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Avian collision risk at an offshore wind farm

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We have been the first to investigate whether long-lived geese and ducks can detect and avoid a large offshore wind farm by tracking their diurnal migration patterns with radar. We found that the percentage of flocks entering the wind farm area decreased significantly (by a factor 4.5) from pre-construction to initial operation. At night, migrating flocks were more prone to enter the wind farm but counteracted the higher risk of collision in the dark by increasing their distance from individual turbines and flying in the corridors between turbines. Overall, less than 1% of the ducks and geese migrated close enough to the turbines to be at any risk of collision.

Keywords: migration; radar; wind turbines; avoidance; collision; waterbirds

1. INTRODUCTION

Since the early 1990s marine wind farms have become a reality (Larsson 1994), and no fewer than 13 000 offshore wind turbines are currently proposed in European waters. At present, two large offshore wind farms operate in Denmark, one of which was the focus of the present radar study. Here, hundreds of thousands of waterbirds migrate annually between breeding and wintering grounds, and there is great public concern at the risk of bird–turbine collisions. The assessments to date of wind turbine collision risk for birds have mostly been conducted on land (Garthe & Hüppop 2004), and offshore investigations are expensive. However, the risk of collision at sea needs to be investigated as well, not in the least because long-lived waterbird populations are especially sensitive to additional mortality (Sæther & Bakke 2000). To help address this, we have investigated the avian avoidance response to offshore wind turbines in order to assess the risk of collisions.

2. MATERIAL AND METHODS

This study was conducted at the Nysted offshore wind farm (160 MW) situated in the western part of the Baltic Sea offshore from southern Denmark. The 72 turbines (each 2.3 MW; blade length: 41 m; hub height: 69 m; red lights (or red flashing lights on edge turbines) mounted on the nacelle top) are placed in eight north–south oriented rows with a distance of 850 m between rows. The distance between each turbine in the rows is 480 m. The flight trajectories of migrating waterbirds were mapped by the use of a surveillance radar (Furuno FR2125, peak power 25 kW, variable pulse length/volume 0.3–1.2 μs, pulse repeat frequency 9410 ± 30 MHz, vertical beam width 20°, monitor resolution 1280 × 1024 pixels where each pixel represents a square of 23 × 23 m) mounted at an 8 m high observation tower situated 5.6 km northeast of the wind farm. Radar range was set to 11 km. There was a shading effect from individual turbines on the echoes of the flying bird flocks, resulting in short parts of the trajectories being undetectable by the radar. These parts where reconstructed by drawing a straight line between the points of disappearance and reappearance. This procedure will most probably neither under- nor overestimate the avoidance behaviour, since the vast majority of the disappearing parts of trajectories were situated between the rows of turbines, and not at the rows themselves, where the measurement of distance between the bird flock and the nearest turbine was performed. The decreasing ability to follow bird flocks by radar with increasing distance was not corrected for, since (i) the data for this analysis represent a subsample of the flocks that was large enough for radar detection and (ii) the species under study tend to migrate in relatively large flocks that are easily detected by this radar at the distance of interest. Furthermore, data collection was conducted only in calm winds (less than 10 m s^{-1}) and no-precipitation situations. Thus, the amount of sea and rain clutter on the radar monitor was minimized and the detectability of birds was optimized.

The species involved in the present analysis comprise mainly common eider (*Somateria mollissima*) and geese, of which approximately 200 000–300 000 and approximately 10 000, respectively, pass the study area each autumn (Kahlert *et al.* 2000). Species identification was conducted visually on a subsample of the flocks, and all flocks were identified by species using radar (flight speed or echo signature). Digitized migration trajectories were transformed to a GIS (geographic information system) platform in the local datum of the UTM (universal transverse mercator) 32 projection for spatial analyses. Spatial movements of migrating flocks were mapped relative to the nearby wind turbines, and hence, were extremely precise with regard to mutual distance between bird flocks and turbines. The same radar, study area and study objects have been the focus of another study by Desholm (2003), where the accuracy of the radar measurements was sufficient to detect a small but significant difference between geese and common eiders in their ability to migrate along straight lines.

