at Zeebrugge in 2004 were below turbine-height (92 percent <16 m), 1 percent were above the rotors (>50 m), while 7 percent flew at rotor height. The collision chance for Common Terns in June 2004, calculated from these data for diurnal flights across the line of turbines at rotor height was 1/848 crossings (or 0.00118); and for flights at all heights 1/13387 (or 0.00007) (Everaert & Stienen 2006). For Sandwich Terns the equivalent values were 1/1130 and 1/18283. Based on size alone, Sandwich Terns would be expected to have higher risk of collision than Commons; suggested explanations for this not being so are that the Sandwich Terns more often flew in straight lines while the Common Terns had more irregular flight paths (also, the Commons nested closer to the turbines and were more often seen circling near them). For 2005, equivalent data for Common Terns crossing at rotor height yielded a collision chance of 1/911 and for Sandwich Terns 1/2176. The 2-year average collision probability was 1/879.5 or 0.00114 for Common Terns and 1/1653 or 0.00060 for Sandwich Terns.

For investigating avoidance, we compare the observed deaths at Zeebrugge (reported by Everaert and Stienen 2006) and the probability of encountering rotors there (estimated from the Bolker model) to the collisions predicted from crossing rotors assuming no avoidance (from the SNHWB model). The expected probability of encountering a turbine rotor, for a single flight direction of 10 degrees and all wind directions, averaged for the actual region of turbines 7 to 12 is 0.16. The estimated collision probability per encounter for the Common Terns crossing the rotors is given by 1/(879.5 x 0.16) = 0.0071. For comparison, the predicted no-avoidance collision risk, obtained from the SNHWB model with Zeebrugge data from J. Everaert is 0.080. The avoidance rate (= 1- (observed deaths/ predicted deaths assuming no avoidance)) derived from these values is 1 – 0.007/0.080 = 0.911. This avoidance rate is low relative to other empirical data, perhaps because of the colony-related behavior of the terns (see below): most studies give values >0.95 (Chamberlain et al. 2006). For Sandwich Terns at Zeebrugge the calculated avoidance rate is 0.953. (Derived as follows: 1 – (1/(1653 x 0.16))/ 0.08) = 0.953).

10. Relevance to Horseshoe Shoal

Any avoidance factor is expected to be strongly location- and species-specific (Chamberlain et al. 2005), so we consider the relevance of these data for Common Terns and Sandwich Terns from Zeebrugge (Z) to the different conditions for Roseate Terns at Horseshoe Shoal (HSS):

-- the species. Roseate Terns are slightly smaller and faster-flying than Common Terns, both of these factors together are expected to reduce collision risk for Roseates at HSS by about one percent, (this is the no-avoidance prediction from the SNHWB model (Band in press), changing only the bird-related data from the values given).

-- the size of the turbines. The turbines at HSS will be higher (rotors at 23 – 134 m) and larger than those at Z and also will have longer rotation period: these factors lead to lower risk of collision for a bird passing through a rotor. The greater height of the turbines means that a smaller fraction of the terns will be flying at rotor-height, because most will be below. These factors are included in the calculations of the no-avoidance collision-rate.

-- visibility. Collision risk per bird is expected to be higher at night, and in rain or fog. The incidences of these weather conditions at Z and HSS have not been comprehensively compared. However, the occurrence of night-flying and of risky activity during adverse weather conditions is substantially less likely at HSS than at Z, near the colony, although no crossings were observed during two nights (as noted above). Fog is more frequent in Nantucket Sound than near Zeebrugge, but directly comparable statistics are not available.

-- behavior of the birds. The close proximity of the turbines to the colony at Zeebrugge is likely to mean that the terns there (especially the Common Terns) behave differently near rotors than expected for terns over HSS. For example, many more are likely to be distracted by social interactions (notably the high courtship flights) as they approach the turbines, which would substantially lower avoidance, especially when combined with habituation to the turbines' presence. Birds such as hunting raptors, with their attention on other things, may be particularly likely to collide with turbines. Conversely, individual experience with the turbines could enhance avoidance. It is not yet possible to assign magnitudes to these effects, but they could readily lead to greater avoidance and thus lower risk at HSS than at Z. The behavioral differences at Z between the two species, noted above, suggest that the findings for the Sandwich Tern are more appropriate for application to HSS than those for Common Tern.

In conclusion, the probability of collision for terns approaching the rotors on HSS is expected to be substantially lower than at Z, so the value for an avoidance factor of 0.911, estimated for Common Terns at Z (see Section 9), is unrealistically low for HSS. Using this value, the upper bound for collision chance for terns encountering a rotor at HSS is estimated as: 0.027 (the estimated no-avoidance risk)
x 0.09 (or, 1 – the lowest avoidance rate of 0.911)
= 0.0024 (or one in 417).

A more likely value for the avoidance factor is that estimated for Sandwich Terns, because their flight behavior at Z is more like that expected for Roseates at HSS, but proximity to the colony and size-difference between the species both suggest that even this avoidance is too low. The value of 0.953 yields a collision chance of:
0.027 x (1 – 0.953) = 0.0013 (or 1 in 769).

It is important to emphasize, yet again, that avoidance is so poorly understood and so important that these estimates need to be validated. A small increase in the avoidance rate, from 0.953 to 0.983 lowers the chance of collision to 0.00046 (one in over two thousand encounters); and avoidance of 0.99 gives a chance of collision of 0.00027; the real avoidance could be higher still. In most other studies, avoidance rates have been estimated to be >0.95, and terns are notably agile birds so that high values are likely. However, there is unknown likelihood of terns being present during "high risk" conditions. In the following estimates "by simple averages", the two values of 0.953 and 0.983 will be used, and thus chances of collision of **0.0013** and **0.00046**. The additional values of 0.91 and 0.99 will enter into the uncertainty analysis in Section 12. (Note: small changes in avoidance rates can produce large changes in results. For example, changing avoidance from 0.95 to 0.98 (about 3%) changes the non-avoidance rate, or 1-avoidance, by 60%).

As shown in Section 6, the expected number of turbines encountered while crossing the HSS windfarm over the full range of rotor height is 0.43. Combining these values for encounters and collision-chance suggests that the expected number of crossings of the windfarm (by Roseate Terns at rotor height) per collision may be about 1000, 1800, 5000 or 9000 for the four values of collision-chance. (This way of presenting the conclusions may be confusing; see Section 15, Piping Plover, for more discussion of this approach). These examples show that precision is limited by the available knowledge about how birds behave near turbines.

