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Effects of wind turbines on flight behaviour of wintering common eiders: implications for habitat use and collision risk

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Summary

1. Wind energy is a fast-growing renewable energy source and many offshore wind parks will be erected in shallow waters (< 40 m deep) where various coastal bird species are found. The two main issues regarding offshore wind farms and birds are disturbance and collision risk. We studied the effect of wind turbines on the flight behaviour of wintering common eiders *Somateria mollissima* in order to identify the properties that cause disturbance and the factors that may increase their risk of collision.
2. The study was conducted at Tunø Knob offshore wind park in the Kattegat, Denmark. We attracted birds though the use of decoys located at increasing distances from the wind park. To discriminate between the potential disturbance effect of the standing towers from that of the revolving rotor blades, wind turbines were switched on or off alternately during 10 experimental trials.
3. Common eiders reacted strongly to the presence of wind turbines. The number of flying birds was significantly related to flight corridor location and position of the decoy group. That behavioural reaction was interpreted to be a consequence of their high speed and low-manoeuvrability flight occurring within the vertical height range of the wind turbines. The number of landing birds also reacted to the position of the decoy group in relation to proximity to the turbines, with the greatest effects observed within the wind park. Such avoidance behaviour might decrease use of otherwise suitable habitat.
4. The movement and noise of rotors affected neither the number of common eiders flying within corridors nor the number of birds reacting to decoys. This suggests that the avoidance behaviour observed was caused by the presence of the structures themselves and that eiders use vision when avoiding human-made structures.
5. *Synthesis and applications*. This study has demonstrated that common eiders avoid flying close to or into the Tunø Knob wind park. This behaviour may result in a reduction in habitat availability within and around wind parks, and raises concerns about the possible impact of the extensive development of large-scale wind parks in shallow offshore waters, which are the main feeding areas for sea ducks and other marine birds. Our results indicate that the disturbance effect of revolving rotor blades is negligible during daylight hours but highlights the need for studies to be carried out during hours of darkness and conditions of poor visibility (e.g. fog and snow). Until more insight is gained, we recommend caution when planning wind parks in areas of high sea duck densities.

Key-words: collision risk, disturbance, flight behaviour, operating wind turbines, *Somateria mollissima*, wind farms

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Introduction

The exploitation of offshore wind energy resources has been subject to increasing attention in recent years, and many offshore wind parks are planned or are under construction. Because wind turbines are a conspicuous anthropogenic element in the marine environment, the number and size of wind parks that currently are envisioned have raised concerns about potential conflicts with nature conservation interests. In the offshore waters of north-western Europe, where plans to develop offshore wind energy are presently most intense, there are large numbers of migrating, moulting and wintering sea ducks. Occurring in high densities in relatively shallow waters (Guillemette *et al*. 1993; Bustnes & Lønne 1997; Larsen & Guillemette 2000) within the same depths as sites proposed for wind parks, sea ducks may be susceptible to negative impacts (Guillemette, Larsen & Clausager 1998; Guillemette & Larsen 2002; Langston & Pullan 2003).

Wind energy is a recent phenomenon and only a few studies have been conducted regarding offshore wind parks (Larsson 1994; Guillemette, Larsen & Clausager 1998; Guillemette & Larsen 2002; Desholm & Kalhert 2005). Many studies have addressed the possible impacts on birds of onshore wind parks (reviewed by Langston & Pullan 2003) but the findings from these studies cannot simply be extended to an offshore scenario because different species will be impacted. For example, many diving species are characterized by short wings and high wing loadings for their body size, resulting in high-speed flight but low manoeuvrability (Rayner 1988).

The two main issues linking offshore wind parks and birds are disturbance and collision risk, with recurrent disturbance potentially leading to loss of feeding habitat or additional energetic costs and collisions potentially leading to increased mortality rates. Studying these impacts is difficult in an offshore setting. With respect to disturbance, a major challenge is to relate apparent disturbance effects with the presence of the wind park, i.e. to establish causality. Disturbance may be related to the presence of the physical structures themselves, the revolving action of the rotor blades (through visual stimuli and/or the noise produced) or the associated support activities (i.e. boat- and helicopter-related traffic). Understanding the cause(s) of disturbance is important as it is the basis for making qualified decisions about potential alleviating measures.

