National Environmental Research Institute
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Annual status report 2003

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Data Sheet

Title:	Visual and radar observations of birds in relation to collision risk at the Horns Rev offshore wind farm
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Information Note

This information note summarises the framework for the three annual status reports for 2003, concerning bird studies in relation to the offshore wind farms at Nysted in the Baltic Sea and Horns Rev in the North Sea.

The three reports are:

Christensen, T. K., Hounisen, J. P., Clausager, I. & Petersen, I. K., 2004: Visual and radar observations of birds in relation to collision risk at the Horns Rev offshore wind farm. Annual status report 2003. - 48 pp.

Kahlert J., Petersen I. K., Fox A. D., Desholm M. & Clausager I. 2004: Investigations of birds during construction and operation of Nysted offshore wind farm at Rødsand. - Annual status report 2003. – 82 pp.

Petersen, I. K., Clausager, I. & Christensen, T. K., 2004. Bird numbers and distribution in the Horns Rev offshore wind farm. - Annual status report 2003. - 36 pp.

Bird studies are to be carried out at Nysted and Horns Rev during the period 1999-2006 under the permitting tems for wind farm construction at the two sites, granted by the Danish authorities. The bird studies are carried out before, during and after construction of both wind farms.

The installation of wind turbines was finished in autumn 2002 (Horns Rev) and summer 2003 (Nysted). Hence, the annual status reports for 2003 merely represent data from one year or less during the initial operational phase of the wind farms. Thus, natural variation between years, seasons, species and sites and the possible habituation effects during the operational phase could not be considered. Therefore, it must be emphasised that the tendencies, suggested by the results in all three annual status reports are to be considered as preliminary, and must await further compilation of data, before firm conclusions can be drawn with respect to impact on birds.

The final environmental impact assessment for the two wind farms is planned to be undertaken upon termination of the environmental monitoring programmes in 2006.

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Contents

Synopsis

The aim of the project is to assess the collision risk between birds and wind turbines at the Horns Rev wind farm. In 2003 the studies focused on describing bird movements in relation to the wind farm and to identify the species-specific behavioural responses towards the wind turbines shown by migrating and staging species. The Horns Rev area lies in a region known to be important for substantial waterbird migration as well as holding internationally important numbers of several wintering and staging waterbird species.

Theoretically, birds approaching the wind farm may:

- pass through the wind farm
- increase flying altitude and pass above the wind farm
- change direction and pass around the wind farm

Only birds passing through the wind farm risk collision with turbines, hence determining the proportions of all migrating birds adopting the above three alternatives is crucial to our assessment of collision risk. Having entered into the wind farm, the risk is assumed to be highest for birds flying in the altitude of the turbine rotors. Consequently, flight altitude is another critical factor for those species entering the wind farm in the assessment of collision risks.

The present study is restricted to the period after the construction of the wind farm. For practical reasons, data from the pre-construction period was not collected. Consequently, no base-line studies of bird movements in the area prior to establishment of the wind farm are available to which the present data can be compared.

All observations of birds were undertaken from the transformer station situated north of the northeasternmost turbine in the wind farm. Mapping of flight movements routes was undertaken using radar surveillance day and night. Visual observations were performed during the daytime along four transects, two located north and east of the wind farm, one along the eastern row of turbines and the fourth crossing diagonally through the wind farm in a southwesterly direction. Combined use of radar and visual observations during the daytime provided species-specific information on bird movements and orientations as well as data on flight altitude. Visual observations were performed in August 2002 and April-May and August-November 2003. Radar observations commenced in August 2003 and continued until November. Due to a temporary cessation of the study, it was not possible to collect data during February-March 2003, the period of peak occurrence of staging divers in the area.

Radar tracks of flying bird were entered into a GIS-database, from which subsets of data were selected to describe bird movements. In this report, radar observations were used to describe:

- The flight direction of migrating birds approaching the wind farm in order to assess the degree of avoidance towards the wind turbines
- The probability of birds flying into the wind farm from the outer edge to measure the overall response of passing birds to the presence of the wind farm
- In combination with visual observations, to describe the species-specific responses (flight direction and altitude) to the wind farm.

Bird movements generally followed a southwesterly orientation and the intensity was highest during night. Only a small percentage of bird tracks entered the wind farm (14-22%). The majority of tracks either changed their orientation and passed around the wind farm, most reacting 400 m from the wind farm (north side) or 1,000 m (east side), or disappeared from the radar screen. The disappearance of radar tracks is most likely the result of birds changing flight direction, resulting in a change in body orientation and hence reduced reflection area of the birds and thus lower detection probabilities by the radar. Loss of tracks may also reflect birds landing on the water. Whatever the precise nature of these disappearances, it is clear that loss of tracks on the radar screen reflects an avian behavioural response to the wind farm by approaching birds. Since most bird tracks disappeared c. 400 m from the outer turbines of the wind farm (north side) or 1,000 m (east side), these distances may represent the general extent to which flying birds avoid such structures.

In the area north of the wind farm, bird movements followed a general southwesterly orientation at distances greater than 400 m from the wind farm. The orientation did not differ between day and night, nor was it affected by different wind directions. Bird tracks within 400 m of the wind farm were predominantly of a southerly orientation and differed significantly from the general southwesterly orientation further away. This suggests that birds approaching the wind farm adjusted their flight direction and those that did pass through the wind farm did so along the open corridors between turbine rows, thereby further reducing the potential collision risk. Birds approaching the wind farm from the east in a southwesterly orientation started to adjust their flight to a more westerly direction within 1,000 m from the eastern border of the wind farm. Probably due to the fact that gulls and terns, which seem to be attracted by the wind farm, were almost exclusively recorded by the radar in the area east of the wind farm, a clear pattern of deflection was not found in this area.

Analyses showed that adjustment of the flight direction (in respect of the turbine rows) was more accurate during the day than at night, which may relate to a more precise recognition of individual turbines by the birds during the hours of daylight.

Dansk resume

Denne rapport omhandler undersøgelsesresultater af fuglelivet ved Horns Rev vindmøllepark med henblik på at tilvejebringe viden om kollisionsrisikoen mellem fugle og vindmøller. Horns Rev ligger i et område, der er kendt for at være af stor betydning for såvel trækkende som overvintrende og rastende vandfugle.

Formålet med denne undersøgelse har været at beskrive fuglebevægelser i relation til vindmølleparken samt at belyse, hvorledes de enkelte fuglearter adfærdsmæssigt reagerer på vindmøllerne under deres træk og rasten.

Flyvende fugle der nærmer sig vindmølleparken kan:

- passere gennem vindmølleparken
- forøge flyvehøjden og passere over vindmølleparken
- ændre den horisontale flyveretning og passere uden om vindmølleparken.

Da det er kun de fugle som passerer gennem vindmølleparken, der vil være udsat for at kollidere med vindmøllerne, er det af afgørende betydning at få belyst hvor stor en andel af de flyvende fugle, der passerer gennem mølleparken, og hvor store andele der henholdsvis flyver over eller uden om parken. For de fugle, der passerer gennem mølleparken, vil de som flyver i rotorhøjde være mest udsat for at kollidere med møllerne. Som en konsekvens heraf vil det også være af stor betydning at få tilvejebragt et bedre kendskab til i hvilke højder, fuglene flyver under deres passage gennem mølleparken.

Af praktiske årsager blev der ikke indsamlet data fra perioden før vindmølleparken blev etableret, derfor foreligger der ikke en base-line undersøgelse, som resultaterne fra denne undersøgelse kan sammenlignes med i vurdering af kollisionsrisikoen.

Alle observationer af fugle i denne undersøgelse er foretaget fra transformerstationen, der er placeret nord for den nordøstligste vindmølle i parken. Fuglenes flyveruter er kortlagt ved hjælp af radarovervågning døgnet igennem. Visuelle observationer er foretaget om dagen langs fire transekter, hvoraf de to er placeret nord og øst for mølleparken, én langs med den østligste række af vindmøller og den fjerde diagonalt gennem mølleparken i en sydvestlig retning. Kombineret brug af radarovervågning og visuelle observationer om dagen gav oplysning om artsspecifikke fuglebevægelser, flyveretninger og flyvehøjder. Radarundersøgelserne startede i august 2003 og fortsatte til november 2003. Visuelle observationer blev gennemført i august 2002 samt i april-maj og august-november 2003. På grund af en midlertidig indstilling af projektet blev der ikke indsamlet data i februar - marts 2003, en periode hvor antallet af rastende lommer normalt er størst.

De tilvejebragte radarspor af flyvende fugle er lagt ind i en GIS-database, hvorfra udvalgte datasæt er benyttet til beskrivelse af fuglebevægelser. I rapporten er radarobservationerne benyttet til at beskrive:

- Flyveretningen for fugle der nærmer sig vindmølleparken med henblik på at fastslå i hvilken grad de forsøger at undgå mølleparken
- Sandsynligheden for at fugle flyver ind i selve mølleparken med henblik på at opgøre den samlede reaktion af passerende fugle på vindmøllernes tilstedeværelse
- I kombination med visuelle observationer at belyse de artsspecifikke reaktioner (flyveretning og -højde) på vindmølleparken.

Generelt fulgte fuglebevægelserne en sydvestlig retning og intensiteten var størst om natten. Kun en mindre del (14-22 %) af radarsporene fortsatte ind i mølleparken. De øvrige radarspor ændrede enten retning og passerede uden om mølleparken (nord for vindmølleparken ændrede de fleste spor retning i en afstand af 400 m, og øst for i en afstand af 1.000 m) eller sporene forsvandt fra radarskærmen. Årsagen til at radarsporene forsvandt, skyldtes sandsynligvis at fuglene ændrede flyveretning, hvilket betød en ændring af kroppens orientering i forhold til radaren, hvilket gav en mindre reflektionsflade og dermed en mindre chance for at give et signal på radarskærmen. Tab af radarspor kunne også skyldes, at fuglene landede på vandet. Hvad den egentlige årsag til radarsporenes forsvinden end er, så er det sandsynligt, at det skyldes en adfærdsmæssig reaktion på vindmøllerne, når fuglene nærmer sig. Da de fleste radarspor forsvandt ca. 400 m fra de yderste vindmøller mod nord og ca. 1.000 m fra de yderste mod øst, så kan disse afstande generelt siges at være de afstande, hvor flyvende fugle begynder at reagere på vindmøllerne.

I området nord for vindmølleparken var fuglenes generelle flyveretning på afstande større end 400 m fra vindmølleparken sydvestlig. Der var ikke forskel i fuglenes orientering mellem dag og nat og under forskellige vindretninger. Fugle der kom tættere på vindmølleparken end 400 m fløj i en sydlig retning, hvilket afveg signifikant fra fuglenes orientering længere væk fra vindmølleparken. Dette resultat antyder, at fugle der nærmede sig vindmølleparken ændrede flyveretning så de fugle der fløj ind i vindmølleparken passerede parken igennem de åbne korridorer mellem rækkerne af vindmøller, og derved reduceredes den potentielle risiko for kollision med møllerne yderligere. Fugle der nærmede sig vindmølleparken fra øst ændrede flyveretning fra en sydvestlig til en vestlig retning på en afstand af 1.000 m fra vindmølleparken. Ændringen i flyveretningen var mindre markant øst for vindmølleparken end nord for vindmølleparken hvilket sandsynligvis skyldtes at måger og terner, som næsten udelukkende blev registreret med radar i dette område, viste en tiltrækning til vindmølleparken.

Yderligere analyser viste, at ændring i fuglenes flyveretning (i forhold til møllerækkerne), var mere nøjagtig om dagen end om natten, hvilket kan hænge sammen med at fuglene i dagslys mere præcist kan orientere sig i forhold til de enkelte vindmøller.

1 Introduction

1.1 Background

In February 1998, the Ministry of the Environment gave Elsam A/S and Eltra A.m.b.a. approval in principal to assess the feasibility of erecting a wind farm, capable of producing 160 MW of electric power, at Horns Rev, west of Blåvands Huk off the west coast of Jutland. The conditions imposed an environmental impact assessment (EIA) on the project which explicitly required that before-, during and after-construction comparisons of bird distributions be carried out to investigate and demonstrate any impacts resulting from the construction of the wind farm.

In order to assess the potential impacts from the offshore wind farm at Horns Rev on bird numbers and distribution, Elsam Engineering A/S (formerly Tech-wise A/S) contracted the National Environmental Research Institute (NERI), Department of Wildlife Ecology and Biodiversity (formerly Department of Coastal Zone Ecology), to take responsibility for these studies.

The southeastern part of the North Sea, including Horns Rev, constitutes major staging and wintering grounds for huge numbers of water- and seabirds (Tasker et al. 1987, Laursen & Frikke 1987, Laursen et al. 1997). In addition, Blåvands Huk, situated east of the wind farm area, acts as an important site for migrating waterbirds as well as for migratory terrestrial bird species, especially during autumn (Jacobsen in prep.).

According to the Ramsar Convention, an area is classified as being of international importance to a species if 1% of its flyway population is present regularly at some time in the annual cycle (Ramsar undated). Based on this 1%-criterion the area around Horns Rev has been identified as being of international importance to staging and wintering Red- and Black-throated Diver *Gavia stellata/arctica* and Red-necked Grebe *Podiceps grisegena* (Laursen et al. 1997). Of the species listed on the Danish Red-list, which includes breeding species that are uncommon or immediately threatened (Stoltze & Pihl 1998a), Little Gull *Larus minutus*, Guillemot *Uria aalge* and Razorbill *Alca torda* occur in considerable numbers at Horns Rev. Of breeding and non-breeding species that are potentially threatened, according to the Danish Yellow-list (Stoltze & Pihl 1998b), Red-throated Diver, Eider *Somateria mollissima*, Common Scoter *Melanitta nigra*, Guillemot and Razorbill occur in large numbers at Horns Rev.

The potential effects of the wind farm on birds are considered to fall under three main headings:

1. Risk of collision (mortality).
2. Disturbance effects (displacement, habitat loss).
3. Physical changes as a result of the construction (changes to the bottom fauna and provision of new structures for loafing).