11. Estimates of mortality at Horseshoe Shoal

In this section four "simple average" estimates of annual collision-mortality for Roseate Terns at HSS are obtained, **as expected values**, by multiplying the appropriate values for each component. Incorporating further uncertainties into this estimation is deferred to Section 12. The several components are as follows:

A- the numbers of terns present in the project area (HSS) summed for the season.
B- the fraction that were Roseates; 2 values derived from Section 1.
C- Roseate Tern-equivalents for the season (A x B).
D- the observed fraction traveling.
E- estimated number of crossings of the windfarm, from Section 3.
F- the fraction of travelers at rotor height and range of heights, from Section 4.
G- the number of rotors encountered, from Section 6.
H- the probability of collision; 2 values from Section 10.

The annual mortality is: C x D x E x F x G x H .

These calculations are performed with 2 values for the fraction of terns that were Roseates, and two different collision probabilities (the middle 2 of the 4 developed in Section 10) to yield **four estimates** that address some of the recognized uncertainty:

C. Roseate equivalents =	567	OR	1773
D. x 53% travelling =	301		940
E. x 87 "crossings/day"=	26187		81780
F. x 5% trav. at rotor ht=	1309		4089
G. x 0.43 rotors encountered=	563		1758
H1. x collision 0.0013 =	**0.73**		**2.29**
Or H2, x collision 0.00046 =	**0.26**		**0.81**

These results show that the expected annual mortality of Roseate Terns from collisions at HSS is strongly affected by the percentage of Roseates observed (compare the 2 columns) and by the avoidance rate (compare the last 2 lines), but none of the 4 values is high. From this analysis, the range of values is approximately 0.3 – 2.3 (median 0.77, mean 1.02) collisions per year. The lower estimates of the number of collisions are more plausible because the high values for percent Roseate seem unlikely and even the highest avoidance rate is likely to be too low. Thus, the conservative estimate, based on “simple averages”, based on the median of these four is roughly **0.8 collisions per year.** To incorporate the uncertainty more completely, and for more variables, the data are analyzed more fully in the following Section, using a combination of Monte Carlo and bootstrapping methods.

12. Uncertainty analysis of kill estimate for Roseate Terns

Each of the quantities used in the estimation of expected annual number of Roseate Terns killed by rotors at HSS contains some uncertainty. This is due to the variable nature of this natural system and to sampling variation. Overall, it is useful to know the range of this uncertainty, because it also tells us what deviations from our expectation are possible, and how likely they are. In this case we can ask, for example, what is the risk that many more, or fewer than two Roseate Terns (for example) are killed annually, given uncertainty in the data.

A number of methods are used to obtain the range of uncertainty, including Bayesian estimation (Gelman et al. 1995) and data resampling or bootstrap methods (Chernick 1999, Manly 2006). Here we use a combination of Monte Carlo and data resampling. In Monte Carlo methods (Manly 2006) a theoretical distribution is used to represent the shape of the frequency distribution of the real data. A large number of values is then sampled at random from this « synthetic » distribution as a way to quantify both the range and the shape of our uncertainty about the data. In bootstrap resampling, the values in the real dataset are treated as the « universe » to be resampled (with replacement); the range of uncertainty contained in the data is represented by a random sample of these values.

Choosing to use one technique over the other depends on the data at hand and on the purpose of the exercise. A data distribution with large gaps but which nonetheless shows the elements of a shape is a good candidate for description using a parametric distribution. These gaps are most usually due to low sample size. If such a discontinuous data distribution were real or described the real process better than a continuous theoretical distribution, then it is preferable to resample from the data distribution using bootstrap methods.

A large variety of theoretical distributions exist and can be fit to the data (Evans et al. 1987, Hogg & Craig 1978). For biological data, a subset of them has proven useful. The Gamma represents a family of distributions, depending on the values of its two parameters; the exponential distribution is a special case of a Gamma, for example, and so are the chi-square and the Poisson distributions (Evans et al. 1987). This makes it a very flexible tool that can be fitted to many data types (Devroye 1986). The Beta distribution is often used when a quantity varies between two limits, such as proportions or probabilities. When there is no information about whether some values are more likely than others within a range, a uniform or a triangular distribution is useful.

In the following text we describe our approach to evaluate the uncertainty about the kill rate of Roseate Terns at HSS. As described above (Section 11), the expected annual number of mortalities of Roseate Terns is obtained through multiplying several estimates. We will go through the same process, but this time picking a value from each of the relevant distributions obtained through resampling, then multiplying these values; this process is repeated many times (in this case 5000 times), so that we obtain a *distribution* of values for the annual number of kills.

Tern-equivalents --The data used to derive a distribution of tern-equivalents are all of the sightings within the project footprint from the aerial surveys of seabirds in Nantucket Sound by CWA in 2002 and 2003 (Table 1). A parallel set of aerial surveys were completed by MAS in 2002-2004, but using a different type of plane at different altitude, and of course different observers. However, because no variance estimates are available for either type of survey, it is unclear how different these values are. In the Sensitivity Analysis section, the MAS survey data, as well as the CWA dataset, are used to create the distributions for numbers of terns present at HSS during the periods being compared.

To create a distribution of number of birds present during an entire season at HSS, the observed numbers in each survey were first transformed from numbers on survey lines to numbers over the whole area of HSS (ESS Group 2006a). These were assumed to be a « snapshot » of the number of birds on the day of a survey (i.e. birds/day). To account for seasonal variations in activity of the birds, the time during which Roseates are present was divided into three parts and surveys occurring within a given part were then resampled with equal probability, for the number of days in that month or months. For example, there were 2 surveys representing May; the counts from these 2 surveys were re-sampled 31 times, each survey having a probability of 0.5 of being picked. These values were summed up for all three periods (May; June-July and August through mid-September) and the process repeated 5,000 times (Fig. 2 a).

Fraction of Terns that are Roseates --Two values are known for this from observations at HSS (0.033 and 0.10). Both values were deemed equally possible, and were resampled with a probability of 0.5.