In terms of collision risk, the underlying factors that may cause mortality must first be identified. This necessitates an analysis of flight behaviour and environmental factors (Barrios & Rodriguez 2004; Garthe & Hüppop 2004). For example, a species that regularly flies during conditions of reduced visibility at an altitude similar to the turbines may be highly susceptible to collisions. In this study, our objectives were to: (i) test whether a small wind park influences the flight behaviour of common eiders *Somateria mollissima* L. and distinguish any effects of the revolving rotors from those caused by the presence of the turbine structure alone; and (ii) identify the underlying factors that may increase the risk of collision in this species.

Methods

STUDY SITE

The study was conducted at Tunø Knob, a shallow water area located in the southern Kattegat Sea, Denmark, where there is a wintering population of 1000–5000 common eiders (Guillemette, Larsen & Clausager 1998). In 1995, a wind park consisting of 10 500-kW turbines was built at this site, the turbines arranged in two north–south orientated rows and situated in water depths of 3–5 m. The distances between turbines and between rows are 200 m and 400 m, respectively. Each turbine tower's hub height is 40·5 m, and the rotor diameter is 39 m, giving a total height of 60 m.

EXPERIMENTAL SET-UP

The presence of the wind turbines may influence the behaviour of common eiders in flight regarding where to fly (flight path) and whether to land (landing willingness). To address both of these possible effects, observations aimed to determine (i) the number of common eiders flying and (ii) the landing frequency of eiders at various distances from the wind park. To assess the willingness of eiders to land in a standardized manner, five groups of decoys were positioned on the sea surface at regular intervals perpendicular to the turbines: a single transect with two sets of decoys inside the wind park, each 100 m from the nearest line of turbines and 200 m from each other, and three sets of decoys outside the wind farm, at distances of 100 m, 300 m and 500 m from the nearest line of turbines (Fig. 1). The east–west layout of decoy transects was chosen because the flight direction of common eiders was mainly north–south orientated (i.e. parallel to the long side of the wind farm). The decoy groups, consisting of three lines of 10 decoys each, were positioned 1 week prior to the start of observations. Observations were conducted by one pair of observers positioned on a turbine platform, each observer overlooking a decoy transect. For every individual/flock encountered, we continuously scanned back and forth over the decoy transect, and recorded whether it passed or reacted. Passing birds were assigned to one of five 200-m wide corridors centred on the decoy groups (Fig. 1). Assigning birds to the correct distance zones outside the wind park was aided by the use of a distance-measuring laser binocular (Zeiss Halem II, Oberkochen, Germany). Reacting birds were defined as birds that landed within or in the vicinity of a group of decoys, or, alternatively, showed intentions to do so by making marked deviations from their flight route towards or by decreasing flight speed near a group of decoys. Individuals landing

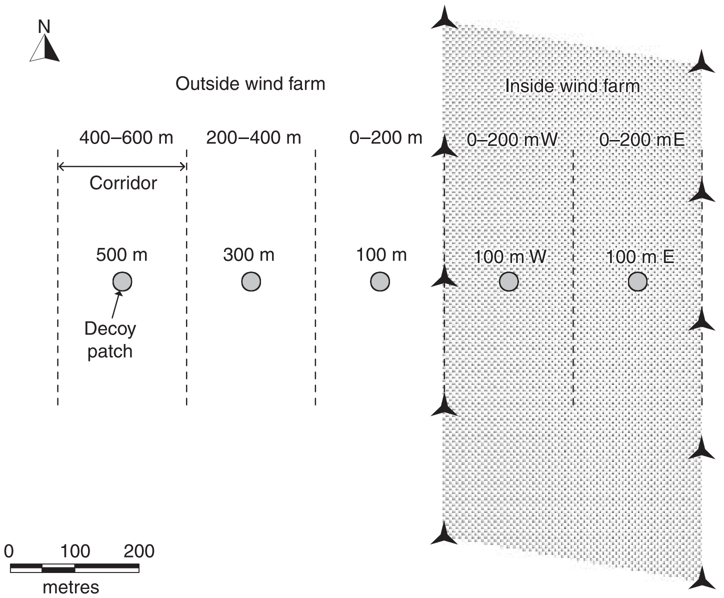

Fig. 1. Study layout showing wind farm and locations of flight corridors and decoys. Observations were conducted from the central wind turbine in the western row of turbines.

among the decoys always left again within a few minutes, either by taking flight or swimming. Therefore, landing birds did not seriously affect the overall 'eider' numbers in the decoy groups.