This report deals exclusively with bird studies in relation to collision risk with wind turbines.

Due to the remoteness of the wind farm area and the harsh environment it was agreed not to carry out a base-line study providing data before erection of the wind turbines on the numbers and phenology of migratory birds at the wind farm site.

If collisions happen they will increase the mortality of bird populations. At the level of a flyway population, the sensitivity to additional mortality caused by collisions with wind turbines will depend on the population dynamics of the species. Long-lived species with a low reproduction rate such as many waterbirds, are likely to be more sensitive to small changes in mortality compared to passerines that suffer a higher annual mortality (in some species more than 50%) and have a correspondingly higher reproductive output (Noer et al. 1996, Morrison et al. 1998).

Direct observations of collisions between birds and wind turbines will always present logistical challenges, as collisions in all probabilities will occur at a very low frequency and will be extremely difficult to observe. For this reason, the approach taken throughout this investigation has been to quantify the probabilities that particular species will come in close proximity to turbines under a range of environmental conditions. Consider, for example, a migrating bird heading straight for a newly constructed wind farm. On seeing the structures, a flying bird may alter its flight trajectory to laterally avoid an unfamiliar visual stimulus and simply fly around the edge of the outermost turbines. It may, alternatively, gain height and fly over the top of the wing-sweep of the turbines and avoid their presence in that way. Finally, the bird may not respond at all and simply continue on a predetermined course through the wind farm. Even here, amongst those birds entering the wind farm, flight altitude and trajectory will greatly affect the collision risk. Birds flying below the turbine sweep height, or those flying between the turbine rows avoiding the vicinity of the turbines will be at no risk of collision.

Against this background, this investigation set out to measure species specific reactions to the newly constructed Horns Rev wind farm using a number of different methods. The objective was to establish probabilities for bird reactions to the wind farm, to determine the likelihoods for collision risk for each species under the range of conditions observed.

During the post-construction phase, this included observations of avoidance responses by flying birds to establish the proportions that deflect laterally when approaching the wind farm or climb to attain height to avoid it altitudinally. Such avoidance responses are likely to be highly species specific, for example mediated by the differential ability of species to manoeuvre, their sensitivity to the visual stimulus of large artificial constructions and interactions with weather factors. Furthermore, displacement from regular migration patterns will indirectly affect the collision risk, as the precise position of the local migration routes is a major determinant of the number of potential encounters. Initially, attempts to establish flight height for the most sensitive and critical species have also been started, to contribute to an accumulating database on species specific risks of collision given flight altitude probabilities under a range of weather conditions.

The report presents the results of observations of bird behaviour collected in 2003 in relation to the collision risk with wind turbines at the Horns Rev wind farm. Because data have only been compiled after the wind farm commenced operation, it has not been possible to make a comparison with bird behaviour or occurrence during pre-construction conditions in the area of the wind farm. Also, because this was the first year of such observations, they are provisional in nature, forming the basis for recommendations for improving data collection in future and filling gaps in existing knowledge.

1.2 The Horns Rev offshore wind farm

The wind farm area is located in the southeastern part of the Horns Rev, c. 14 km west-southwest of Blåvands Huk in the Danish part of the North Sea (Fig. 1). Geomorphologically, the Horns Rev formation is a terminal moraine ridge, consisting of relatively well sorted sediments of gravel and sand (Danish Hydraulic Institute 1999). The water depth within the wind farm area varies from 6.5 m to 13.5 m.

Construction activities at Horns Rev started in September 2001 and were finished in summer 2002.

The wind farm has a capacity of 160 MW and comprises 80 turbines. The height of each turbine tower is 70 m and the rotor diameter is 80 m resulting in a maximum height to the upper wing tip of 110 m. The minimum free height from sea level to the lower wing tip is 30 m. The distance between adjacent turbines and the turbine rows is 560 m giving an open space of 500 m between the turbines. The turbines are equipped with a

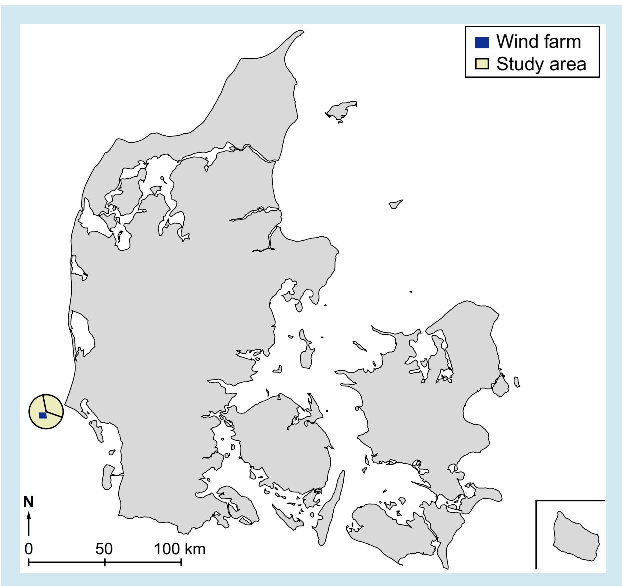

Figure 1. The study area, with indication of the Horns Rev wind farm position.

white navigation strobe light about 10 m above sea level for ship traffic and with a red strobe light at the top of the turbines for air traffic. The wind farm covers an area of c. 20 km².

A transformer station (dimensions 20 x 28 m) is situated on three support legs 10-23 m above sea level located 560 m north of the northeasternmost wind turbine.

Service and maintenance of the turbines are estimated to constitute 150 days of activity per year carried out partly by ship and partly by helicopter.

In 2003, the service and maintenance activities have been higher than expected. The activities have mainly concerned transportation of personnel between separate wind turbines by small ships.

1.3 Investigations of collision risk

Any predictive assessments of the collision risk to birds presented by the wind farm at Horns Rev are severely hampered because the general knowledge of bird species occurring at the Horns Rev wind farm area is very poor. Likewise, information about behavioural responses to offshore wind turbines of sea birds and terrestrial species is not available.

The wind turbines may impose a potential collision risk in relation to several types of bird movements:

- Annual migration of birds between breeding and wintering areas
- Daily flights of birds between roosting sites and foraging areas (including compensatory repositioning due to drift caused by current and wind. These movements usually occur at dawn)
- Birds flushed due to disturbance (e.g. as a result of turbine maintenance activities)
- Birds attracted to the wind farm area
- Active foraging flights.

When flying birds approach an offshore wind farm they may react in a number of ways, the frequency of which will affect the probability of collision.

These include:

1. Changing flight direction to fly round the wind farm or return
2. Increasing their flight altitude to fly above the wind farm
3. Decreasing their flight altitude to fly through the wind farm
4. Continuing to fly through the wind farm without changing direction and/or altitude
5. Continuing to fly through the wind farm and adjust their direction and/or altitude so they pass the turbines at a safe distance
5. Interrupt their flight and land on the water before adopting one of the above.

Flying birds completely avoiding the wind farm suffer no collision risk from the wind farm. Hence, the proportion of birds doing so represents an important measure of overall collision risk. Nevertheless, even amongst that proportion entering the wind farm, the collision risk will vary considerably dependent upon bird species, flock size, flight speed, flight direction, flight altitude, weather conditions, etc.

From the outset, it is expected that collisions may be very rare and widely separated in time and space, making direct measurement of collision rates difficult. Therefore the studies have been designed to focus upon critical species such as those occurring in internationally important numbers. Emphasis has been put upon the assessment of likely collision rates of birds based on observations of bird activity and behaviour in the vicinity of, and in response to, the wind turbines. The studies include a combination of both radar and visual observations (see 2.1 for detailed description).

This report presents the results of the investigations obtained in 2003 as well as in August 2002. The report describes:

1. General flight trajectories of migratory waterbirds and passerines during the autumn period
2. Lateral changes observed in the migration orientation of birds approaching the wind farm
3. Seasonal and diurnal occurrence and migration intensity of specific bird species
4. Migration altitude of individual species

5. Migration speed of individual species
5. Occurrence of birds that use the turbines as resting platforms.

The report also includes brief descriptions of the precise behaviour of individual bird species when approaching the wind farm and of variation of flock size of different species.

2 Methods

2.1 Methodological approach

The overall purpose of the bird studies in this project is to assess the collision risk of birds with wind turbines. Given the lack of knowledge on bird migration, local movements and behaviour of birds in the wind farm area the first part of the project focuses on providing basic information on:

1. Diurnal and nocturnal migration routes/corridors through the Horns Rev area
2. Intensity of bird migration
3. Local movements of birds within and around the planned wind farm in relation to various environmental conditions
4. The species involved.

2.1.1 Radar studies

To record bird/bird flock activity in the vicinity of the wind farm area and adjacent waters a ship-radar (Furuno FR 2125) was mounted on the transformer station (in October 2003 a Furuno FR 2110 was used). Each echo on the radar monitor (PPI) corresponded to a single bird or a flock in the study area, and in this way the spatial pattern of migration in this area of open sea could be described during both day and night. The distance from the transformer station to the periphery of the study area covered by the radar was at most six nautical miles (c. 11 km), but coverage was only possible over shorter ranges during some periods. The radar antenna was placed on the southwestern corner of the transformer station, and for health and safety reasons the radar beam was shut off between 350° and 110° to avoid uncontrolled reflection within the transformer station area where the observers were present (Fig. 2).

Bird echoes on the radar monitor appear as distinct dots moving at different velocities. Each migration trajectory was mapped by tracing the course of bird flocks from the radar monitor on to a transparency. At all times, as many tracks as possible were followed, normally comprising less than 10 tracks at the same time. Periods with no bird activity were noted. On all transparencies, the location of the transformer station (i.e. the site of the radar), the meteorological mast and wind turbines were defined. Subsequently, transparencies were digitised and entered into a GIS-database. To determine species involved for each of the radar tracks, visual observations were coordinated with radar observations during daytime by direct communication between the radar operator and the visual observer.

2.1.2 Visual observations

Visual observations were also carried out from the transformer station by two observers and took place during daylight hours along three transects during August 2002, located west (285°), east (90°) and south (175°) of the transformer station. From April 2003, observations made along a fourth transect diagonally crossing the wind farm in a southwesterly direction (225°) were included (see Fig. 2). A telescope (30x) was used, and data were recorded in 15-minute periods. All birds passing the transects were recorded including identification of species with details of flock size, direction, flight altitude (if possible) and behaviour.

2.1.3 Flight altitude

Flight altitude is a key factor in the assessments of the collision risk between birds and wind turbines. The probability of collision is most likely

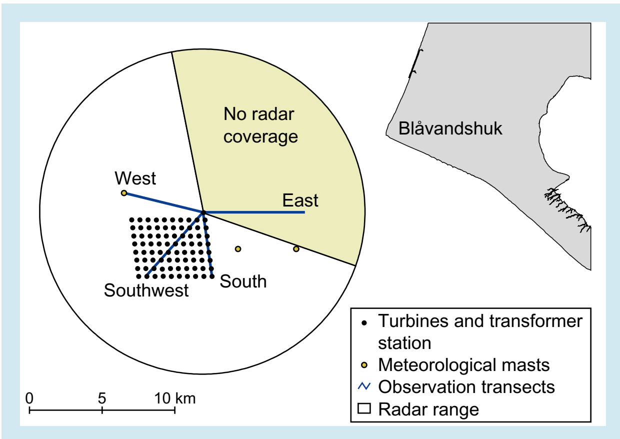

Figure 2. The study area with location of the four transects used in the visual observations and the areas covered/not covered by radar.

highest for birds flying in the area swept by the rotors (at Horns Rev 30-110 m above sea level). The present study is considered to be a pilot study, and the methods used will be evaluated and developed accordingly as a result of experience in 2003.

Flight altitudes of flocks identified to species from visual confirmation were calculated using simple trigonometry. The visual observer was able to measure the angle of the bird from the horizontal plane (using a levelling device attached to a telescope accurate to within 0.1°) at the transformer station. The height above sea level of the levelling device was precisely known and the distance to the birds could be calculated from the point at which the angle was measured, based on the radar track on the screen.

Within the ranges of distances over which angle measurements were performed (940-9,265 m; average distance = 3,219 m), the theoretical precision of the altitude measurements ranged between ± 1.74 m and ± 15.70 m increasing with distance (calculated as e.g., ± (tan 0.2° * distance - tan 0.1° * distance). For the average distance of 3,219 m the precision of measurements was ± 5.6 m.

2.1.4 Flight speed

Data on ground speed of migrating birds were obtained from radar tracks using a standard inbuilt software tool. Recording of ground speed of bird echoes was undertaken for two main reasons:

1. Flight speed of bird flocks that potentially cross the area swept by turbine rotors should be used in the assessment of the collision risk, as flight speed is highly likely to affect the risk of being hit by the rotors
2. Flight speed of known species should be used in the discrimination of nocturnally migrating species or species groups based on species specific flight speeds during the day assuming similar flight speeds by day and night.

2.2 Study periods

Radar and visual observations were performed during eight periods (Table 1). These periods coincide with the main migration period of a substantial number of the species of waterbirds and passerines, and during late autumn with the peak occurrence of staging seabirds.

Due to a temporary suspension of the bird programme during September 2002 - April 2003, the first test of radar observations of bird movements was not conducted until May 2003, leading to full implementation in August 2003. Radar tracking was not possible in September 2003 due to severe weather conditions. Strong winds produced too much sea-clutter (reflected from wave crests) on the radar to enable identification of bird echoes.

2.3 Hypotheses and data analyses

2.3.1 Relative migration intensity

A total of 1,088 bird tracks was obtained from the

Table 1. The period of effective observations (visual and radar) conducted from the transformer station at Horns Rev during 2002 and 2003.