Fraction traveling --The data available from boat surveys provided a range of 0.33 to 0.81 for this quantity, as well as a likely central or median value of about 0.53. A triangular distribution was fitted to these values and resampled, as shown in Fig. 2 b.

Fraction at rotor height --The distribution of the proportion of birds flying at rotor height was based on data from Table 3, and is shown in Fig. 2 c. To obtain a parametric distribution of these proportions, the observed proportions were weighted by the sample size : the larger the sample size, the more likely the value derived from it, so the more frequently it is resampled. In the Sensitivity Analysis section below, we check the effect of weighting on the estimated number of birds killed. A Beta distribution (parameters a=1.01,b=35.28) appeared to provide a realistic fit to the relatively sparse data (Fig 2.c).

Number of crossings --The distribution of daily number of crossings through the rotor field by a tern was determined from flight time through the field and the amount of flight time available in a day. The flight time is modeled using data on crossing times from the Bolker model (Fig. 2 d). The unusual distribution results from the shape of the windfarm. Time available for flying (daylength minus travel) is the mean value for the season of 12.5 hours per day.

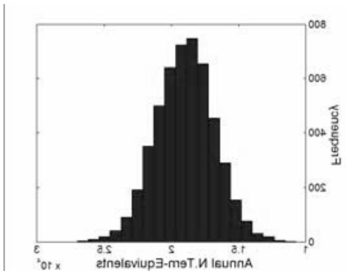
Rotors encountered --The number of encounters by terns with rotors was based on the Windfarm-v0.98.3 Excel file of Bolker et al. 2007; no field data exists on this quantity. Our distribution of encounters was resampled (bootstrapped) directly from the set of values for the average number of turbines encountered with all flight directions selected, and for wind directions from 0 to 180° calculated with the Windfarm program. This distribution is shown in Fig.2 d. We chose a bootstrap sampling procedure because the encounter distribution obtained in Windfarm was not easily fitted by simple parametric distributions.

Probability of collision --Values for the range of "no avoidance" collision probability, if a turbine is encountered, were extracted from the Band/SNHWB collision risk model for birds flying downwind; this model calculates the risk at multiple points along the radius of rotor blades (Fig. 2e). The distribution of these risks was resampled by bootstrapping.

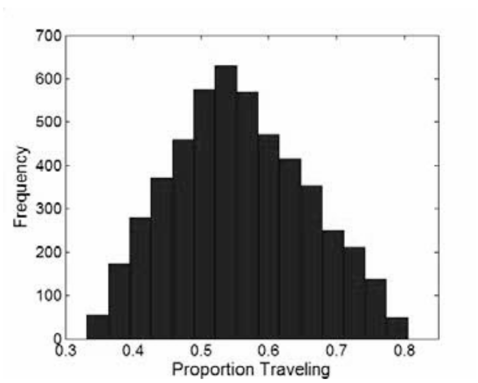
Avoidance Rate -- Roseate Terns are agile flyers but little is known on the range of their avoidance rate; based on the analysis of data from Zeebrugge (Sections 9, 10) a triangular distribution between the values of 0.91 and 0.99 (median of 0.95) was used for resampling, resulting in a sample distribution as in Fig 2 f.

Figure 2, a to f. Uncertainty distributions for the parameters used in estimating the annual number of Roseate Terns killed due to windfarm activity at HSS.

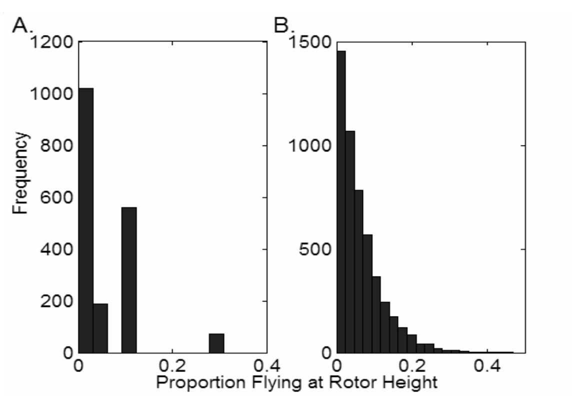
a) Distribution of number of Roseate Terns present in an entire season at HSS, based on CWA aerial survey data.



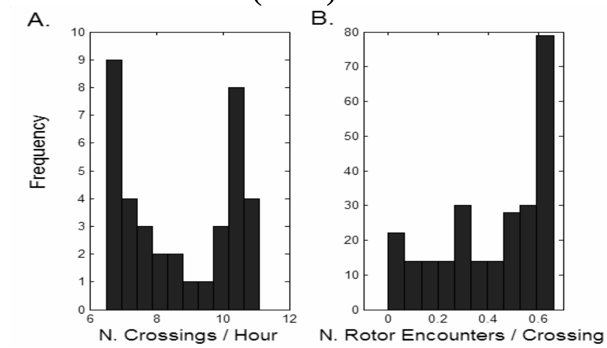
b) Bootstrap distribution of fraction of terns that were traveling.



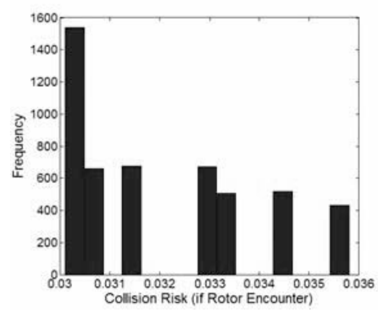
c). **A**. Distribution of observed proportion of terns flying at rotor height at HSS. **B**. Distribution used for the Monte Carlo resampling.



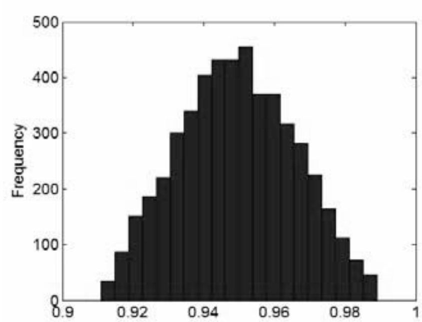
d) **A**. Distribution of number of flights by tern-equivalents per hour across the windfarm, from the Bolker et al. model (2007). **B**. Distribution of number of rotors encountered by a Roseate Tern in one crossing of the rotor field, from the Bolker et al. model (2007).



e) Distribution of “no avoidance” risk of collision with a rotor, given a Roseate Tern is within the rotor perimeter, from the Band model (in press). Median 0.03.



f) Distribution of rotor avoidance rate by model Roseate Terns.