Flying common eiders were assigned visually to altitude intervals of < 10 m, 10–20 m and > 20 m, by using the height of the observer (5 m above sea level) and the rotor blades as reference points. The intervals correspond to the lower and upper half of the area below the rotors and the rotor-swept area, respectively.

The effect of the revolving turbine rotors was examined by experimentally manipulating the operational state of the turbines while observing the flight behaviour of common eiders during the morning. The morning flight, during which the birds move to their feeding grounds after having drifted as a result of wind and currents during the night, seems to be the period when the flight activity of wintering birds is at its highest. In 10 trials conducted from mid-February to late March 1998, flight behaviour was observed with the turbines operating normally (on) and stationary (off), respectively. Each trial started half an hour before sunrise and consisted of two observation periods differing in operational state of the turbines: an early period of 25 min and a late period of 60 min, separated by an intermediate period of 2–5 min during which the operational state of the turbines was changed. The order of the on and off state of the turbines were altered in a systematic manner between trials. The length of observation periods was adjusted to reflect the fact that the frequency of flights was skewed towards the start of trials. The turbines were made to stop and restart by radio communication from a remote-control centre.

STATISTICAL ANALYSIS

The effect of the revolving turbine rotors on eider flight behaviour was tested with two-way ANOVAs, with the operational state of the turbines (i.e. on or off) and corridor/decoy group location as independent variables. For dependent variables, we used the number of entering birds (passing + reacting birds) in the flight path analysis, the number of birds reacting to the decoys in the absolute landing frequency analysis, and the proportion of reacting birds [reacting/(passing + reacting)] in the analysis of relative landing frequency (willingness to land). For the first two analyses, numbers were $\log_{10}(x + 1)$ transformed to approximate a normal distribution pattern and to comply with requirements for homogeneity of variance.

Results

FLIGHT PATHS

The number of flying common eiders in the study corridors was significantly related to their location relative to the wind farm (ANOVA, $F_{3\cdot 90} = 3\cdot 931$, $P = 0\cdot 005$): the numbers of common eiders entering the 0–200-m outside corridor and the two corridors within the wind park were 19% and 50–53% lower, respectively, than the numbers in the 200–400- and 400–600-m outside corridors (percentage calculations based on back-transformed mean numbers). The spatial pattern of flying common eiders relative to the wind farm, however, was not affected by the operational state of the wind turbines (interaction, $F_{3\cdot 90} = 0\cdot 048$, $P = 0\cdot 996$). The total number of common eiders flying in the study area also was unaffected by the turbines' operational state ($F_{1\cdot 90} = 0\cdot 259$, $P = 0\cdot 612$; Fig. 2a).

WILLINGNESS TO LAND

The absolute number of common eiders reacting to the decoys was significantly related to the position of decoy groups relative to the wind farm (ANOVA, $F_{3\cdot 90} = 4\cdot 178$, $P = 0\cdot 004$): numbers reacting to the decoy group 100 m outside and the decoy groups within the wind park were 48% and 54–60% lower, respectively, than numbers for the two furthest decoy groups outside the wind park. However, the number of common eiders that reacted was not affected by the operational state of the wind turbines, neither with respect to the position of the decoy groups relative to the wind farm (interaction, $F_{3\cdot 90} = 0\cdot 070$, $P = 0\cdot 991$) nor for the entire study area ($F_{1\cdot 90} = 0\cdot 408$, $P = 0\cdot 525$; Fig. 2b).

The proportion of common eiders entering each corridor that reacted to the decoys varied little and did not differ significantly between corridors (ANOVA, $F_{3\cdot 90} = 1\cdot 493$, $P = 0\cdot 211$). Similarly, there were no significant effects of the operational state of the turbines on the relative frequency of reacting birds, neither with respect to corridor location relative to the wind park (interaction, $F_{3\cdot 90} = 0\cdot 340$, $P = 0\cdot 850$) nor for the study area as a whole ($F_{1\cdot 90} < 0\cdot 001$, $P = 0\cdot 998$; Fig. 2c).