In order to compare situations with good and poor visibility only, the data collected during twilight were excluded from the analysis. Night was defined as the period from 2 h after sunset to 2 h before sunrise, and day as the period from sunrise to sunset. During daylight the birds were most probably responding to the turbines themselves, and at night to the red warning lights. For the proportion analysis, only flocks passing both transect A (11 km long; oriented parallel to the eastern row of turbines and 5.3 km from these) due south of the radar platform and either transect B, C or D (see below) were included (transects A–D are depicted in figure 3 in the Electronic Appendix). Flocks were defined as entering the wind farm if they crossed transect B, situated along the eastern row of turbines. Flocks were defined as not entering the wind farm if they crossed either transect C, between the north-eastern corner of the wind farm and the radar platform, or transect D, between the southeastern corner of the wind farm and the southern end of transect A. The avoidance response has previously been shown to be consistent irrespective of various crosswind conditions (Kahlert *et al.* 2004).

3. RESULTS

By tracking the spatial migration pattern of waterbirds by radar (figure 1) we found that the diurnal percentage of flocks entering the wind farm area decreased significantly (by a factor 4.5) from pre-construction to initial operation. At night, 13.8% of flocks entered the area of the initially operating turbines, but only 6.5% of those flew closer than 50 m to turbines. During the day, over the same period, these figures were 4.5 and 12.3%, respectively. This means, *ceteris paribus*, that only 0.9% of the night migrants and 0.6% of the day migrants flew close enough to the turbines to be at risk of colliding with the turbines.

The proportion of flocks ($P_{\text{day \& night}}$) entering the wind farm (Kahlert *et al.* 2004) decreased significantly from 40.4% ($n=1406$) during pre-construction (2000–2002) to 8.9% ($n=779$) during initial operation (2003; $\chi^2=239.9$, $p<0.001$). P_{night} was significantly higher compared with P_{day} (13.8%; $n=289$ and 4.5%; $n=378$, respectively; $\chi^2=17.1$, $p<0.001$).

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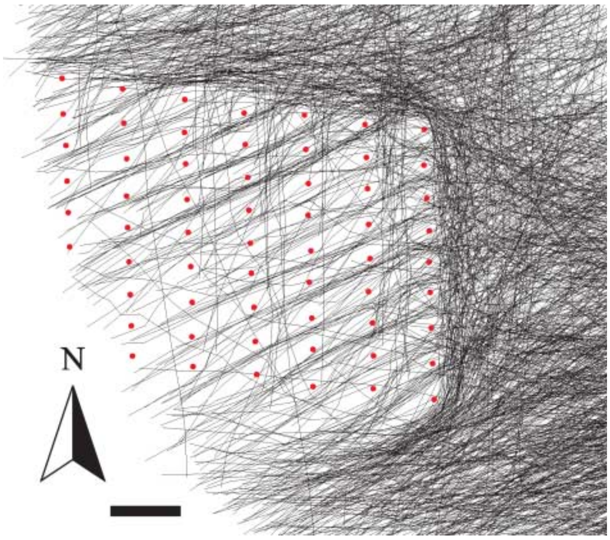

Figure 1. The westerly oriented flight trajectories during the initial operation of the wind turbines. Black lines indicate migrating waterbird flocks, red dots the wind turbines. Scale bar, 1000 m.