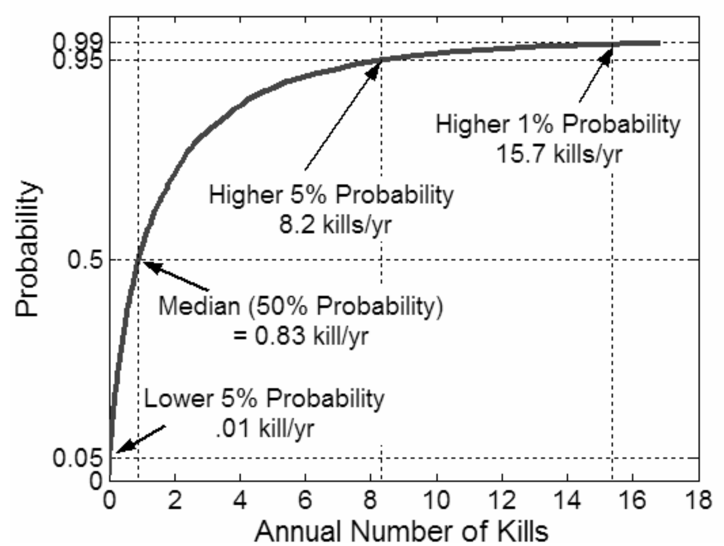
Annual Kills Estimate

The probability Pr (or uncertainty) distribution of total number of Roseate Terns killed at HSS in a year (Fig. 3, below) was calculated by picking one value at random from each of the above distributions, multiplying them together, and repeating the process 5,000 times :

Pr(N. Roseate Terns killed/year) = N.Tern-equivalents (summed over all days when Roseate terns are around HSS)
x Pr(Roseate)
x Pr(Traveling)
x Pr(at rotor height)
x N. crossings / tern, in a day
x Pr(Rotor encounter)
x Pr(Collision if rotor encountered)
x Pr(No avoidance)

The probability plot (i.e. the probability or risk of kill of a given number of Roseate Terns in a year) resulting from this model is shown below (Fig. 3). The 5%, 95% and 99% probabilities are the 250th, 1750th and 4950th values, respectively, of the 5000 resamples sorted by increasing value.

Figure 3. Probability distribution of annual number of Roseate Terns killed by rotors, given the distributions (i.e. uncertainties) of model parameters.



The probability distribution of annual kills is very asymmetrical (or statistically highly skewed) and not bell-shaped. The median, which indicates the point where 50% of the values are below, and 50% are above it, is at 0.83 birds killed/yr. Of the 5,000 resamples, 95% are below 8.2 birds per year, and 99% are below 15.7 birds per year, while 5% are less than 0.01 birds per year, or one bird in 100 years. These results show how the uncertainty around each of the parameters involved in the calculation compound to create a large range of uncertainty about the annual kill risk. The 95% or 99% values should **not** be interpreted in terms of the usual confidence intervals of hypothesis testing. Rather, they indicate how much we do not know about the system, and how this lack of knowledge affects the range around the median value.

12.1 Sensitivity Analysis

To further test the sensitivity of the annual kill estimate to parameter assumptions, we made the following changes, and compared output with the basic result (shown as "No Change"). These results are shown in Table 4.

- Using only the high value (0.1) or low value (0.033) for proportion of terns that are Roseate (#2 and #3 in Table 4).
- Using the observed proportions of terns at rotor height, without weighting by sample size (#4).
- Using a triangular distribution of rotor avoidance rate, but changing the most likely value (i.e. changing the position of the triangle peak) (#5 and #6).
- Using MAS aerial survey count data instead of CWA data; confined to June-September counts in both datasets because MAS did not complete counts in May (#7 and #8).

Table 4. Sensitivity of kill estimates to assumptions of model. Scenarios # 7 & 8 should only be compared with each other, because they are based on shorter sampling seasons.

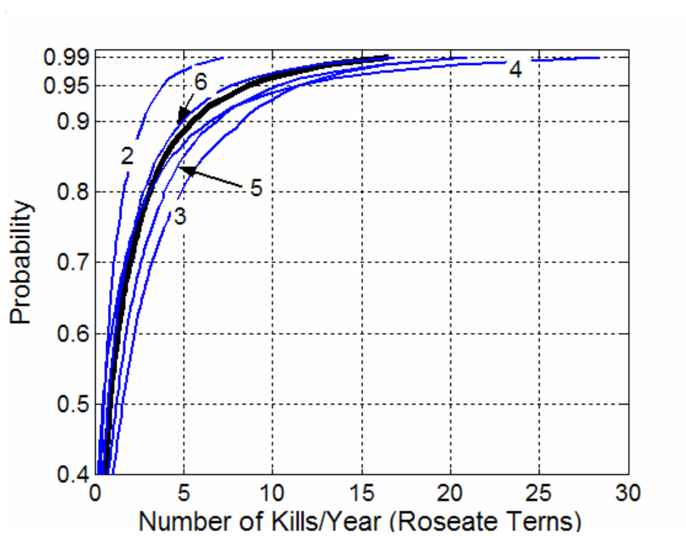
#	Change Applied	Number of Roseate Terns killed / year:			
		Median	***5% Probability***	***95% Probability***	***99% Probability***
1	No Change	0.83	0.010	8.20	15.69
2	Proportion Roseates = 0.033 only	0.55	0.013	3.85	7.20
3	Proportion Roseates = 0.1 only	1.59	0.033	11.44	20.80
4	Proportion at Rotor Height, NO weighting by sample size	0.46	$5.2x10^{-5}$	11.39	28.23
5	Avoidance Rate distribution : triangle peak at 0.95	1.23	0.031	10.28	20.88
6	Avoidance Rate distribution : triangle peak at 0.99	0.79	0.008	7.63	16.89
7	Using CWA Survey Counts, June-Sept	0.16	0.003	3.21	7.14
8	Using MAS Survey Counts, June-Sept.	0.41	0.009	4.04	8.79

Overall, the sensitivity analysis shows that the median estimate for the annual number of kills for Roseate Terns (# 1-6) varies by less than one order of magnitude; the scenarios tested result in medians from 0.46 to 1.59 kills / year. The 95% and 99% vary from one to two orders of magnitude, depending on the scenario. The wide differences in the edges of the distributions (Fig. 4) are the consequence of the uncertainty about each of the estimates used in this calculation, that is to say, of our lack of knowledge about the potential interaction between Roseate Terns and the windfarm at HSS. However, the median values appear to converge within a relatively narrow range of annual kill rates, showing that this result is particularly robust.