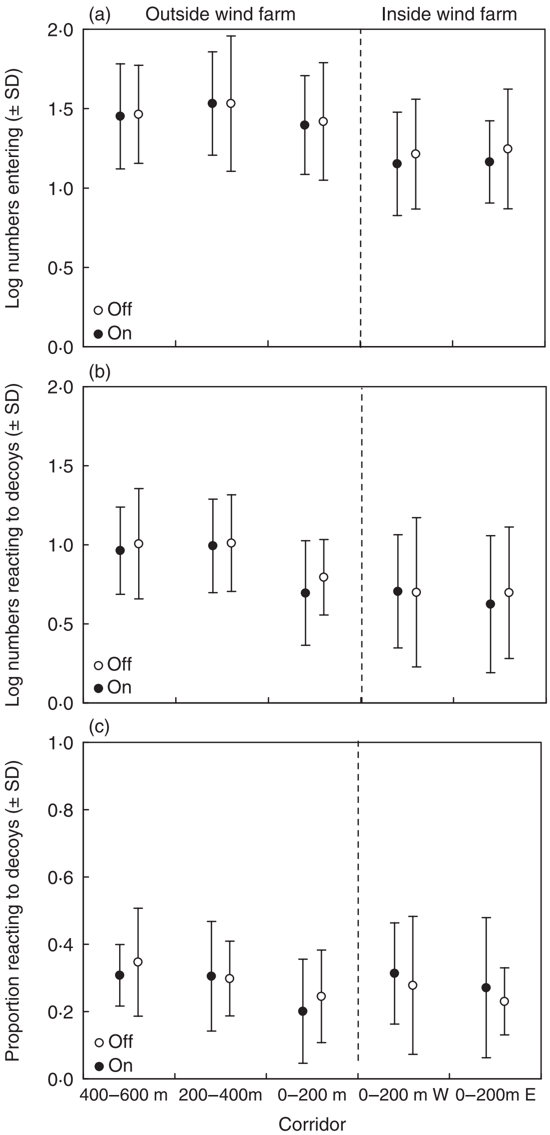

Fig. 2. The relationship between operational state of the wind turbines and (a) numbers of common eiders entering flight corridors, (b) numbers reacting to decoys in flight corridors and (c) the proportion of flying birds reacting to turbines in flight corridors (n = 10 in each case).

FLIGHT ALTITUDE

Most birds flew at low altitudes around the Tunø Knob wind park, with 91% of the flocks (n = 1277) flying below 10 m, 7% between 10 and 20 m and 2% at heights > 20 m. No flocks were seen flying above the upper altitude reached by the rotors (60 m); all birds flew within the vertical height range of the turbines (including rotor diameter) and only 2% of the flocks were flying at the height of the rotor-swept area.

Discussion

The fact that common eiders are highly attracted to conspecifics was used to measure their behavioural response to wind turbines at varying distances from the wind park. Each decoy group was expected to attract a similar number of individuals, so any reduction of flight and landing frequency in the immediate vicinity of the turbines could be interpreted as an avoidance response. Common eiders were observed to reduce both the frequency of flights and landings on the sea surface at a distance of about 200 m from the wind park, which is much shorter distance than the 1500–2000 m reported by Tulp *et al*. (1999) from radar-based observations. Surprisingly, Tulp *et al*. (1999) were not able to detect any avoidance behaviour at shorter distances. Three explanations may account for the discrepancy. First, Tulp *et al*. (1999) were not able to eliminate the possibility that the observed flight path was a passive reflection of the distribution of food and conspecifics. Aggregations of eiders at 1000–1500 m from the Tunø Knob wind park (Guillemette, Larsen & Clausager 1999) may have attracted flying eiders and confounded the results in the Tulp *et al*. (1999) study. Unfortunately, the distribution of foraging eiders was not recorded in their study. Secondly, the scale of observations was different in the two studies; our observations were made only within 600 m of the wind park (Fig. 1). It is possible that eiders first react at a greater distance from the wind park and then adjust their flight path again in the immediate vicinity of the wind park. Recent studies with radar suggest that migrating common eiders may change their flight paths in relation to offshore wind parks as much as 4 km away (Desholm & Kalhert 2005). Thirdly, visual observations may allow more accurate estimates of numbers and a finer-scaled spatial resolution of observations than radar-based observations. It is well-documented that the ability of conventional surveillance radars to detect flocks of flying birds is strongly influenced by flock size, flight altitude and distance (Pettersson 2005), for example causing smaller flocks (prevalent in our study area) flying at close distance to the radar to be underrepresented.