Period	Visual observations	Radar observations
28-30 August 2002	22h 0min	
28 April - 1 May 2003	26h 15min	
12-15 May 2003	29h 30min	
6-8 August 2003	9h 30min	7h 53min
25-29 August 2003	14h 0min	32h 20min
22-25 September 2003	27h 30min	
13-16 October 2003	5h 30min	39h 20min
11-13 November 2003	7h 45min	32h 45min
Total	142h 0min	112h 18min

radar observations. Of these, 128 were of very short length (less than 1 km) and were not included in the subsequent analyses.

Bird migration intensity in the covered area was calculated as the total length (in metres) of all tracks occurring within squares of 500 x 500 m imposed on the total area. Within each grid, correction for differences was performed in covered periods, i.e., number of hours covered at different radar ranges and between the areas northwest and southeast to the radar. Differences in radar coverage were due to:

1. Experimentation with different radar settings over various distances
2. Reduced detectability of bird echoes in areas viewed into a headwind (as a result of reflection clutter signals generated from incoming waves).

The total periods covered by radar observations divided into different radar ranges and the areas southwest to north of the wind farm and east to south of the wind farm are listed in Appendix 1.

2.3.2 Lateral changes in migration routes

In previous studies, lateral avoidance has been considered the most frequent bird response to established wind farms (Winkelman 1992). An alternative hypothesis would be that birds are attracted for example by illumination of wind turbines (Lensink et al. 1999), a phenomenon that only relates to nocturnal migrants. It is also possible that gulls and Cormorants, for example, will use the static turbine superstructure for resting during both day and night, resulting in relatively high numbers of radar tracks moving into the wind farm.

Main hypothesis: migratory birds show a lateral avoidance response to the wind farm. Based on this, the following predictions are made:

1) A gradual and systematic deflection of the migration route will occur involving significant changes in flight direction close to the wind farm.
2) The change in flight direction will occur closer to the wind farm at night and during periods of poor visibility than during daytime with good visual conditions.

Alternative hypothesis: migratory birds show a lateral attraction response to the wind farm. Based on this the following prediction is made:

3) A gradual and systematic deflection towards the wind farm will occur with significant changes in flight direction close to the wind farm area.

Methods: In order to assess lateral changes in the generally southward-oriented migration during autumn, radar tracks of migrating birds were collected. The analyses were carried out for birds approaching the wind farm from the north and from the east.

The area north of the wind farm was divided into 15 transects parallel to the most northern row of turbines at positions of 50, 100, 200, 300, 400, 500, 1,000, 1,500, 2,000, 2,500, 3,000, 4,000, 5,000, 6,000 and 7,000 m from the turbines. The transects were established parallel to, and of the same length as the turbine rows (Fig. 3).

The area east of the wind farm was likewise divided into 15 transects parallel to the most eastern row of turbines at positions of 50, 100, 150, 200, 250, 300, 400, 500, 1,000, 1,500, 2,000, 2,500, 3,000, 3,500 and 4,000 m from the turbines. Due to the blind angle of the radar, the covered area did only reach out to four kilometres east of the wind farm. The transects had the same orientation and length as the turbine rows (see Fig. 3).

The unequal intervals between the transects were adopted as a provisional solution, aiming in the

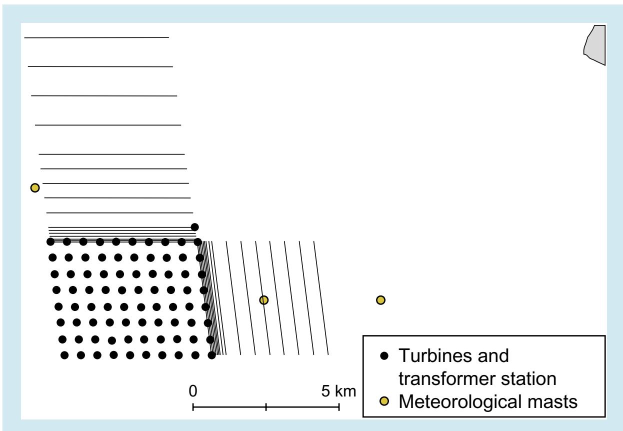

Figure 3. Location of transects north and east of the wind farm used in the analyses of lateral changes in migration orientation of birds during the autumn 2003. The locations of the three meteorological masts are also shown (yellow spots).

first instance at detecting all the possible changes in migration routes at increasing distance from the wind farm.

Tracks that did not pass at least two adjacent transects and tracks that moved northwards were excluded from the analyses. Hence, of the 960 tracks recorded during autumn 2003, 357 and 271, respectively, were selected for analyses of lateral changes in migration routes to the north and to the east of the wind farm.

For each interval between two adjacent transects the migration course were calculated for each track that intersected these two adjacent transects. For each transect interval the mean migration course was subsequently calculated from all considered tracks. Hence, long tracks crossing several transects contributed to the analyses with several track segments from which orientation was calculated, whereas short tracks crossing two or three transects contributed with only one or two track segments, respectively.

Mapping of migration routes gives the opportunity to test potential changes in the mean flight direction at different distances from the wind farm area, and to test whether a systematic change in migration route has occurred. If data from all sectors are normally distributed and show equal variance, the differences in the mean course at a specific distance can be tested using a t-test. However, if birds show lateral changes in the distributions of migration courses with respect to distance to the wind turbines, e.g. a deflection of individuals both to the west and east in birds that approach the wind farm from the north, this will result in a bimodal distribution close to the wind farm, but a unimodal distribution further away where the deflection has not yet begun. Such a tendency could be detected by testing for an increase in the variance of the angle measure with decreasing distance to the wind farm (Kahlert et al. in prep). Alternatively tracks will show a unimodal deflection to one side of the wind farm, but the angle of orientation will show a significant change.

Easterly and westerly winds can displace south-flying flocks to the west and east, respectively. Visibility and time of day (day and night) may also affect the orientation of migration routes. The effects of wind direction, time of day, distance to the wind farm on the orientation of migration were tested using ANOVA (SAS 1999) (except on 13 November 2003, see section 2.4). Analyses of the effect of visibility on orientation of migration at different distances from the wind farm area have not been carried out as no data on local visibility could be obtained for the Horns Rev area specifically.

Tracks of local movements by waterbirds could not always be distinguished from migrating birds and may cause some slight bias in defining overall migration patterns. However, most tracks of such local movements recognised on the radar were shorter than 1,000 m and these were omitted from the analyses.

Migration of terrestrial bird species could not be followed by radar with the same consistency as waterbirds due to the smaller size of passerines, which dominate the autumn migration from land areas (Christensen & Grell 1989). For this reason, it is considered that very few of the recorded bird tracks represent those of passerines and other terrestrial bird species.

During the day the degree of deflection of bird migration was also studied by direct visual observations. These observations included both visual transect counts and opportunistic observations. For all species, except gulls and terns, the behavioural responses to the wind farm were systematically noted, to provide a series of case stories relating to specific species.

No data could be obtained on bird flocks approaching the wind farm from the south as this was beyond the maximum range of both radar and telescope.

2.3.3 Probability of birds passing into the wind farm area

The main hypothesis is that migratory birds will show a lateral avoidance response to the wind farm. However, it is further hypothesised that the probability of passing into the wind farm area may depend on factors such as wind direction, time of day (day/night) and direction of approach.

For each area, the analyses included only tracks that specifically passed two transect-lines 2,000 m and 1,500 m away from the northernmost and easternmost row of wind turbines (the transects used in analyses of lateral changes) which headed towards the wind farm and that were longer than 2,000 m. Of the 960 migration tracks recorded during autumn 2003 89 and 96 were extracted for analyses for the areas north and east of the wind farm respectively.

In each area, all tracks were followed to see whether they entered the wind farm area or not, and the proportion of flocks that actually did so was calculated. Likewise the proportions of tracks that turned west or south before entering the wind farm and the proportions of tracks that disappeared before entering the wind farm were calculated.

In order to analyse the migration pattern in detail, logistic regression models (SAS 1999) were used to describe the probability of passing into the wind farm area incorporating the following factors:

1) Flight direction between the 2,000 m and 1,500 m transects.
2) Time of day (day and night).
3) Wind (westerly and easterly).

2.3.4 Species composition, numbers and flock size

The results obtained from the daytime telescope observations enabled a species specific description of the abundance and phenology. The observations made an important contribution to the assessment of the potential impact and its consequence at a species level. The data presented include a description of the seasonal and diurnal occurrence, expressed as the number of birds observed per hour of observation and the mean number of birds per 15-minute period (migration intensity) during the spring and autumn periods on the four transects (see Fig. 2). Diurnal patterns were defined as 'morning', 'daytime' or 'evening', where 'morning' represents the first two hours after sunrise, 'evening' the last two hours before sunset, and 'daytime' the rest of the day. As the species specific distributions of migration intensity and flock sizes differed markedly from normal distributions, log-transformation of data was undertaken when calculating the mean migration intensity, mean flock size and the respective 95% confidence limits.

2.4 Weather data

Weather conditions were incorporated into the analyses of effects of the wind farm on migration routes to increase confidence of the conclusions. Elsam collected data on wind force and direction (at 60 m a.s.l.) every 10 minutes at a weather station at the wind farm site. Weather data from 13 November were not available, thus, analyses including weather data did not include records of birds made on this date. No visibility data were compiled at the wind farm and are therefore not included in the present analyses. Since visibility is a very local phenomenon, data from the nearest meteorological station at Hvide Sande (> 55 km away) were not considered reliable in the analyses of potential effects on bird migration at Horns Rev.

A summary of daily means of wind direction and wind speed on dates with observations at Horns Rev is given in Appendix 2.

2.5 Quality control

The present report is subject to the following quality control:

1. Internal scientific review by a senior researcher
2. Internal editorial and linguistic revision
3. Internal proof-reading including spell check
4. Layout followed by proof-reading
5. Approval by project managers.

3 Results

3.1 Bird movements recorded by radar

Radar tracks of migrating waterbirds were superimposed on a grid-based system to present relative densities, expressed as the sum of metres of track lengths within each grid cell (Fig. 4) and as original tracks (Fig. 5). Although the detectability of bird tracks by radar declines with increasing distance, the highest concentration of migratory bird activity occurred north and northwest of the wind farm. The migration intensity east and southeast of the wind farm was highest close to the wind farm. In both areas the mean orientation of bird migration was southwest. With the present number of tracks, no specific migration corridors could be identified, although it seems that most migration takes place north of the wind farm. However, the general southwesterly orientation of the migration recorded and the known southward movements of migratory bird species along the coast north of Blåvands Huk suggest that the recorded bird movements at Horns Rev reflect a general continuation of the southwards migration along the coast.

During autumn 2003, a total of 793 tracks were recorded as southbound migration and 167 tracks as northbound migration (see Fig 5). A substantial number of northbound tracks were located east of the wind farm, whereas southbound tracks were more evenly distributed north and east of the wind farm.

The intensity of migration showed a marked diurnal variation based on tracks recorded before sunrise and after sunset and between sunrise and sunset during all study periods in 2003 (Fig. 6). Migration intensity was markedly greater late at night than during the daytime and early night. Southward migration dominated during nighttime, whereas movements during the daytime were more evenly distributed between southward and northward directions.

Species identification was obtained for 154 tracks of 18 different species. Most records of gulls and terns (Fig. 7), with only small numbers of other species. Tracks of gulls and terns were almost exclusively recorded east of the wind farm making local movements to and from the wind farm

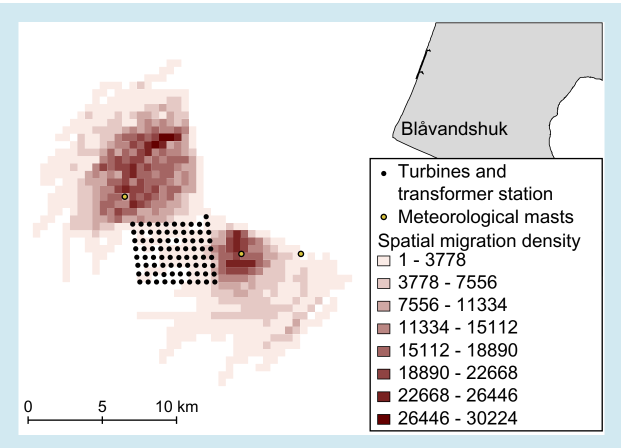

Figure 4. Spatial density of 960 birds/bird flocks migrating at Horns Rev during autumn 2003 recorded by radar, expressed at total metres of radar tracks per 500 x 500 m grid square.

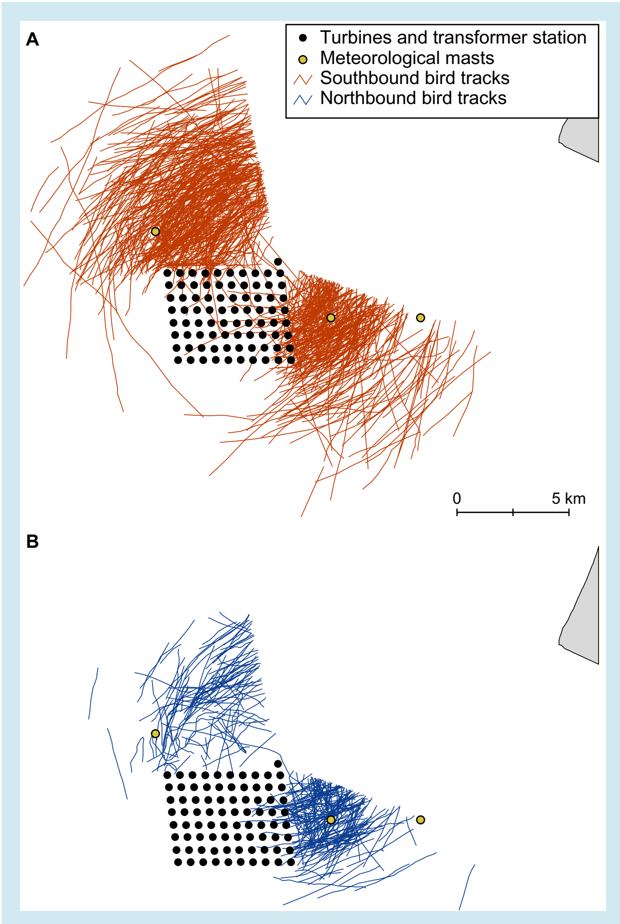

Figure 5. Radar registration of 793 tracks of birds/bird flocks migrating southwards (A) and northwards (B) at Horns Rev during autumn 2003.