The annual kill estimate is especially sensitive to our assumptions about the proportion of the terns at HSS that are Roseates (scenarios & lines 2 and 3). The two values available, 0.033 and 0.1, produce a low and the highest estimates, respectively, of the whole sensitivity analysis. There is clearly a need to document this variable further with field data. Dropping the weighting by sample size of the proportion at rotor height (scenario 4) has a modest effect on the median but causes a large increase in variance, the edges of the uncertainty distribution are much more affected. Varying the shape of the avoidance rate distribution, scenarios 5 and 6, has modest effects on the kill rate estimate.

Changes # 7 & 8 should only be compared with each other, this allowed a comparison between two sets of field counts at HSS (see section xx). Some of this variation is due to natural changes in numbers of terns around HSS over the season; it is also due to the variance in each estimate caused by survey methodology. Scenario 7 differs from scenario 1 only in excluding two May surveys from the uncertainty analysis; this causes a substantial reduction in the range of possible kill rates, because the wide difference between these two survey estimates (because large numbers of terns were seen in May. The median estimate from the MAS surveys is 2-3 times that of the CWA survey, due to higher counts and different survey methods (transect width, survey platform, observers).

Figure 4. Probability distributions for numbers of Roseate Terns killed using the changed assumptions shown in Table 4. (The thick line is the "No Change" scenario and numbers identify the other scenarios listed there.)



13. Comparisons with other analyses and limits to the data

The mortality estimates for Horseshoe Shoal presented in the first DEIS used the findings at Zeebrugge and several scaling factors based on professional judgment to produce an upper bound of 0.5 collision-deaths per year for Roseate Terns. In response to comments on that document the present estimate makes use of data newly available as well as those on hand in 2004 and includes more extensive analyses. The outcomes are similar to the earlier estimate: expected values derived from multiplying “simple averages” of the variables are approximately 0.77 (range of four estimates: 0.26 – 2.29) collision-deaths/year (Section 11, above). The uncertainty analysis in Section 12 indicates that the median for estimated mortality is 0.83/year, with lower and higher 5 percent probabilities of 0.01 to 8.2 deaths/year.

A limitation already noted is that the observations were restricted to relatively good weather. In stormy weather, any terns active may be more likely to fly at rotor height than in milder conditions, but also to be travelling downwind when they do so.

14. Impacts of mortality

The consequences of mortality attributable to collisions at a windfarm depend on the ecological characteristics of the species in question. Most waterbirds, including the Roseate Tern, have relatively high adult survival and produce few young each year so that they are likely to be relatively sensitive to changes in survival rates. Even small increases in mortality can affect the trajectory of small populations such as that of Roseate Terns in the northwest Atlantic. To investigate the sensitivity of a population to specified changes requires making projections of numbers under appropriate scenarios. This procedure is termed Population Viability Analysis (PVA) and such analyses have been prepared for the two Federally-listed species, the Roseate Tern (see Arnold (2007)) and the Piping Plover (see Section 15 below and Brault (2007)). The wide uncertainties for the mortality estimates (Section 12) are addressed by including an appropriately wide range of values into the projections.

For inclusion in the PVA, the relevant mortality estimate is the number of male Roseates killed because the model is designed from the male perspective. The sex-ratio of the population is female-biased: about 45 percent male (Nisbet and Hatch 1999; Szczys et al 2001). If this ratio applies to the birds killed, then the **expected kill of male Roseate Terns is about 0.4/year.** The known male bias in provisioning chicks and in post-fledging parental care (Teets 1998) suggests that males might be at greater risk than females but too little is known about use of HSS by males and females to draw any useful conclusions about differences.

The Cape Wind turbines on Horseshoe Shoal would be the first large offshore windfarm to be encountered by Roseate Terns from this population, so they do not yet face problems of the cumulative effects of such installations. (The 17-turbine coastal (onshore) windfarm at Pubnico, Nova Scotia, is near to a tern colony on The Brothers Is. with 60 - 90 pairs of Roseates but terns there do not significantly encounter the turbines.) The three known, projected windfarm locations in the northwest Atlantic; in Buzzards Bay, south of Nantucket and Tuckernuck Islands, and near the eastern end of Long Island, NY would each present potential for cumulative effects, as would others in the same region. However, the migration routes of Roseate Terns are such that any sites for offshore windfarms further south on the Atlantic coast would be unlikely to pose significant problems.

15. Other species

The preceding analysis has been focused on the Federally Threatened Roseate Tern. Much of the argument applies to other species of concern and need not be repeated for every case. This Section will briefly summarize the salient conclusions for the other species that have been the subjects of particular discussion in connection with the proposed windfarm in Nantucket Sound.

The **Common Tern** is State-listed as being of Special Concern; unlike the Roseate Tern, the breeding population has been increasing since the mid-1970s (Nisbet 2002). This species uses Horseshoe Shoal in generally similar ways to the Roseate Tern. Because it is more numerous, both in pairs nesting around Nantucket Sound and in birds recorded at Horseshoe Shoal, as well as present in Massachusetts for longer each year, the potential numbers of collisions are higher. For terns nesting west of HSS, principally in Buzzards Bay, the ratio of Roseate to Common in 2005 was 1480 to 5172 pairs (or 22 percent Roseate); for both tern species in the Cape Cod area (thus, principally adding the large Monomoy colony) the ratio was 1502 to 15160 pairs (or 9 percent Roseate) (Mostello 2006). The Common Terns passing through Nantucket Sound are thought to include many of those that nest in northern New England and in Canada; however, there is no direct evidence for the migration routes of these birds or the likely numbers. Banding recoveries of Common Terns have not been analysed in sufficient depth to shed much light on the route taken by migrants leaving Cape Cod, but, like Roseate Terns, they probably travel over the ocean. Such migrants would be unlikely to cross HSS. The estimated annual collision-mortality of Common Terns under present conditions is likely to be roughly 15x that of Roseates, or about 12 individuals/year, with lower and upper 5% probabilities of 1.5 and 120.