This raises the issue of how this behavioural response would change if flight activity occurred at night. Tulp *et al*. (1999) observed nocturnal flight activity in the eider and noted that flight intensity was much higher on moonlit nights than on moonless nights. They also observed that eiders changed their flight path in relation to the wind park more often during moonlit nights than during moonless nights. These results show that common eiders can fly at least in dim light and suggest that their visual discrimination decreased during darkness. Thus future studies should include hours of darkness when assessing the impact of offshore wind parks on birds because it may represent a period of higher risk. Recently, Desholm & Kalhert (2005) found that a higher proportion of migrants (mostly common eiders) entered a large wind park at night than during the daytime but that the eiders counteracted the higher risk of collision in the dark by increasing their distances from individual turbines and flying in the corridors between turbines. These authors did not emphasize the fact that the offshore wind turbines were equipped with both flashing and non-flashing red lights. An anti-collision lighting system was found to reduce flight speeds of eiders and increase avoidance of an oil-production island near Prudhoe Bay, Alaska (R. H. Day, personal communication). Taken together, these results suggest that nocturnal studies should discriminate the effect of artificial lighting from the effect of the wind turbines themselves, otherwise confusion about the risks of collision may arise.

FLIGHT MORPHOLOGY AND BEHAVIOUR

We expect many bird species to avoid individual wind turbines by reacting at much closer distances than reported here (Langston & Pullan 2003). That common eiders largely avoid offshore wind parks (Guillemette & Larsen 2002; Desholm & Kalhert 2005; Pettersson 2005; this study) probably results from their intrinsic reluctance to approach human-made structures. Common eiders are characterized by short, pointed wings and high wing loadings (Guillemette & Ouellet 2005), with the consequence that flight is rapid but not very manoeuvrable (Rayner 1988). Common eiders also have the highest flight speed observed among birds using flapping flight (range 57–137 km h^{-1}, mean 84 km h^{-1}; Day *et al*. 2004). Tail winds increase flight (ground) speed of common eiders further (Day *et al*. 2004), which may reduce the time available for an avoidance response. These features are shared with other sea ducks and most diving birds (Rayner 1988), which are adapted to fly in unobstructed environments with plenty of space allowing for sustained high speed. We suggest that a wind park constitutes a conspicuous and new element in the environment of common eiders and that, given their high-speed flight, these birds have to adjust their flight well before reaching a turbine in order to avoid any risk of collision.

It is well known that most sea ducks fly low above the sea surface, and in this study most common eider flights were made within the vertical height range of the wind turbines (see the Results), with only 2% observed at an altitude equivalent to the rotor-swept area (> 20 m). Similarly, migrating eiders in Alaska flew at a mean height of 12 m (Day *et al*. 2004).

Common eider increase flight altitude to avoid a physical element of the landscape (e.g. a peninsula, ship or wind turbine; M. Guillemette, personal observation). Pettersson (2005) observed a higher flight altitude than in our study, in relation to large sized turbines, and found that 3–8% of common eider flocks were flying at an altitude similar to the rotor-swept area (30–100 m) whereas 0–6% were flying above them. Most of our observations of flight altitude were made during side and head winds, both of which decrease flight altitude in common eiders, whereas tail winds increase flight altitude (Day *et al*. 2004). Thus tail winds may increase the proportion of birds flying within the circle swept by the rotors. However, calculations of collision probabilities derived from our results indicated that the mortality rate was two orders of magnitude higher for the tower than for the rotor (M. Guillemette, unpublished data), a result stemming mostly from the fact that 98% of eiders were flying below the rotor.

LANDING FREQUENCY AND HABITAT LOSS

In a similar experiment conducted in winter 1996–97, Guillemette & Larsen (2002) found that eiders markedly decreased their landing and flying frequency close to a wind park and that the avoidance rate was similar on both sides of the wind park. However, decoy groups were absent within the wind park and it was not possible to discriminate the effects of the structures themselves from the action of the revolving rotors. In our study, flying birds were less likely to enter and land within a wind park (48–60% decrease in frequency) compared with the two outer-most groups of decoys. This observation supports the suggestion that eiders are reluctant to approach human-made structures. In addition, because the number of landing birds was considerably reduced within the wind park, this avoidance behaviour functionally results in habitat loss. Guillemette & Larsen (2002) discussed the intricate relationship between the presence/absence of disturbance and the probability of collision with turbines. They observed that, despite a lower landing frequency close to the wind park, the exploitation of food patches was not reduced. They hypothesized, for Tunø Knob, that eiders landing at great distances from the wind park may compensate by swimming towards a potential food patch close to or within the wind park. However, such behaviour may not apply to that of large-scale wind parks that cover entire shoals. Large wind parks typically consist of several rows of turbines extending over many square kilometres, and it seems less likely that swimming behaviour would be able to compensate for the reluctance to enter wind parks by flight. Clearly, our study needs to be replicated within larger wind parks.