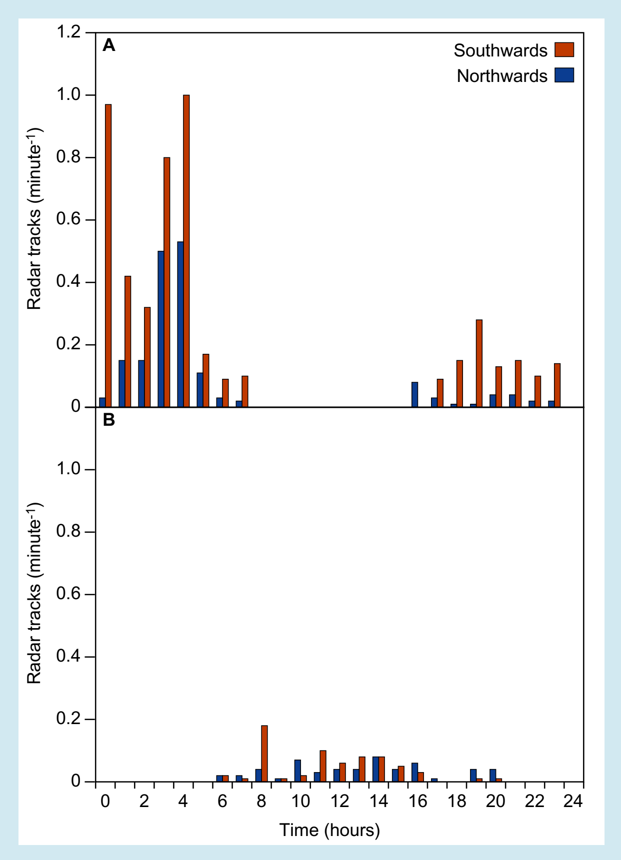

Figure 6. The number of tracks of birds flying north and south per minute recorded by radar during night-time (A) and daytime (B) during the autumn 2003 (all 1,088 tracks included). Note that the seasonal variation in the timing of sunrise and sunset results in overlaps in time between day and night.

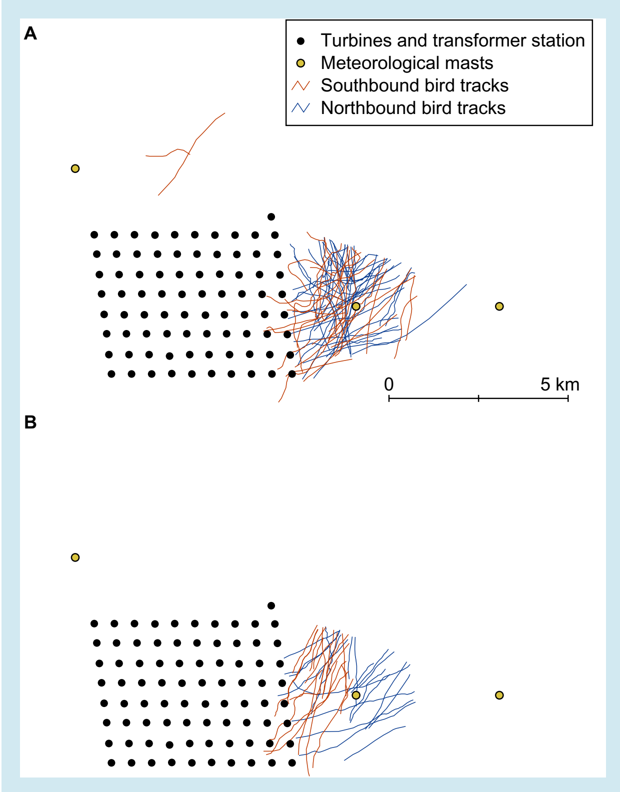

Figure 7. Radar registration of 72 gulls (A) and 38 terns (B) migrating southwards and northwards at Horns Rev during autumn 2003.

area. Marked movements out of the eastern gate of the wind farm towards the northeast were obvious on some days just after sunset. A few of these were visually identified as terns and gulls and thus probably represented night-time roost movements to sheltered areas close to land. A more detailed description of identified species will be given below.

3.1.1 Lateral changes in migration routes

Radar observations of bird tracks

The selected tracks of migrating waterbirds moving in a southerly direction towards the northern border of the wind farm area showed a mean orientation of the migratory flocks which ranged between 185º-232º (Fig. 8). Migration orientation changed significantly with distance to the wind farm from a southwesterly direction to a southerly direction close to the wind farm (ANOVA: $F_{42,509} = 4.19$, $P < 0.0001$, $N = 552$ track segments).

The most dramatic change was the statistically significant shift in orientation at 400 m from the wind farm (Fig. 8).

To exploit the effect of distance on the orientation of bird migration, separate analyses were performed on track segments recorded at distances of more than 400 m from the wind farm and on track segments recorded less than 400 m

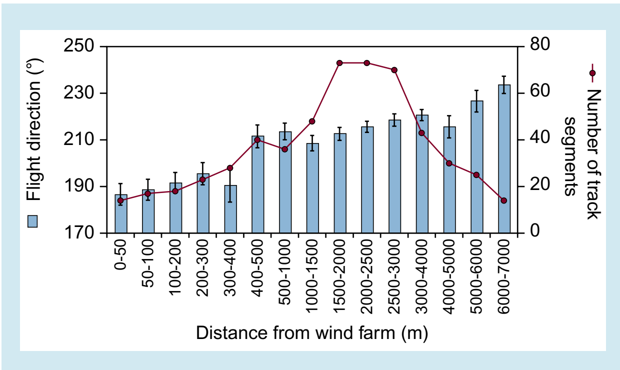

Figure 8. Mean orientation of tracks of migrating birds recorded north of the wind farm in relation to distance to the wind farm and the number of tracks recorded at different distance intervals. The north-south orientation of turbine rows is c. 175º.

from the wind farm. At distances of more than 400 m, the mean orientation of migration was 214° ± 1.1 SE and did not differ between day and night nor between periods of easterly and westerly winds (ANOVA: $F_{23,389} = 1.07$, $P = 0.372$, $N = 413$ track segments). At distances less than 400 m from the wind farm the orientation of migration averaged 189° ± 2.6 SE, but were significantly affected by both time of day and by wind direction (ANOVA: $F_{14,85} = 4.17$, $P < 0.0001$, $N = 100$ track segments). During the day, the mean orientation was significantly more southerly (177° ± 4.9 SE, N = 38) than at night (195° ± 2.6 SE, N = 62) (t-test: t = 3.44, df = 58, P < 0.01). During easterly winds, the mean orientation tended to be more westerly (191° ± 2.3 SE, N = 93) and more easterly (168° ± 21.5 SE, N = 6) during westerly winds, but the difference was not significant (t-test: t = 1.03, df = 6, P = 0.341).

There was a substantial decrease in the number of tracks with decreasing distance to the wind farm (Fig. 8). Thus few birds/bird flocks actually entered the wind farm area. The marked reduction in track numbers close to the wind farm partly reflects a lateral deflection in tracks moving directly west at some point before entering the wind farm, but also the fact that many echoes, for unknown reasons, disappeared on the screen (see below). Deflection of tracks to the east of the wind farm was not observed.

The selected tracks of migrating waterbirds moving in a southerly direction towards the eastern border of the wind farm area showed a mean orientation of the migratory flocks ranging between 233º-256º (Fig. 9). A multi-factorial three-way analysis (3-way ANOVA) showed significant

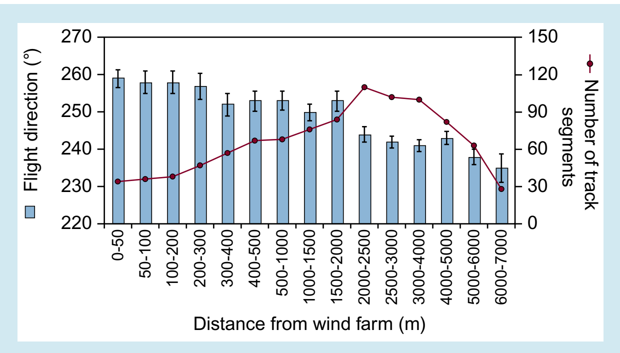

Figure 9. Mean orientation of tracks of migrating birds recorded east of the wind farm in relation to distance to the wind farm and the number of track segments recorded at different distance intervals. The east-west orientation of turbine rows is 270º.

change in migration orientation with distance to the wind farm, from a southwesterly direction to a more westerly direction closer to the wind farm (ANOVA: $F_{45,946} = 4.09$, $P < 0.0001$, $N = 992$ track segments). Migration orientation was also significantly affected by wind direction.

The effect of distance on the orientation of bird migration disappeared when analysing the data separately for distances of more and less than 1,000 m from the wind farm. In separate analyses, wind direction was the only single factor that affected the orientation of migration (more than 1,000 m from the wind farm: F = 21.27, df = 1, P < 0.0001, N = 485 track segments; closer than 1,000 m from the wind farm: F = 14.63, df = 1, P < 0.0001, N = 507 track segments), although there was a significant interaction between time of day (day/night) and wind direction on migration orientation in birds close to the wind farm (F = 12.01, df = 1, P < 0.001, N = 485 track segments).

As was the case north of the wind farm, the number of tracks declined with decreasing distance to the wind farm. Thus, at the eastern row of wind turbines, few birds/bird flocks actually entered the wind farm, and those birds/bird flocks that did so entered the wind farm heading west, almost parallel with the turbine rows. As for the area north of the wind farm, a reduction in track numbers with decreasing distance to the wind farm was found. No deflection of tracks to the north was observed.

3.1.2 Probability of birds passing into wind farm area

During autumn 2003, the overall proportion of birds entering the wind farm area was 13.9% for flocks of southbound waterbird migrating north of the wind farm and 21.9% for flocks of southbound waterbird migrating east of the wind farm. In order to describe the probability of bird flocks passing into the wind farm area in further detail, logistic regression models for different wind situations (easterly (0°-179°) and westerly (180°-360°)) and for day and night were computed incorporating direction of migration measured as the mean orientation between track-points located 1,500 m and 2,000 m from the wind farm.

The logistic regression models did not show any significant effects on the probability of entering the wind farm from the factors included. Thus, there was no significant difference in the probability of entering the wind farm during day and night and under different wind conditions.

Of the 86 tracks recorded north of the wind farm and included in the analyses, a total of 12 tracks (13.9%) entered the wind farm, while 32 (37.2%) deflected westwards north of the wind farm. The remaining 42 tracks (48.8%) were unaccounted for. Of the 96 tracks recorded east of the wind farm and included in the analyses, a total of 21 (21.9%) tracks entered the wind farm, while 22 (22.9%) deflected southwards east of the wind farm, and 53 tracks (55.2%) were unaccounted for.

As mentioned above, tracks that disappeared before entering the wind farm could be birds that cease migration to sit on the water or represent birds changing flight course with the result of providing less cross-sectional area to reflect the radar signal. Until more data can be collected, it is not possible to provide a full explanation for these disappearances. However, whatever the precise course, these disappearances reflect a potential reaction towards the wind farm. The cumulative percentage of tracks that disappear (corrected for differences in distance intervals) with distance to the wind farm is shown in Fig. 10. In the area north of the wind farm, the greatest proportion of bird tracks disappeared between 200-300 m and 300-400 m, suggesting that most birds react to the wind farm at this distance. In the area east of the wind farm, bird tracks disappeared increasingly towards the edge of the wind farm, although the most marked disappearance (40%) occurred close to wind farm between 0-100 m and 100-200 m. Although this result suggests that birds reacted differently to the wind farm depending on whether they are approaching the wind farm from north or east, it should be noted that the presence of gulls and terns, that showed no marked reactions to wind turbines, were almost exclusively recorded on the east side of the wind farm, close to wind turbines.

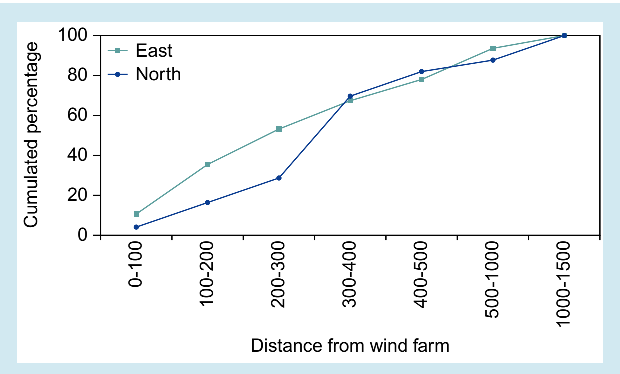

Figure 10. Cumulative percentage of the number of bird tracks that approached the wind farm from the north and east, respectively, but 'disappeared' from the radar for unknown reasons before entering or passing around the wind farm.

3.1.3 Avian behavioural reactions to the wind farm - case stories

It has previously been highlighted that the risk of collision between birds and wind turbines mainly concerns birds species that will occur at critical altitudes (i.e. at rotor heights) either when foraging or when migrating. Likewise, species occurring in substantial numbers through specific periods of the annual cycle may be at risk. At Horns Rev divers, Gannet, skuas, gulls and terns have been listed as species that may fly regularly at critical altitudes, and Common Scoter as a species that occurs in substantial numbers (Noer et al. 2000, Christensen et al. 2001, 2002, 2003). Consequently focus was placed on documenting avoidance reactions of these species.

A brief description of reactions of bird species approaching the wind farm made by visual observation is given below. The observations presented here were made opportunistically, together with some gathered during transect counts.

Divers Gavia spp.

Of the 70 divers recorded during transect observations 13 were recorded approaching the wind farm from the north crossing transect West. No divers were observed to enter the wind farm area, and all deflected westwards passing the edge of the wind farm before turning south again. One observation of two divers flying east between the wind farm and transformer station was made. Movements of divers were observed on all sides of the wind farm.