The State-listed **Least Tern** *S. antillarum* nests on beaches around Nantucket Sound, about 1000 pairs in total, often in small scattered colonies, but large colonies of several hundred pairs have been located near Hyannis and/or on Nantucket in some recent years (Mostello 2006). These birds feed almost entirely close inshore (within 2 km, or a mile) and were reported very rarely in or near the project area during the fieldwork. During all the aerial and boat surveys conducted by CWA and MAS only 12 Least Tern sightings were recorded within the project area plus a 1-km buffer. The risk of collision mortalities for this species is minimal.

The Federally Threatened **Piping Plover** nests and feeds on shores from the Carolinas to Canada, including around Nantucket Sound, and winters from North Carolina to Mexico, Cuba and The Bahamas. Plovers from Massachusetts have been reported in winter from as far west as Texas. The plovers are relatively sedentary in their breeding and wintering areas but behavior during the intervening periods is largely unknown (Haig and Elliott-Smith 2004). No observations have been reported of these birds crossing Horseshoe Shoal but they may do so during migration or post-breeding dispersal. Some of the 888 plovers color-banded in Atlantic Canada in 1991 - 2001 were subsequently reported during the migration seasons at intermediate coastal locations, of which the main areas were in MA, NY, NJ and NC (D. Amirault, pers.comm.). The routes and altitudes of any such flights are not known, nor are the numbers of plovers at risk, so that it is impossible to make accurate predictions from available information. Since about 2000, the numbers of plovers involved (post-breeding estimates of adults plus fledglings, assuming no mortality) have been approximately as follows: 800 for Canada, 130 for Maine and NewHampshire, and 1400 for Massachusetts). However, the peak counts in fall at South Beach, Chatham, of about 70 individuals are thought to include such transients and perhaps others from wider parts of the breeding range, although post-breeding dispersal is poorly known. If such staging birds flew from South Beach, MA to Long Island, NY, at turbine height, they might cross the windfarm and be at risk of collision.

The first DEIS acknowledged the absence of essential information and suggested, on the basis of the limited knowledge, that collisions would be very few; estimated conservatively as 0.08/year. Reviewers of that document noted with disbelief that the plover estimate was higher than the tern estimate. Using the tools described earlier it is possible to make a new attempt at estimates around which to base evaluation of current concerns: these are the likely numbers of **crossings of the windfarm per collision**, based on several assumptions. (This ignores, for the present, the numbers of birds involved.) It is important to acknowledge, yet again, that such an estimate is not robust because so little is known about the behavior of birds at turbines.

Estimation of the probability of collision of Piping Plovers per crossing of the windfarm requires the following:

- collision risk for passing through a rotor (a no-avoidance estimate from the Band model, see Section 7) = 0.068. This is the average of the upwind and downwind estimates, using the plover speed in still air of 13 m/sec and assuming that plovers will fly below rotor height when flying into headwinds exceeding 9 m/sec. Input bird speed in the model was determined by combining the wind speed with the plover speed in still air. For the downwind calculation, the speeds were added. For the upwind calculation, the wind speed was subtracted from the plover speed in still air. Determination of turbine rotation period and wind speeds modeled was as described in Section 7 for Roseate Terns. Wind speed frequencies were multiplied by the collision risk probabilities and the results summed across all wind speeds to determine the overall risk for either upwind or downwind flying birds. For comparison, the no-avoidance collision risk estimate for birds flying only downwind at rotor height is 0.023.

- an avoidance rate, for which four alternatives will be used (Table 5). There are no published data for plovers, these values (0.91 to 0.99) are from Chamberlain et al. 2005. The expected mortality probability is given by (the collision risk x (1 – the avoidance rate)).

- the expected number of turbine rotors encountered by plovers (from the Bolker model, which assumes no avoidance, see Section 6). For the purpose of this analysis we have run the model for all flight directions and without considering wind-direction. This treats all turbines as if they were aligned perpendicular to the bird’s track and therefore overestimates the encounters, and we report on crossings of the circle containing the windfarm. For illustrative purposes, the expected number of encounters is presented for 3 different height distributions of the crossings, selected as an informative range of possibilities. If all plovers fly below 30 m (about 100 feet) asl, most will be below the rotors and expected encounters per crossing will be 0.07; if all fly within the rotor-swept zone (23 – 134 m asl) then there will be 0.67 expected encounters; if crossings are evenly distributed from 30 – 600 m asl (about 100 – 2000 feet) then 0.13 expected encounters. The probability of a bird surviving an encounter with a turbine is very high (see Sections 7 and 8, above).

The estimated collision probabilities are developed below and then summarized in Table 5, which illustrates the wide range of possible outcomes. The probability of collision, C, using an avoidance rate of 0.98, equals

0.068 x (1- 0.98) x 0.67 = 0.00091 for plovers confined to the rotor-swept zone; and C = 0.00010 for those near sea level; and C = 0.00018 for the wider height-range of 30-600 m. The estimated number of crossings per collision, CPC, is given by the reciprocal of this probability, or about 1,000; 10,000; and 5,500 crossings, respectively, for the three height-ranges examined.

Using a lower avoidance rate (0.95) yields CPCs of about 440; 4,200; and 2,300, respectively, and using a very low value of 0.91 yields CPCs of about 240; 2,300; and 1,250, respectively. A higher avoidance rate (0.99) yields CPCs of about 2,200; 20,000; and 11,100, respectively. From this wide range of estimates, shown in Table 5, it is clear that no exact estimate of mortality is possible with the available information. The crossings per collision must be related to the population numbers: at present about 600 pairs in New England and 200 pairs in Atlantic Canada.

Table 5. Estimated crossings per collision (CPC) of Piping Plovers at Horseshoe Shoal, for three height ranges and four avoidance-rates (AR).