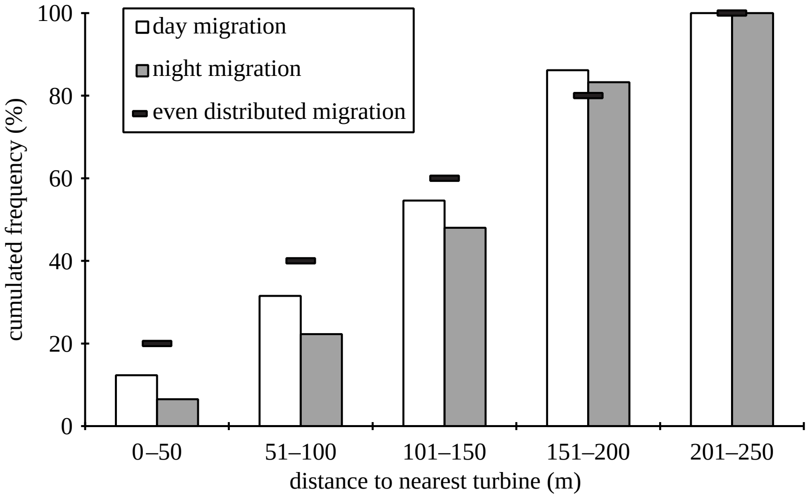

Figure 2. The cumulated frequency distribution $F_N(x)$ of the distances between bird flocks and the nearest turbine when passing the north–south oriented rows of turbines.

The cumulated frequency distribution, $F_N(x)$, of the distances between bird flocks and the nearest turbine when passing the north–south oriented rows of turbines was significantly different from an evenly distributed migration pattern both during day- and night-time (figure 2; Kolmogorov–Smirnov one-sample test; $D=0.0846$, $n=260$, $p<0.05$ and $D=0.1775$, $n=400$, $p<0.01$ for day and night, respectively). Finally, birds migrated significantly closer to individual turbines during the daytime than at night (Kolmogorov–Smirnov two-sample two-tailed test, $D=0.1273$, $n_{\text{day}}=260$, $n_{\text{night}}=400$, d.f.$=2$, $p<0.05$; figure 1). Mean flock sizes (95% confidence intervals) on log-transformed data of common eider and geese for autumn 2003 were 14.6 (13.3–16.2) and 7.7 (5.8–10.4), respectively. As the species-specific distributions of flock sizes differed markedly from normal distributions, log-transformation of data was undertaken when calculating the mean flock size and the 95% confidence intervals. This approach is generally less sensitive to extreme observations of very large flocks, which may occur at a very low frequency, compared to calculation of simple averages.

4. DISCUSSION

To date, 14 marine wind farms (in total 213 turbines) are in operation around the world (five in Denmark, three in Sweden, two in the Dutch IJsselmeer and two in the UK). However, few have provided adequate case studies upon which to base the current advice relating to the impacts of offshore wind farms on birds. The present radar study documents a substantial avoidance response by migrating waterbirds to a large offshore wind farm. A larger proportion of the birds fly within the wind farm at night- compared with day-time, but counteract this higher risk of colliding with the turbines in the dark by remaining at a greater distance from the individual turbines. Overall, less than 1% of the ducks and geese fly close enough to the turbines to be at any risk of collision. To date, the avian avoidance factor has never been implemented in models for estimating the number of bird-turbine collisions. Our findings stress the importance of applying the avoidance factor when dealing with wind farm-related mortality.

These estimates of potential collision risk are over-inflated since those bird flocks migrating within the horizontal reach of the turbine blades may actually fly below or above, or fly unharmed through the turbine's sweep area (Tucker 1996). Quantification of these altitude options will be addressed in subsequent research. Caution should be taken, though, since this study covers one year of initial operation only and has focused on waterbirds (mainly geese and common eiders). During the initial operation, frequent visits of maintenance vessels may have influenced the avian avoidance response to the sweeping turbines in an uncertain way. Before solid conclusions can be reached, complementary studies at other sites are needed to confirm these findings, to include possible habituation behaviour over the years to come, and to cover other focal species such as divers (*Gavia* sp.) and common scoter (*Melanitta nigra*).

These findings also stress that the agenda for future environmental impact assessments should change. Rather than focus only on possible local catastrophe, efforts should also be made to assess the cumulative impacts of small-scale local effects on the different geographically defined avian populations. Such an approach necessitates collaboration among scientists, reflecting that the preservation of migrating birds is, by its nature, an international effort.

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The supplementary Electronic Appendix is available at http://dx.doi.org/10.1098/rsbl.2005.0336 or via http://www.pubs.royalsoc.ac.uk.