Grebes Podiceps spp.

On 14 October 2003, three Red-necked Grebes were observed entering the wind farm from the north. Between the first and second row, the birds showed signs of panic and spread out, before they gathered again and continued at sea level southwards.

Gannet Sula bassanus

Of 243 Gannets recorded during transect observations, 28 were recorded approaching the wind farm from the north crossing transect West. None of these were observed to enter the wind farm area, and all deflected westwards passing the wind farm before turning south again. Movements of Gannets were observed on all sides of the wind farm.

Cormorant Phalacrocorax carbo

Six flocks of Cormorants were observed approaching the wind farm, four of which were recorded by radar (Fig. 11). One flock of six birds was observed flying above the turbines and one flock of 40 birds entered the wind farm at rotor height and continued through the wind farm. These flocks did not show any marked changes in behaviour when entering the wind farm. Two flocks (6 and 13 birds) showed a marked reaction at a distance of 200-300 m north of the wind farm: the birds reduced speed and stalled, turned in small circles, scattered from a line formation before lining up again, ultimately entering the wind farm in a loose line-formation. In these flocks, some birds were seen making 'panic' descents prior to entering the wind farm.

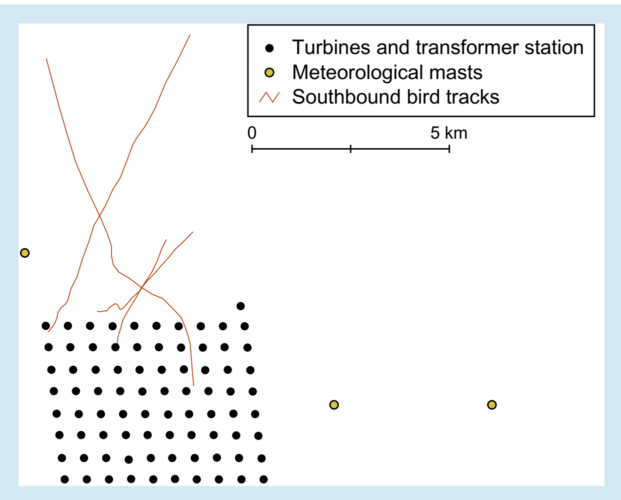

Figure 11. Radar tracks of four flocks of Cormorants migrating southwards at Horns Rev during autumn 2003.

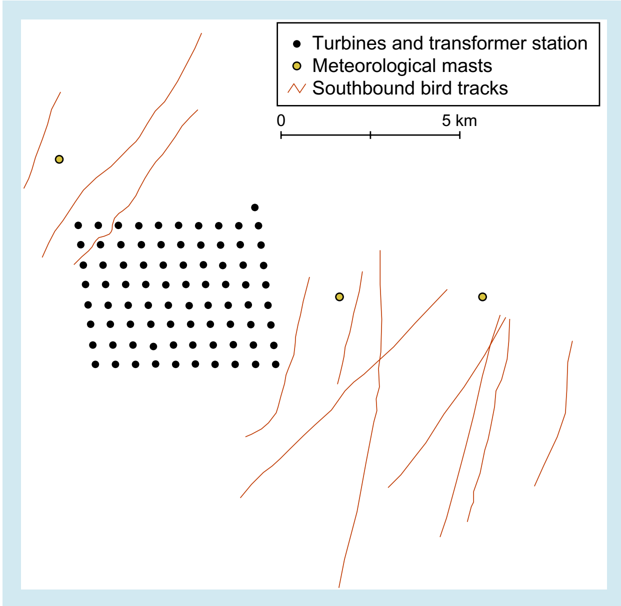

Figure 12. Radar tracks of 11 flocks of geese migrating southwards at Horns Rev during autumn 2003.

Geese Anser sp.

Of a total of 11 flocks of geese, one flock of 53 individuals was observed entering the wind farm area from the north (Fig. 12). This flock constantly increased flight altitude from before entering the wind farm and when flying within the wind farm, ultimately flying in rotor height. Within the wind farm, the birds showed less stability in flight resulting in a disrupted flock structure.

Common Scoter Melanitta nigra

Of 293 Common Scoters recorded during transect observations 28 were recorded approaching the wind farm from the north crossing transect West. None of these birds were observed to enter the wind farm area. Deflection was recorded both westwards skirting the wind farm and eastwards passing north of the transformer station. A total of 13 flocks of Common Scoter was recorded by radar, all outside the wind farm (Fig. 13).

On several occasions, large flocks of Common Scoters resting at the reef north and northwest of the wind farm were flushed by boat traffic, and approached the wind farm in these situations. Many of these flocks moved towards the wind farm several times before either passing west or east around the wind farm, making turns at distances between 300 m and 1,000 m from the tur-

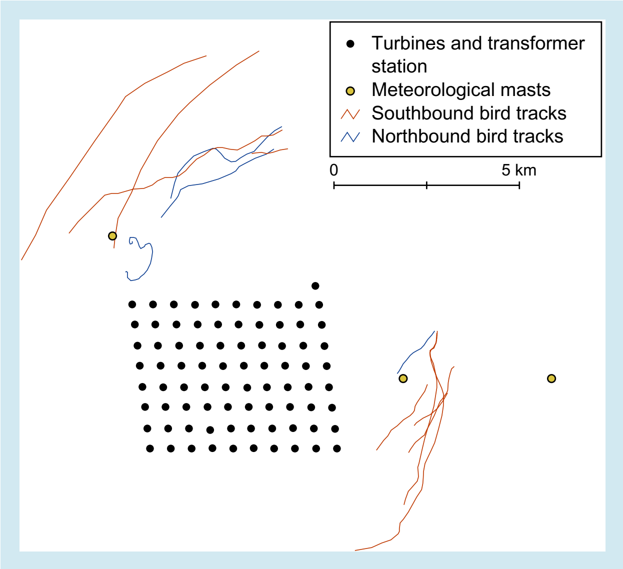

Figure 13. Radar tracks of 13 flocks of Common Scoters migrating southwards and northwards at Horns Rev during autumn 2003.

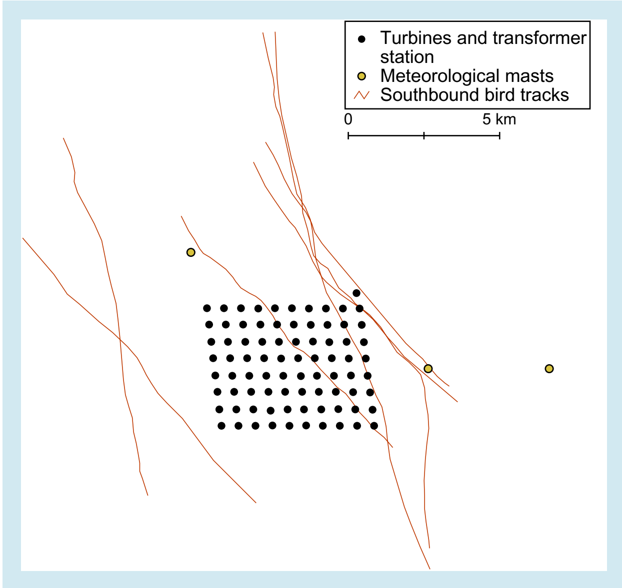

Figure 14. Radar tracks of seven flocks of Wood Pigeons migrating southwards at Horns Rev during autumn 2003.

bines. Movements of Common Scoter were observed on all sides of the wind farm.

Gulls and Terns Larus, Rissa, Sterna spp.

Several gull and tern species were very frequently observed entering the wind farm. Most birds were flying below rotor altitude, but Herring Gulls and Great Black-backed Gulls were observed passing turbine rows at rotor height. Only on one occasion was a panic reaction observed; a Great Black-backed Gull made a rapid about-turn just before entering the wind farm. Sandwich Terns did not show any reaction towards wind turbines when entering the wind farm. Common/Arctic Terns were, however, often seen returning out of the wind farm after they had passed 100-200 m beyond the first row of turbines.

Arctic Skua Stercorarius parasiticus

Of the 27 Arctic Skuas recorded entering the wind farm none showed reactions towards the wind turbines. Within the wind farm, skuas were observed chasing terns at various altitudes on several occasions.

Shorebirds

Individuals of four species, 11 Golden Plovers *Pluvialis apricaria*, 4 Curlews *Numenius arquata*, 1 Whimbrel *Numenius phaeopus* and 15 Oystercatchers *Haematopus ostralegus* were observed passing the wind farm area. Golden Plovers and Oystercatchers passed above the turbines, while one Whimbrel entered the wind farm at the height of the rotors. The one flock of Curlews stalled just before the wind farm and increased altitude before passing above the wind farm, markedly increasing wing beat frequency.

Terrestrial birds

Wood Pigeons and a flock of unidentified thrushes were observed passing the wind farm. All flocks of Wood Pigeons (Fig. 14) passed above turbine height. One flock of Wood Pigeons was observed to increase flight altitude when approaching the wind farm, and passed c. 300 m above the turbines. One large flock (300) of thrushes split into two groups close (<500 m) to the wind farm. The first half passed into the wind farm, whereas the other half made some turns and increased altitude before passing above the turbines.

3.2 Bird movements recorded by visual observations

During a total of 142 hours of observations on the four transects East, West, South and Southwest (see Fig. 2) a total of 47,534 individual birds was recorded. Complete lists of species and numbers recorded on separate dates on the four transects are given in Appendix 3-6).

In order to describe the occurrence of birds within and around the wind farm, the following section describes the seasonal and diurnal occurrence of the most abundant species and species groups, as well as species of special interest. The intensity of migration across the four transects is compared to assess species specific movements around the wind farm, into and out of the wind farm and within the wind farm.

Divers

A total of 70 divers was recorded during the transect counts. Most birds were recorded in May (22.8%) and during September-November (72.9%) with highest migration intensity during the morning hours in both spring and autumn (Fig. 15). Average flock size was 1.39 birds (95% c.l.: 1.01 - 1.9) in spring and 1.22 birds (95% c.l.: 1.1 – 1.35) in autumn, ranging from 1 to 3 individuals per flock.

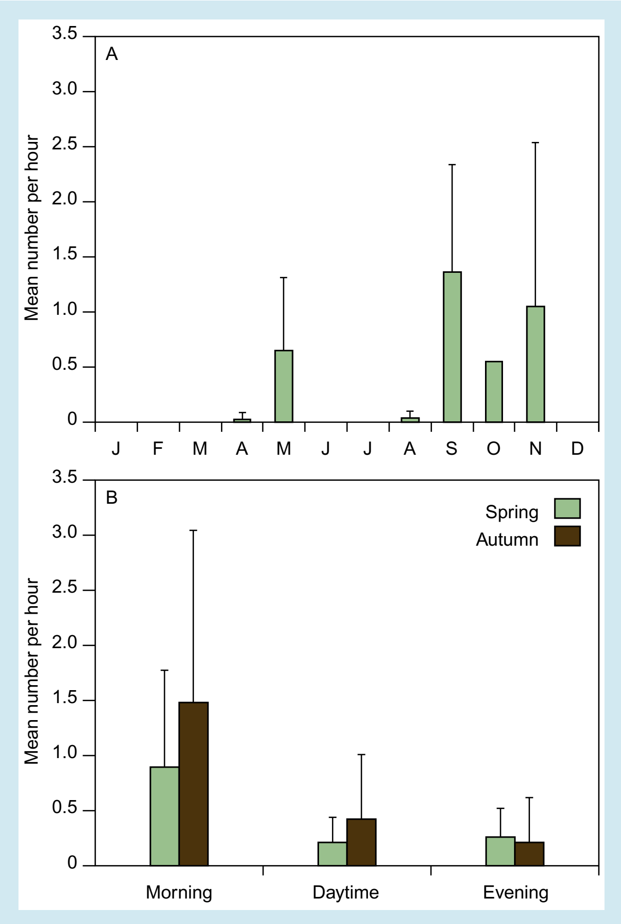

Figure 15. The number of divers recorded per hour of observation (± standard deviation) during A) April-May and August-November in 2002 and 2003, and B) morning, daytime and evening hours. 'Morning' includes observations made the first 2 hours from sunrise, 'Evening' includes observations the last 2 hours before sunset, and 'Daytime' includes the period in between.

No divers were recorded flying within the wind farm. Divers were only recorded on transect West and East with most divers (56) observed migrating east of the wind farm (Fig. 16). In spring 58.8% of the birds were migrating north while in autumn 82.0% were migrating south.

One diver was recorded foraging at the edge of the wind farm, and several were observed foraging at distances of 100-800 m from nearest wind turbine.

Grebes

A total of six Red-necked Grebes was recorded in October. All birds were recorded migrating north crossing transect East. Two unidentified grebes recorded migrating northeast of the wind farm in October, were probably also Red-necked Grebes.

Fulmar Fulmarus glacialis

A total of three Fulmars was recorded during transect counts in August and September. All birds were migrating north crossing transect East.

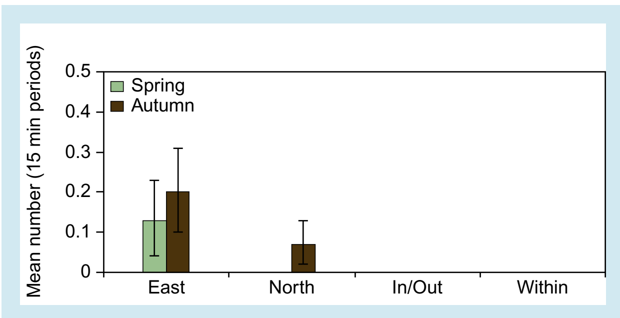

Figure 16. Migration intensity of divers (± 95% confidence limits) recorded by visual observation on the four transects placed east of the wind farm (transect East) north of the wind farm (transect West), along the eastern row of turbines (transect South) and within the wind farm (transect Southwest) at Horns Rev during spring and autumn 2002 and 2003.