Furthermore, our study showed that the main behavioural response of flying common eiders to the wind turbines was an adjustment of flight path. The wind turbines did not affect whether a flying bird reacted to conspecifics decoys, as the numbers of birds landing at different distances from the wind turbines were proportional to the numbers flying within a given distance zone (Fig. 2c).

EFFECTS OF TURBINE OPERATION

Our results strongly suggest that the revolving action of the wind turbine rotors and the associated noise form an insignificant source of disturbance for common eiders during morning flights. Indeed, the operational state of the wind turbines affected neither flight paths relative to the wind farm nor the willingness to land. In addition, our results are supported by two similar on–off experiments investigating the escape behaviour of swimming birds and habitat use (Guillemette & Larsen

2002). Taken together, these results suggest that flying, swimming, foraging and resting common eiders are insensitive to the movements and noise generated by the rotors. The physical structures themselves appear to be the cause of the observed avoidance behaviour (maintenance activities being absent during the study). In contrast, other studies have found apparent effects of the operative state of wind turbines on aspects of flight behaviour. Winkelman (1992a) and De Lucas, Jans & Ferrer (2004) observed a lower frequency of marked flight direction changes within 100 m of wind turbines when they were not operating and, for some species of daytime migrating birds, Winkelman (1992b) found a doubling of numbers flying through a wind farm when turbines were not operating. These studies were all based on observational studies when both wind turbines and birds may have been influenced by wind velocity and direction and, hence, direct comparisons with the present study are difficult.

Some waterfowl species have the potential to habituate to moving and noisy anthropogenic objects, provided they are regular and predictable in space and do not constitute any real threat (Conomy *et al*. 1998a, 1998b; Ward *et al*. 1999), characteristics that apply to wind turbine rotors. The fact that common eiders largely avoided flying close to and within the wind park (Fig. 2) during good visibility should lower the probability of collision. It also suggests that the apparent indifference of common eiders to the noise (mostly aerodynamic) associated with operating turbines would increase the risk of collision during conditions of low visibility. This is corroborated by the findings of Still *et al*. (1994) at a wind farm in Scotland: all nine common eiders collisions recorded during winter and spring of 1993 took place during poor weather conditions with low visibility (Winkelman 1992a).

SYNTHESIS AND APPLICATIONS

This study demonstrates that common eiders avoided flying close to and within the wind park to a large degree, and that this avoidance was caused not by the action of the wind turbine rotors but by the presence of the turbine structures themselves. This implies that habitat use within, and possibly around, wind parks may be markedly reduced. While the potential loss of feeding habitat for the small-scale Tunø Knob wind park may be of relatively minor importance if considered as an isolated case, when compared with the overall availability of shallow water feeding areas to wintering common eiders, the cumulative effect of multiple large-scale wind parks could be large. Further studies should seek to establish the extent of the 'exclusion zone' and the effect on the exploitation of available food resources within this zone. In order to assess the impacts of habitat loss at the population level, there is a pressing need for greater information on the feeding ecology of wintering sea ducks, and the extent to which winter food availability is a limiting factor. Until such information is available, we suggest caution in locating wind parks, avoiding areas with large concentrations of sea ducks and other species of marine birds.

The avoidance behaviour observed in our study implies that the risk of collision is negligible in good visibility conditions but potentially is high under conditions of poor visibility, for example during hours of darkness and extreme weather such as fog and snow. Further research is needed to examine collision risk during such conditions. Our study highlights the need to obtain information on flight frequencies, flight altitudes, population size and other risk factors throughout the year. Achieving this is complex because (i) different sensory abilities may be involved (visual vs. auditory); (ii) birds may reduce their vulnerability through modifications to their behaviour; and (iii) some responses may be weather dependent. Given the number of large-scale wind parks planned and the collision risk to birds, there is an urgent need to gather the necessary information before wind parks are constructed as part of an environmental assessment.

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