A R	Rotor-swept zone	0 - 30 meters	30 - 60 meters
0.91	244	2,326	1,250
0.95	439	4,167	2,273
0.98	1,099	10,000	5,556
0.99	2,174	20,000	11,111

In the course of comments on the first DEIS (letter, page 7), MassWildlife suggested that the number of crossings of the windfarm might be <200 each year. The estimate was based on all PIPL nesting from Massachusetts northwards (including Canada), so that 2458 cross the Massachusetts coastline (based on adults in spring and fall, and the young of the year). The proposed fraction passing over HSS was 0.1. We use 200 crossings for developing this example with several possible ranges of altitude and collision probability. Based on the first-mentioned of the preceding analyses (with avoidance rate of 0.98), this number would result in one plover death in 5.5 years if all crossings were confined to the height range of the turbine rotors (which seems very unlikely), or one in 50 years if all flew below 30 m, or one in 28 years if the height range was 30 – 600 m. The lowest avoidance rate (0.91) suggests 1.2 collisions/year if all flew at rotor height, one in 12 years if all flew below 30 meters and one in 6 years if the height range was 30 – 600 m. Of course, the mortality would be zero if no plovers crossed the windfarm, or if they all flew close to the sea-surface.

Each of the preceding estimates is subject to uncertainty, but it is important to recognize that robust estimates for collision mortality require that **all** of the components be adequately known, and this particularly applies to avoidance behavior. This behavior is best-addressed with species-specific observations at operating turbines. Thus, for example, even detailed tracks are of limited value without knowledge of the altitude at which the tracked individuals are flying. The prospects for achieving usefully accurate collision estimates seem remote. A **more useful**

conclusion from the preceding analyses is that mortalities are likely to be rare and thus not irremediable

Seaducks, principally Common Eider, 3 species of scoter, and Long-tailed Duck, are present in Nantucket Sound in large numbers as transients during migration and as winter residents. They are heavy, fast-flying birds with relatively poor maneuverability and they generally fly in flocks. All these features make them poor prospects for last-moment avoidance behavior (unlike terns). This could place them at some risk of colliding with stationary structures such as the monopoles as well as the rotors. However, experience at the operating offshore windfarms in Denmark and Sweden shows that flocks of migrating eiders (and other waterfowl) deviate their flight paths around the windfarm; this is the principal component of the high level of avoidance shown by these migrants (Desholm and Kahlert 2006). They also avoid the turbines by flying midway between the rows or by changing height (Desholm and Kahlert 2005, 2006; Pettersson 2005). Radar observations indicate that many such flocks react to turbines by changing course at distances of 1.5 km or more by day and 0.5 km by night.). Flight patterns of flocks flying at night appear to be unaffected by mist (Pettersson 2005). There are no data for behavior under extreme conditions, such as storm and thick fog, but observations in Sweden suggest that little migration occurs under such conditions (Pettersson 2005).

In Nantucket Sound, scattered visual observations indicate that local movements of scoters and eiders are generally below rotor height. Some migrants fly at rotor height, especially when heading landward, but the location and scope of such movements have not been quantified. The radar data gathered by GMI from Nantucket Sound in 2002 and 2006 showed numerous targets classified as “large” or “flock-sized” flying at rotor height but have not been used to identify seaducks. (The GMI reports do not include analyses of the tracks, with airspeeds and groundspeeds, of targets identified during ground-truthing which might allow provisional identification.) However, the seasonal migrations of seaducks across HSS appear to include very much smaller numbers than the 235,000 Common Eiders that pass the Danish offshore windfarm of Nysted (72 turbines) during autumn migration. Intensive pre- and post-construction studies using radar, visual observations, and thermal-imaging video cameras have been conducted at this windfarm. The conclusion from a stochastic collision risk model was that the estimated average number of collisions is 47 Common Eiders per autumn. Depending on the numbers and course of movements in spring, this amounts to roughly one eider/turbine/year. While such averaging may obscure important features, and possibly magnify some surmised consequences, it does suggest a tentative conclusion that collisions at HSS are likely to be very much lower than the annual hunting kill of 15-20 000 of eiders and of Long-tailed Ducks in the Atlantic Flyway (USFWS 2006). In addition to twice-yearly migration, the daily movements of Long-tailed Ducks are of particular concern and are being studied by MAS in conjunction with seaduck experts from USGS, Patuxent, MD. The limited visual observations for Cape Wind in 2005-6 suggested that these daily movements in and out of Nantucket Sound do not bring many of the Longtails close to the project area (ESS Group 2006c).

16. References cited

Alerstam, T. 1985. Strategies of migratory flight, illustrated by arctic and common terns, *Sterna paradisaea* and *Sterna hirundo*. Contrib. Mar. Sci. (Suppl.) 27:580-603.

Arnold, J.M. 2007. Population Viability Analysis for the Northeast Population of the Roseate Tern. XX

Band, W., Madders, M., and Whitfield, D.P. (in press) Developing field and analytical methods to assess avian collision risk at windfarms. In: de Lucas, M., Janss, G. & Ferrer, M. (eds.) Birds and Wind Power. Lynx Edicions, Barcelona.

Bolker, E.D., Hatch, J.J., and Zara, C. (2007) Modeling bird passage through a windfarm. (For manuscript and spreadsheet (under development) see this website http://www.cs.umb.edu/~eb/windfarm/

Brault, S. 2007. Population Viability Analysis for the New England population of the Piping Plover. XX

Chamberlain, D.E., Freeman, S.N., Rehfisch, M.R., Fox, T., and Desholm, M. 2005. Appraisal of Scottish Natural Heritage's wind farm collision risk model and its application. BTO Research Report 401, 52 pages.

Chamberlain, D.E., Rehfisch, M.R., Fox, A.D., Desholm, M., and Anthony, S.J. 2006. The effect of avoidance rates on bird mortality predictions made by wind turbine collision risk models. Ibis 148:198 – 202.

Chernick, M. R. 1999. Bootstrap Methods, A Practitioner's Guide. Wiley & Sons Inc.

Christensen, T.K. et al. 2004. Visual and radar observations of birds in relation to collision risk at the Horns Rev offshore wind farm. Annual status report, 2003. NERI

Cullen, J.M. 1956. A study of the behaviour of the Arctic Tern (*Sterna macrura*). D.Phil. diss., Oxford University.

Desholm, M., Fox, A.D., Beasley, P.D., and Kahlert, J. 2006. Remote techniques for counting and estimating the number of bird-wind turbine collisions at sea: a review. Ibis 148:76-89.

Desholm, M. and Kahlert, J. 2005. Avian collision risk at an offshore wind farm. Biology Letters 1: 256-258.