One bird moving south towards the wind farm turned west around the wind farm.

Gannet

A total of 243 Gannets was recorded during the transect counts. Gannets were recorded during April and May (69.5%) and during August-September (30.5%). In both spring and autumn the migration intensity was highest during the morning hours (Fig. 17). Average flock size was 1.16 birds (95% c.l.: 1.09-1.22) in spring and 1.13 birds (95% c.l.: 1.08-1.18) in autumn, ranging from 1 to 7 individuals per flock.

Most Gannets (189) were recorded east of the wind farm (Fig. 18). Two individuals were observed within the wind farm. One of these was

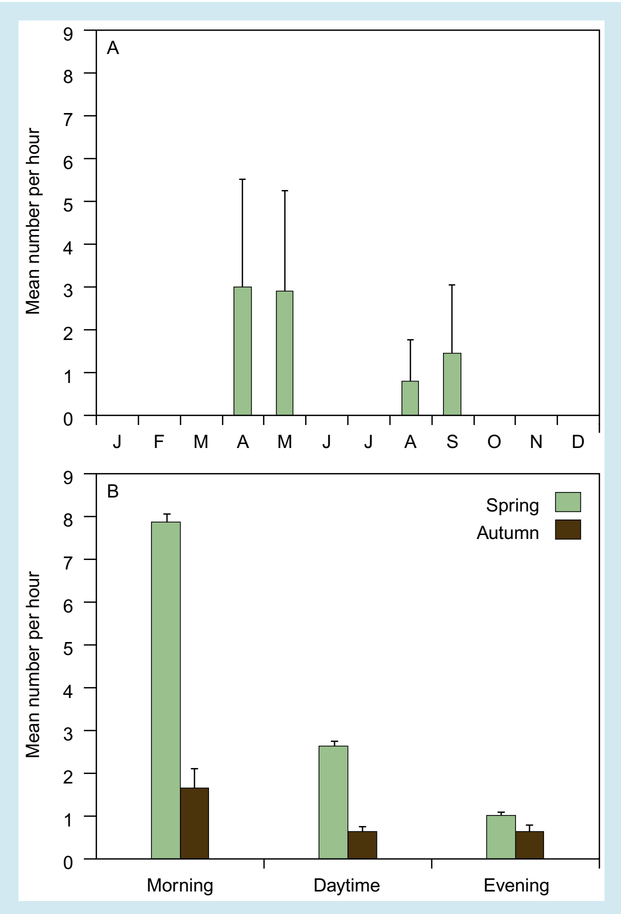

Figure 17. The number of Gannets recorded per hour of observation (± standard deviation) during A) April-May and August-November in 2002 and 2003, and B) morning, daytime and evening hours. 'Morning' includes observations made the first 2 hours from sunrise, 'Evening' includes observations the last 2 hours before sunset, and 'Daytime' includes the period in between.

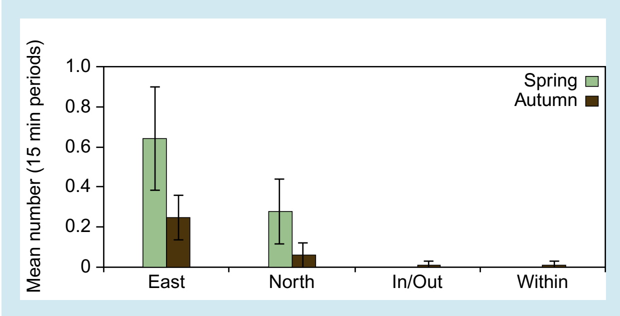

Figure 18. Migration intensity of Gannets (± 95% confidence limits) recorded by visual observation on the four transects placed east of the wind farm (transect East) north of the wind farm (transect West), along the eastern row of turbines (transect South) and within the wind farm (transect Southwest) at Horns Rev during spring and autumn 2002 and 2003.

observed crossing transect Southwest within the wind farm, subsequently to leave the wind farm crossing the transect South and the other was observed flying out of the wind farm.

Gannets were observed foraging along the reef contour, approximately 1,000 m north of the wind farm in both spring and autumn. Migrating Gannets were observed on all sides of the wind farm. In spring 63.4% of the birds were migrating north while in autumn 45.5% were migrating south.

Cormorant

A total of 147 Cormorants was recorded on the transect counts. Of these 133 were observed in November, with 130 individuals in one flock east of the wind farm. All other observations were of single birds.

Three birds were observed crossing the eastern row of turbines and four birds were observed within the wind farm.

Geese

A total of 142 Pink-footed Geese and 199 Greylag Geese were recorded on the transect counts. One flock of 7 Pink-footed Geese migrated north in May and two flocks of 5 and 130 birds, respectively, migrated south in October. All observations were on transect East.

Four flocks of 27, 11, 28 and 53 Greylag Goose migrated south in November. Except the last flock that was observed on transect West, all flocks were observed on transect East.

Substantial southward migration of geese, probably Pink-footed Geese, were recorded far west of the wind farm on several days in September.

Common Scoter

A total of 35,780 Common Scoters was recorded during the transect counts. Most birds were recorded in April (15,9%) and May (81.4%). Migration intensity was highest during the morning hours in both spring and autumn (Fig. 19). Average flock size was 4.63 birds (95% c.l.: 4.38 – 4.88) in spring and 4.49 birds (95% c.l.: 4.27 – 4.72) in autumn. Flock size in spring ranged between 1 and 210, but was not recorded in the most active periods. In autumn, flock size ranged between 1 and 23 individuals.

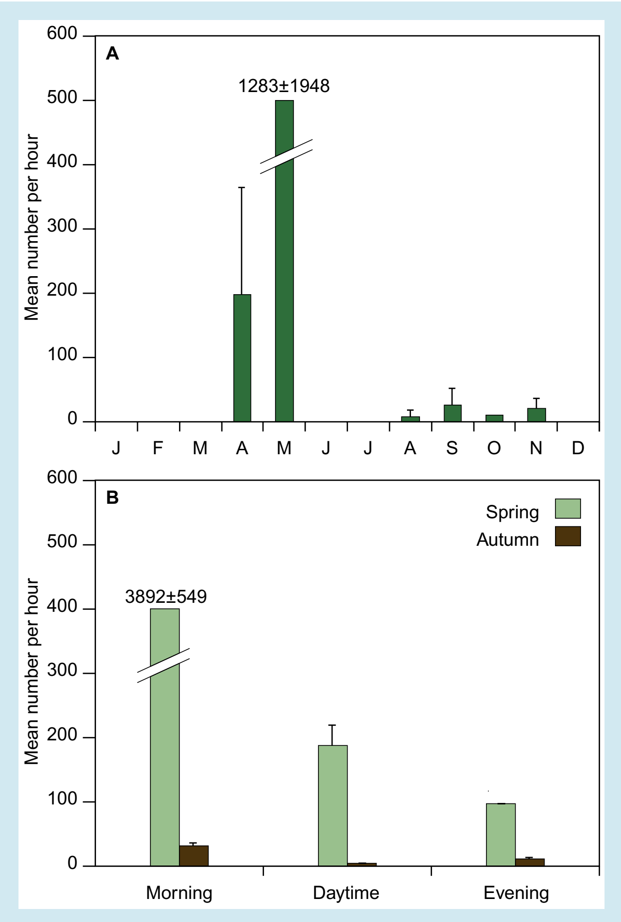

Figure 19. The number of Common Scoters recorded per hour of observation (± standard deviation) during A) April-May and August-November in 2002 and 2003, and B) morning , daytime and evening hours. 'Morning' includes observations made the first 2 hours from sunrise, 'Evening' includes observations the last 2 hours before sunset, and 'Daytime' includes the period in between.

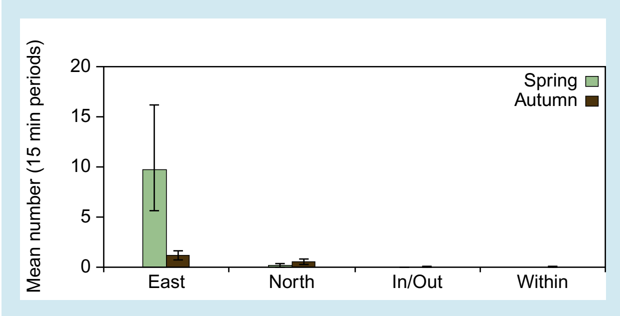

Figure 20. Migration intensity of Common Scoters (± 95% confidence limits) recorded by visual observation on the four transects placed east of the wind farm (transect East) north of the wind farm (transect West), along the eastern row of turbines (transect South) and within the wind farm (transect Southwest) at Horns Rev during spring and autumn 2002 and 2003.

A total of 10 Common Scoters was recorded in the wind farm. Two flocks of two and four birds were observed flying into the wind farm in November, while three solitary individuals were observed flying out of the wind farm in May (1) and September (2).

In April-May many thousand Common Scoters were staging northwest and north of the wind farm on the reef proper. In October-November smaller numbers were observed staging in the same area. The high numbers recorded on transect East in spring (Fig. 20), reflected local movements from the area north of the wind farm to the area southeast of the wind farm. In spring 7.5% of the birds were observed flying north while in autumn 61.1% were flying south. During a 30-minute period in the morning of 13 May 2003, a total of 775 birds was recorded flying north in transect East, whereas 19,620 birds were recorded flying south. Although the highest numbers of Common Scoters were recorded during the mornings on all days, the occurrence on 13 May was for unknown reasons more concentrated than on other days.

Gulls and terns

Gulls and terns were the most consistently observed species on the transect counts. The most numerous species were Herring Gull (1,289), Great Black-backed Gull (1,355) and Kittiwake (804), with lower numbers of Common Gull (227),

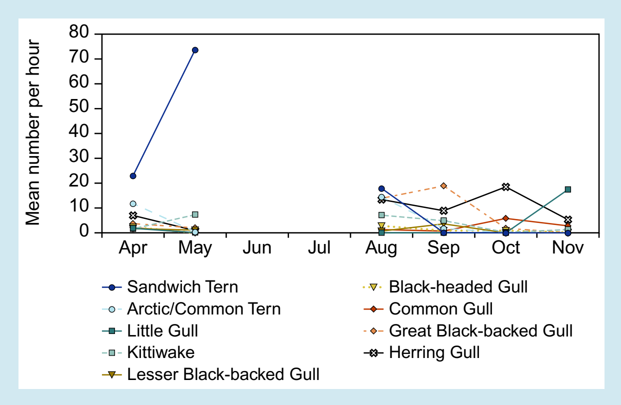

Figure 21. The number of gulls and terns recorded per hour of observation during the month April-May and August-November in 2002 and 2003 at Horns Rev.

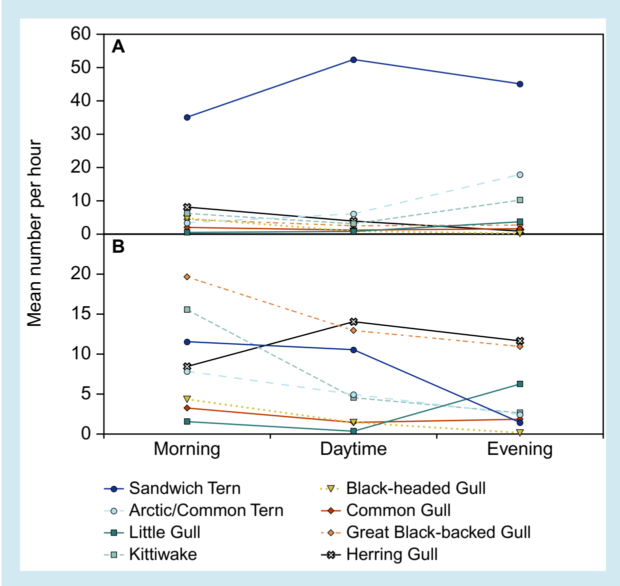

Figure 22. The number of gulls and terns recorded per hour of observation during morning, daytime and evening hours during spring (A) and autumn (B). 'Morning' includes observations made the first 2 hours from sunrise, 'Evening' includes observations the last 2 hours before sunset, and 'Daytime' includes the period in between.

Black-headed Gull (221), Lesser Black-backed Gull (156) and Little Gull (193). Sandwich Tern was one of the most numerous tern species with 3,539 individuals followed by Arctic/Common Terns (847).

The seasonal occurrence showed that most gulls decreased in numbers from April to May, except Kittiwake (Fig. 21). In autumn, Herring Gull and Great Black-backed Gull occurred in higher numbers than in spring, peaking in October and September respectively. Little Gull showed a marked increase in November. In spring, the Sandwich Tern increased markedly between April and May, while Arctic/Common Terns decreased. In autumn, most terns were recorded in August, and nearly all had left the area by the end of September. Flock size of gulls and terns during spring and autumn is shown in Table 2. Generally, most species occurred as solitary individuals, although Black-headed Gull, Little Gull and Arctic/Common Tern tended to occur in small groups.

Marked differences in diurnal occurrence were found both between species and between spring and autumn periods (Fig. 22).

Migration intensity or activity, expressed as the mean number of gulls and terns observed per 15 minutes of observation on the four transects is shown in Table 3. Generally, migration intensity in and out of the eastern border of the wind farm was highest and migration intensity lowest within the wind farm. Migration intensity east and north of the wind farm showed mainly intermediate values.

Table 2. Mean flock size (M) with 95% lower (L) and upper (U) confidence limits, and total number of flocks (N) observed during spring and autumn 2003. Data were log-transformed.

	Spring				Autumn			
	L	M	U	N	L	M	U	N
Herring Gull	1.08	1.13	1.18	183	1.06	1.07	1.09	1,014
Great Black-backed Gull	1.07	1.13	1.19	126	1.07	1.08	1.10	1,108
Black-headed Gull	1.39	2.51	4.52	15	1.80	2.45	3.34	33
Common Gull	1.08	1.19	1.32	55	1.11	1.18	1.25	117
Little Gull	1.44	1.84	2.35	27	1.53	1.75	2.01	60
Kittiwake	1.11	1.17	1.23	191	1.09	1.11	1.13	495
Arctic/Common Tern	1.79	2.04	2.32	139	1.61	1.73	1.86	224
Sandwich Tern	1.25	1.27	1.29	1,962	1.26	1.28	1.30	515

Table 3. Mean number (M) of birds per 15-minute visual observation periods with 95% lower (L) and upper (U) confidence limits and total number of individuals (N) for Herring Gull, Great Black-backed Gull, Arctic/Common Tern and Sandwich Tern and the group 'other gulls' (all other identified and unidentified gulls) recorded visually during autumn and spring on four transects located east and north of the wind farm, along the eastern row of turbine (In/out) and crossing the wind farm (Within).

		Spring				Autumn			
		L	M	U	N	L	M	U	N
Herring Gull	East	0.17	0.32	0.48	51	0.8	1.13	1.53	444
	North	0.22	0.43	0.47	76	0.51	0.71	0.93	260
	In/Out	0.23	0.53	0.89	85	1.27	1.71	2.24	301
	Within	-0.01	0.05	0.12	5	0.25	0.41	0.59	67
Great Black-backed Gull	East	0.24	0.41	0.6	67	0.8	1.09	1.44	411
	North	0.17	0.31	0.47	39	0.61	0.86	1.12	317
	In/Out	0.11	0.27	0.45	29	1.73	2.25	2.88	356
	Within	0.06	0.16	0.27	15	0.34	0.56	0.81	121
Other gulls	East	0.38	0.61	0.88	119	0.72	1	1.33	373
	North	0.17	0.35	0.56	56	0.48	0.74	1.04	330
	In/Out	0.29	0.56	0.89	72	1.1	1.58	2.18	360
	Within	0.1	0.31	0.55	56	0.55	0.87	1.26	226
Arctic/Common Tern	East	0.24	0.5	0.82	154	0.41	0.66	0.94	274
	North	0.11	0.32	0.58	75	0.09	0.19	0.29	47
	In/Out	0.26	0.64	1.12	176	0.27	0.45	0.67	97
	Within	-0.03	0.03	0.08	3	0.02	0.12	0.23	21
Sandwich Tern	East	1.18	1.66	2.24	490	0.36	0.58	0.83	204
	North	1.59	2.36	3.37	743	0.32	0.52	0.74	234
	In/Out	4.35	6.91	10.71	1,048	0.65	1.02	1.48	317
	Within	0.96	1.6	2.44	462	0.09	0.24	0.41	43

This pattern of high bird activity in and out of the wind farm and low activity within the wind farm suggests that both gulls and terns may use the wind farm as a 'land-mark' at sea, towards which the birds are oriented during local movements from the coast to offshore foraging areas. Even though most gulls and terns did not show reactions towards the wind turbines, the low activity within the wind farm indicates that this area is (for whatever reason) less attractive for foraging or resting birds. Thus, the greater activity at the eastern row of wind turbines may reflect local responses of birds that first move in and then out of the wind farm. Although this behaviour was only recognised specifically for Arctic/Common Tern, very similar proportions of birds were recorded between turbines moving westwards (in) and eastwards (out) (Table 4).

Skuas Stercorarius spp.

A total of 103 Arctic Skuas was recorded during the transect counts. Most birds were recorded during May (87.5%). The majority was observed as solitary individuals or occasionally as two or three together when chasing terns or small gulls.

Most birds were observed east (N = 48) and north (N = 28) of the wind farm, but 19 were observed passing the eastern row of turbines and 8 observed within the wind farm. In spring, 44.9% of

Table 4. The percentages of gulls and terns flying in and out of the wind farm through the eastern row of wind turbines (transect South), excluding birds observed between the transformer station and the wind turbines.

	In	Out	N
Herring Gull	54.6	45.4	100
Great Black-backed Gull	53.6	46.4	138
Other gulls	61.6	38.4	292
Arctic/Common Tern	58.8	41.2	34
Sandwich Tern	63.6	36.4	1,020

the birds were migrating north while in autumn 75.0% were migrating south.

The peak occurrence of skuas in May probably reflects the numerous occurrence of terns, as skuas are known to follow terns during migration.

Shorebirds

Eight species of shorebirds were observed during transect counts: 15 Oystercatchers, 9 Golden Plovers, 2 Ruffs *Philomachus pugnax*, 1 Greenshank *Tringa nebularia*, 2 Redshanks *Tringa totanus*, 2 *Calidris sp.*, 3 Bar-tailed Goodwits *Limosa lapponica* and 7 Curlews. All, except 1 Oystercatcher in April and 4 Curlews in September, were observed in August.

Terrestrial birds

Passerine species were recorded during the transect observations, including 118 Starlings *Sturnus vulgaris*, 2 Swallows *Hirundo rustica*, 2 Meadow Pipits *Anthus pratensis*, 1 White Wagtail *Motacilla alba* and 727 unidentified individuals. The majority of the species was observed in September coinciding with the peak migration period of most small passerines. Starling migration takes place later in the autumn, and most of these species were recorded in November. Of other terrestrial species, only 3 Sparrowhawks *Accipiter nisus* and 2 Grey Herons *Ardea cinerea* were recorded during transect observations.

However, as both the species identification and the numbers counted decreased markedly with observation distance along the transects for small species, these were not subject to further analyses. Although the identified passerine species in all probability represent the species involved in the recorded passerine migration at the wind farm, a number of other species was observed at the transformer station during the present study, many using this platform for resting. A list of passerine birds observed is given in Appendix 7.

3.3 Flight altitudes

A total of 77 measurements of flight altitudes were obtained from 61 flocks of nine species (Table 5). There was at least 30 seconds between two measurements on the same bird flock. The flight altitudes of identified species were compared and showed significant differences between species and groups of species (One-way ANOVA: $F_{8,68} = 7.19$, $P < 0.0001$). Even though the numbers included are small for most species/species groups the percentage of records of birds/flocks that occurred in the altitude of the turbine rotors (30-110 m above sea surface) is shown for the most frequently recorded species.

No significant differences in flight altitude in relation to distance to wind turbines were found for gulls (ANOVA: $F_{6,35} = 0.55$, $P = 0.763$) or terns ($F_{5,5} = 3.24$, $P = 0.112$), when grouped in distance intervals of 500 m. Due to small sample size, altitude data from other species/species groups could not be analysed in relation to distance to the wind farm.

Table 5. Mean flight altitude, standard deviation (SD), recorded altitude range and percentage recorded in rotor altitude for 9 bird species recorded during the autumn 2003 at Horns Rev.

Species/-groups	Mean altitude (m)	SD	Range (m)	% in rotor range	N
Cormorant *Phalacrocorax carbo*	58.3	8.4	46.0 - 70.0	100%	6
Geese *Anserini*	64.2	35.5	34.0 - 105.0	100%	5
Pintail *Anas acuta*	238.0	-	-	-	1
Common Scoter *Melanitta nigra*	4.0	5.2	0.0 - 8.0	-	2
Bar-tailed Godwit *Limosa lapponicus*	119.0	14.1	109.0 - 129.0	-	2
Arctic Skua *Stercorarius parasiticus*	49.0	-	-	-	1
Gulls *Laridae*	71.2	67.9	2.0 - 395.0	61%	42
Terns *Sternidae*	21.2	5.3	16.0 - 33.0	9%	11
Wood Pigeon *Columba palumbus*	210.4	87.6	126.0 - 385.0	0%	7

3.4 Flight speed

A total of 821 ground speed measurements was obtained on 636 unidentified bird echoes and 67 measurements on 43 tracks of birds identified to species or species group. The minimum duration between two measurements on the same bird echoes was 30 seconds, and for this reason considered as independent measures.

Data on flight speed of identified species were compared and showed overall significant differences between species/groups (Table 6, One-way ANOVA: $F_{7,876} = 280.74$, $P < 0.0001$). Significant differences (T-tests, $P < 0.05$) existed between several of the identified species/groups Thus gulls and terns showed significantly slower flight speeds than all other species/groups.

A multi-factorial analysis (2-way ANOVA) on all species and species groups was performed and showed that the only factor that did not affect flight speed was time of day (day, night). All other factors (species, wind speed, wind direction) and interactions turned out significant ($F_{11,872} = 22.37$, $P < 0.0001$). The effects of wind direction (north, west, east and south) (one-way ANOVA: $F_{3,880}$, $P < 0.0001$), were related to higher flight speed during easterly winds (mainly tail-winds) and lower during westerly winds (mainly head-winds).

3.5 Birds resting on turbines

The presence of wind turbines at Horns Rev may potentially attract perching species such as gulls, terns and Cormorants, which may use the turbines for loafing. Likewise, the turbines may offer a safe spot to other bird species (terrestrial species) that normally do not occur at sea. As attraction by wind turbines may potentially increase the collision risk, data on birds resting on turbines were collected.

Data on birds resting/sitting on the wind turbine foundations (exclusively on the safety railings eight metres above sea surface) were collected during all visits to the transformer station. However, the number of wind turbines that could be covered varied markedly in relation to visibility dependent on weather, and especially light conditions. Likewise, several of the most distant turbines were obscured to observers by nearer turbines. In addition, birds sitting on the turbines positioned themselves in relation to wind direction; some times sitting on the northern side of the turbines (mainly in northerly winds) and some times at the southern side of the turbine where they were impossible to observe from the transformer station (mainly in southerly winds). Consequently, the interpretation of data on birds resting/sitting on the turbines should be viewed with caution in the light of these restrictions.

During autumn 2003, more systematic counts of birds resting on turbine foundations were collected at the start of each count on transect South and Southwest, respectively (see Fig. 2). These counts included the species and number of birds resting and, in case birds were recorded, recording of whether the turbine rotors were turning or not.

During all counts, seven species were recorded resting on the turbine foundations: Herring Gull,

Table 6. Mean flight speed (km/h), standard deviation (SD), range (km/h) and sample size (N) of flying bird species and species groups recorded by radar during autumn 2003 at Horns Rev. Unidentified species/species groups were separated in two groups (A and B) based on differences in flight speed.

Species/-groups		Mean (km/h)	SD	Range (km/h)	N
Cormorant *Phalacrocorax carbo*		69.0	7.7	59.8 - 78.5	6
Geese *Anserini*		68.0	6.4	54.1 - 77.0	13
Common Scoter *Melanitta nigra*		75.3	10.7	46.9 - 86.1	11
Gulls *Laridae*		38.4	12.6	18.5 - 55.6	12
Terns *Sternidae*		32.8	7.8	25.5 - 41.1	3
Wood Pigeon *Columba palumbus*		60.3	5.8	50.2 - 69.4	18
Unidentified species (speed < 60 km/h)	A	43.6	10.4	17.2 - 59.8	481
Unidentified species (speed > 60 km/h)	B	75.5	10.8	60.0 - 107.8	340

Great Black-backed Gull, Kittiwake, Arctic/Common Tern, Cormorant and Sparrow Hawk.

During the transect counts a total of 20 birds was recorded resting on the turbines in 57 counts. Excluding a few records where species identification was not possible, 13 birds from 34 counts were recorded resting on turbines in transect South, including observations of solitary individuals of Herring Gull (4), Great Black-backed Gull (7), and Sparrowhawk (2). Of these, 4 observations were made on turbines that were active (1 Herring Gull and 3 Great Black-backed Gulls), while 9 observations were made on turbines that were stopped. On transect Southwest 2 birds in 18 counts were recorded on turbines (one Great Black-backed Gull on a non-active turbine and one Cormorant on an active turbine).

4 Discussion and conclusions

4.1 Occurrence of birds at Horns Rev

The importance of the study area at Horns Rev for migrating and staging waterbird species was confirmed during spring and autumn 2003. The Common Scoter was the most numerously recorded species, but this was predominantly the result of substantial numbers in May. Otherwise, gulls and terns dominated the count results in the area during both spring and autumn.

Bird migration patterns at the nearby coast of Blåvands Huk are well described (Kjær 2002, Jacobsen in prep.), documenting the southward autumn migration along the coast of Jutland of many waterbirds and terrestrial species during autumn. In the present study, observations suggested that most autumn migration activity occurred north and east of the wind farm area. Given the general southwesterly orientation of the southbound migration, the nature of the main migration route in the area of the wind farm probably reflects the continuation of the general migration along the coastline north of Blåvands Huk. In the present study, it was not possible to undertake radar observations of bird migration northeast of the wind farm, but studies in this area may give a more detailed picture of the overall migration pattern of birds approaching from this direction.

Most radar observations of bird movements were made during the night and showed the most intensive bird movements north of the wind farm. In contrast, visual observations during daytime showed greater numbers passing east of the wind farm. Thus, it may be possible that bird migration during night-time occurs farther from the shoreline than during daytime, but this may also be the consequence of different species involved in daytime and night-time migration and for the confounding affects of local movements at different times of the day, and so requires further studies.

It must be stressed, that direct comparison between bird numbers and bird movement activity recorded by radar and those registered during visual observations can not be made. For example, in many instances, where only one or few individuals of small-sized bird species are involved, the radar will fail to detect an echo, whereas visual observations would be able to register such birds.

Visual daytime observations showed that migration of passerines, pigeons and raptors occurs at very low intensity at Horns Rev. Most passerine species were observed resting at the transformer station, and although many different species were recorded, only a few species occurred regularly namely: Meadow Pipit, White Wagtail, Swallow and Starling, although only few individuals of these species were recorded during transect counts.

Of the focal waterbird species, divers, Gannet, Common Scoter, gulls and terns, only gulls and terns were observed regularly within the wind farm area. Although greater numbers of divers, Gannet and Common Scoter were recorded on all sides of the wind farm, only Gannet (two individuals) and 5 flocks of Common Scoters (9 individuals) were observed inside the wind farm. Compared to the total numbers recorded of divers (70), Gannet (243) and Common Scoter (35,780) during transect counts and observations of avoidance reactions, the few observations within the wind farm strongly suggest that these species actively avoided the wind farm. It should be noted, however, that the peak period of occurrence of divers at Horns Rev, February-March was not covered by this study (see Christensen et al. 2001, 2002, 2003).