Desholm, M. and Kahlert, J. 2006. A stochastic model analysis of avian collision risk at wind farms. pages 103-127 in Desholm, M. thesis: Wind farm related mortality among avian migrants. http://www.dmu.dk/Pub/PHD_MDE.pdf

Devroye, L. 1986. Non-Uniform Random Variate Generation. Springer-Verlag.

Drake, K. R., J. E. Thompson, K. L. Drake, C. Zonick. 2001. Movements, habitat use, and survival of nonbreeding Piping Plovers. Condor 103: 259-267.

ESS Group 2006a. Summary of the Cape Wind and Massachusetts Audubon Aerial Surveys, 2002-2006. ESS Project # E159-502. ESS Group, Inc., 401 Wampanoag Trail, East Providence, Rhode Island.

ESS Group 2006b. Tern Observations near Monomoy Island, August 28-31, 2006, Nantucket Sound, Massachusetts. ESS Project # E159-502. ESS Group, Inc., 401 Wampanoag Trail, East Providence, Rhode Island.

ESS Group 2006c. Long-tailed Duck Report, Winter 2005-2006, Nantucket Sound, Massachusetts.

Evans, M., N. Hastings, and B. Peacock. 2000. Statistical Distributions, 3rd. Ed. New York: Wiley.

Everaert, J. 2003. (Wind turbines and birds in Flanders: preliminary study results and recommendations.) Natuur.oriolus 69: 145-155. (English translation….

Everaert, J. and Stienen, E.W.M. 2006. Impact of wind turbines on birds in Zeebrugge (Belgium): Significant effect on breeding tern colony due to collisions. Biodiversity and Conservation (in press) (DOI 10.1007/s10531-006-9082-1) at www.springerlink.com/content/n724201117657644/

Gelman, A., J.B. Carlin, H.S. Stern and D.B. Rubin. 1995. Bayesian Data Analysis. Chapman & Hall/CRC.

Gochfeld, M., Burger,J. and Nisbet, I.C.T. 1998. Roseate Tern (*Sterna dougallii*). *In* The Birds of North America, No. 370 (A. Poole and F. Gill, eds.). The Birds of North America, Inc., Philadelphia, PA.

Haig, S. M., and Elliott-Smith, E. 2004. Piping Plover. *The Birds of North America Online*. (A. Poole, Ed.) Ithaca: Cornell Laboratory of Ornithology; Retrieved from The Birds of North American Online database: http://bna.birds.cornell.edu/BNA/account/Piping_Plover/

Heinemann, D.1992. Foraging ecology of Roseate Terns on Bird Island, Buzzards Bay, Massachusetts. Unpublished report to USFWS, Newton Corner, MA.

Hogg, R. V. and A. T. Craig. 1978. Introduction to Mathematical Statistics, 4th edition. New York: Macmillan.

Krueger, T., and Garthe, S. 2001. Flight altitude of coastal birds in relation to wind direction and speed. Atlantic Seabirds 3: 203-216.

Manly, F.J. 2006. Randomization, Bootstrap and Monte Carlo Methods in Biology. Chapman & Hall.

Mostello, C.S. 2006. Inventory of Terns, Laughing Gulls, and Black Skimmers nesting in Massachusetts in 2005. Massachusetts Division of Fisheries and Wildlife, Westborough, Mass.

Nisbet, I.C.T. 2002. Common Tern (*Sterna hirundo*). *In* The Birds of North America, no. 618 (A.Poole and F.Gill, eds.). The Birds of North America, Inc., Philadelphia, PA.

Nisbet, I.C.T. and Hatch, J.J. 1999. Consequences of a female-biased sex-ratio in a socially monogamous bird: female-female pairs in the Roseate Tern *Sterna dougallii* . Ibis 141 (2): 307-320.

Perrow, M.R. et al. 2006. Radio telemetry as a tool for impact assessment of wind farms: the case of Little Terns *Sterna albifrons* at Scroby Sands, Norfolk, UK. Ibis 148: 57-75.

Petersen, I.K. et al. 2006. Final results of bird studies at the offshore windfarms at Nysted and Horns Rev, Denmark. NERI Report. http://www.ens.dk/graphics/Energiforsyning/Vedvarende_energi/Vind/havvindmoeller/vvm%20Horns%20Rev%202/Nysted/Birds%20final%202005.pdf

Pettersson, J. 2005. The impact of offshore wind farms on bird life in southern Kalmar Sound, Sweden. A final report based on studies 1999 – 2003. Lund University and Swedish Energy Agency.

Sadoti, G., et al. 2005a. A survey of tern activity within Nantucket Sound, Massachusetts, during the 2004 breeding period. Final Report for Massachusetts Technology Collaborative; Massachusetts Audubon Society, Lincoln, MA.

Sadoti, G., et al. 2005b. A survey of tern activity within Nantucket Sound, Massachusetts, during the 2004 Fall staging period. Final Report for Massachusetts Technology Collaborative; Massachusetts Audubon Society, Lincoln, MA.

Shire, G.G., K. Brown, and G. Winegrad. 2000. Communication towers: a deadly hazard to birds. American Bird Conservancy, Washington, DC.

Szczys, P. et al. 2001. Sex ratio bias at hatching and fledging in the Roseate Tern. Condor 103: 385-398.

Teets, M.J. 1998. Allocation of parental care around the time of fledging in the Roseate Tern *Sterna dougallii*. Masters Thesis , University of Massachusetts, Boston.

Trull, P., et al. 1999. Staging of Roseate Terns *Sterna dougallii* in post-breeding period around Cape Cod, Massachusetts. Atlantic Seabirds 1:145-158.

Tucker, V.A. 1996. A mathematical model of bird collisions with wind turbine rotors. J. Solar Energy Engineering 118: 253 – 262.

U.S. Fish and Wildlife Service. 2006. Migratory bird hunting activity and harvest during the 2004 and 2005 hunting seasons: Preliminary estimates. U.S. Department of Interior, Washington, D.C.

Winkelman, J.E. 1992. The impact of the Sep wind park near Oosterbierum (Fr.), The Netherlands, on birds, 1: Collision Victims (RIN-rapport 92/2), 2:Nocturnal Collision Risks (RIN-rapport 92/3). DLO-Instituut voor Bos- en Natuuroderzoek. (in Dutch, English translations of summaries and titles).