The high flight intensities of gulls and terns occurring along the eastern row of turbines compared to the low flight intensity within the wind farm suggest that gulls and terns were making foraging flights from the coast to offshore areas, using the wind farm as a navigation 'land-mark' at sea, and only to a lesser extent as an area for foraging. Marked behavioural reactions towards the wind farm and single turbines were not observed in gull and tern species, although Arctic/Common Terns were observed entering between the turbines for a few hundred metres before turning to leave the wind farm again.

Very few radar tracks were recorded within the wind farm. This probably reflects the fact that fewer birds actually occur within the wind farm than outside. However, studies showed that the turbines themselves caused radar shadow on the screen, which reduced the detectability of individual tracks beyond each turbine in line with the angle from the radar antenna. This shadow effect was evident in several bird echoes that moved behind turbines showing disrupted tracks, and resulted in a poor detectability when birds were moving farther than two or three turbine rows within the park (as seen from the transformer station). Consequently, the number of bird echoes recorded within the wind farm reflects a minimum measurement of activity, especially in the western and southwestern parts of the wind farm area.

4.1.1 Lateral change in migration routes

The radar study of autumn migration orientation was aimed at detecting lateral changes in migration routes caused by the wind farm, based on all recorded southbound flight tracks which originated north and east of the wind farm area.

In autumn 2003 waterbird movements showed a general southwesterly orientation of 227° ± 0.8 SE at some distance from the wind farm. A significant change in flight direction was, however, found in bird tracks approaching the wind farm from both the north and from the east. In both orientations these modifications to flight direction resulted ultimately in an almost perpendicular entrance to the edge of the wind farm.

The orientation of bird movements at long distances from the wind farm was not affected by time of day (day/night) or by wind direction. However, at short range (< 400 m), the orientation of bird movements north of the wind farm was significantly affected by time of day and wind direction. This suggests that those birds that came in close to the wind farm adjust their orientation by visual recognition of the wind turbines, in a way associated with the prevailing wind direction.

In the area north of the wind farm with low numbers of gulls and terns, the mean track orientation of birds that entered the wind farm during night was 195° ± 2.6 SE, whereas the mean heading during daytime was 177° ± 4.9 SE. This result may suggest that while birds are able to see the rows of turbines by day more clearly and adjust their orientation to pass through the wind farm in the free corridors between turbines, birds that migrate at night are more likely to cross between turbine rows when passing through the wind farm area.

In the area east of the wind farm, time of day (day/night) was not found to affect flight orientation. The large numbers of gulls and terns, making local movements to and from Horns Rev to coastal areas, may mask the potential existence of a pattern similar to that observed north of the wind farm.

In the present analyses, the change in flight orientation occurred at 400 m north of the wind farm at a similar distance to the major decrease in the number of bird tracks detected on the radar. This suggests that a large proportion of the birds or bird species that approached the wind farm from the north reacted by either changing flight direction or stopped (i.e. to settle on water) at this point (see below). On the eastern side of the wind farm, this point of deflection was found to occur c. 1,000 m from the wind turbines. In this area, however, substantial movements of gulls and terns close to the wind farm will, if they use the wind farm as a point of migration, be expected to contribute to such a pattern.

During the periods of data collection, visibility was not markedly reduced by the presence of heavy fog or misty conditions. Thus, the recorded flight direction of birds that approached the wind farm included bird movements during daytime or during clear night conditions. Under these circumstances, the birds were probably able to detect the wind farm visually, either directly during daytime or by the flashing red lights located on turbine nacelles during the night.

The ability of migrating birds to avoid collisions with offshore wind turbines is expected to decrease with decreasing visibility, and hence, it is predicted that the collision frequency will be higher in situations with poor visibility. As the visibility was better than 2 km for the vast majority of the main migration periods during the present study, and given the above described prediction, it can be concluded that collisions may occur as relatively rare, clumped and discrete events rather than as continuously occurring casualties. This necessitates a continuously operating remote collision monitoring system, which can collect data independent of human operators. The

Thermal Animal Detection System (TADS; see Desholm 2003), based on infra-red video cameras, meets these requirements, and the final offshore testing of the system has been conducted in the autumn 2003. The results of this test will be assessed in relation to the future collision monitoring programme at the Horns Rev wind farm.

4.1.2 Probability of birds passing into the wind farm area

Of the tracks selected for analyses, the percentage of the waterbirds that passed through the northern and eastern gates of the wind farm area during autumn 2003 was 13.9% and 21.9%, respectively.

The probability of entering the wind farm was not affected by time of day (day/night), wind direction (east/west) or by the orientation of the birds measured between 1,500 and 2,000 m from the wind farm.

A high proportion of bird tracks deflected laterally before entering the wind farm, but most disappeared on the radar at various distances to the wind farm.

In the area north of the wind farm the largest proportion of tracks disappeared between 300 and 400 m from the wind farm. Although disappearance of radar tracks outside the wind farm may have several explanations, e.g., birds settle on the water, echoes disappear due to a change in bird orientation (reduced target size), these all reflect responses of the birds to the wind farm.

4.1.3 Flight altitude and speed

Flight altitude is a key factor, as the risk of collision is considered much higher if the birds fly at turbine rotor height than if they fly below or above the rotors.

In the present study, it was only possible to measure flight altitude rarely amongst a restricted number of species. Only gulls and terns were recorded in numbers that allow some interpretation of mean flight altitude. Gulls showed a variable range of flight altitudes and 61% of the records occurred within turbine rotor heights. Terns showed a less variable range of flight altitudes, being more confined to altitudes below the height of the turbine rotors, only 9% of the records occurred at rotor height. Gulls thus seem to have a higher probability of colliding with wind turbines than terns, although the risk of collision may also depend on several other factors, e.g., species, weather condition and behaviour (migrating, foraging etc.).

The levelling device could only be used to obtain data on flight altitude during daylight hours. Thus, measurements of flight altitude for birds migrating at night is an important factor to be included in following studies, especially as the risk of collision is expected to be highest during periods of poor visibility, when visual observations can not be made. Collection of data on flight altitude during night and also during foggy periods should have a high priority in the continuing programme of collision risk assessment. The use of vertically positioned radar, should be considered as an appropriate method to measure flight altitude.

Flight speed was recorded routinely during radar observations with the aim to subsequently assign unidentified radar tracks to species group or species from known flight speeds of identified birds. Measurements of flight speed were, however, also included as flight speed will affect the probability of being hit by a turbine rotor if birds are found to pass the wind farm in the height of the turbine rotors. Thus data on flight speed are expected to be included in final risk assessments of collisions between birds and wind turbines.

Although relatively few records of flight speed on identified species were obtained it seems that separation between gulls and terns from other species of waterbirds is possible based on flight speed differences. More data are, however, needed to improve the assignment of unidentified birds.

4.1.4 Birds resting on turbines

Very few birds were recorded using the turbines as loafing platforms. Except from two observations of Sparrowhawk and of one Cormorant, only gulls and terns were observed to rest on the turbine foundations.

Most birds were recorded on the turbine foundations on the turbines located at the edge of the wind farm (13), while only two birds were recorded on turbines on the transect crossing the wind farm. Likewise, there was a tendency for most birds to be recorded on turbines that had stopped. Although data are scarce, this may suggest that birds are more reluctant to use turbines for resting within the wind farm than at the edge of the wind farm and that most species, with the possible exception of Great Black-backed Gull, avoid resting on actively rotating turbines.

4.1.5 General phenology and migration intensity

It has often been pointed out that the intensity of migrating birds depends on several factors, especially the weather conditions, not just in the study area, but also along the entire migration route (Geil et al. 1974, Alerstam 1990). Thus, even when controlling for several influential factors, a substantial proportion of the variation in the occurrence and intensity of migration may remain unexplained. For this reason, migration intensity may be the least sensitive variable to detect potential effects of the operating wind farm. The apparent deviations from the normal distribution during some of the observation periods and wind directions must also be considered in future comparison of data between different seasons.

In general, the seasonal occurrence of recorded species made during the present study is in agreement with the results obtained during aerial bird surveys at Horns Rev 1999-2002 (Noer et al. 2000, Christensen et al. 2001, 2002, 2003). As a consequence, the seasonal timing of data collection is presently considered adequate to provide a description of the periods of peak occurrence for species that occur at Horns Rev, although emphasis on the period February – May is essential to track the migration periods of divers and Common Scoter, two critical species occurring in the area.

With the exception of gulls and terns, the intensity of bird flights was lowest within and at the edge of the wind farm. Most species, even those recorded in very high numbers outside the wind farm, were not, or only very occasionally, recorded within the wind farm. Of these species, Common Scoter represented the most extreme example, with a total of 35,779 recorded individuals of which only 9 birds were observed flying in between turbines.

Gulls and terns were the most numerously occurring species within the wind farm and showed generally no reactions to single wind turbines. For most species of gulls and terns flight intensity was markedly higher at the transect located at the eastern row of wind turbines than at transects north and east and within the wind farm. Lowest flight intensity was however, recorded within the wind farm, indicating that gulls and terns in general did not pass the wind farm from east to west, and that the high numbers recorded at the eastern row of turbines reflected birds that moved in and subsequently out again. In combination with a change in migratory direction towards the wind farm on distances out to 1,000 m east of the wind farm, this may reflect the fact that gulls and terns used the wind farm as a point of migration, and thus that the wind farm potentially attracts these species at least to the periphery.

4.2 Concluding remarks

The present study constitutes the first detailed investigation of bird occurrence and behaviour at the Horns Rev wind farm in relation to the risk of collision between birds and wind turbines. As expected, no observations were made of actual collisions during the eight periods of observation performed at the wind farm site.

Although a substantial proportion of bird radar tracks that approached the wind farm for unknown reasons disappeared before entering the wind farm, the majority of the longest bird tracks showed a lateral deflection in orientation, resulting in birds flying around the wind farm. Consequently only a few bird echoes (7.1% of all 1,088 tracks) were recorded entering the wind farm. This low number was in all probably somewhat affected by reduced detectability of radar tracks within the wind farm related to a shadow effect from every single turbine hampering recordings of bird echoes within the wind farm. However, consistent visual observations of lateral deflections around the wind farm in several species indicate that avoidance of the wind farm was a frequent behavioural response shown by most of the bird species occurring at Horns Rev.

With the radar located at the southwestern corner of the transformer station, a full 360 horizontal view could not be obtained, leading to the lack of coverage of the area north and east of the wind farm. The dominant southbound autumn movements of birds recorded at Horns Rev during the present study originated from this direction, probably reflecting a continuation of the coastal migration of waterbirds along Jutland. Hence, if major deflections in the migration routes occur as a response to the wind farm, it was not possible to describe with the set-up used in this study. To be able to describe bird movements in this area, the radar should be relocated to the northern side of the transformer station. This will, however, result in no coverage in the direction of the wind farm. Alternatively, a combined use of two antennas would result in a full 360° coverage.

Given the present one year of study, the aim was to describe a series of variables that is considered the most important parameters to contribute to a final risk assessments for bird species occurring at Horns Rev. Based on the results obtained through the present study, no final conclusions about the risk of collision can be drawn. It seems, however, reasonable to cautiously conclude that since most species react to the presence of the turbines at relatively long distances and many avoid entering the wind farm altogether. Those that do so fly in the corridors between turbine rows; thus the risk of collision seems to be lower than if birds did not modify their flight behaviour when approaching the wind farm. Likewise, the turbines were not found to act as resting platforms that potentially would attract large numbers of perching bird species such as gull, terns and Cormorants, that potentially would collide with the turbines.

Based on the recorded patterns of deflection in the orientation of migrating birds approaching the wind farm, it may be possible that birds that migrate at night may experience an increased risk of collision compared to those doing so by day. At night, adjustment in flight direction of birds occurring close to the wind farm corresponded less to a trajectory that was confined to the areas between turbine rows, than amongst birds migrating during daytime. This probably results in a higher frequency of birds passing across one or more rows of turbines, and hence increase the risk of collision. Taking into account that the majority of migration occurs at night, an important task of the future monitoring programme will be to generate an assessment of the flight altitude of nocturnally migrating birds, in order to document whether birds that enter or cross the wind farm at night fly in altitudes below, within or above the heights of the turbine rotors.

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Appendix 1

Temporal extent of radar coverage of the study area, expressed as a number of minutes of radar coverage at increasing ranges from the transformer station conducted in the areas west and east of the wind farm at Horns Rev during autumn 2003.

		Radar range (nautical miles)					
		1 nm	2 nm	3 nm	4 nm	5 nm	6 nm
West	Covered time	5,000	4,855	4,855	3,600	2,825	1,285
East	Covered time	4,810	4,605	4,090	2,020	1,705	1,270

Appendix 2

Daily mean wind direction (in degrees) and wind speeds recorded at Horns Rev on days when observations were carried out during 2002 and 2003.

	Wind direction (degrees)	Wind speed (m/sec)		
Date	Mean	Mean	Max	Min
28 August 2002	334	6.2	8.0	1.6
29 August 2002	237	6.7	11.7	2.1
30 August 2002	227	9.3	14.6	5.9
28 April 2003	200	10.8	15.2	7.1
29 April 2003	227	12.4	14.7	10.5
30 April 2003	215	9.5	13.4	1.1
1 May 2003	237	11.6	15.6	7.4
12 May 2003	197	7.3	11.9	1.78
13 May 2003	238	8.6	11.8	5.1
14 May 2003	247	11.4	14.8	5.7
15 May 2003	301	12.2	16.1	6.6
6 August 2003	74	4.4	7.2	1.1
7 August 2003	88	4.4	7.9	0.1
8 August 2003	206	3.8	6.5	0.9
25 August 2003	207	6.1	11.0	0.4
26 August 2003	318	12.4	19.5	8.2
27 August 2003	328	15.0	20.3	5.0
28 August 2003	293	3.9	7.4	1.0
29 August 2003	83	4.5	8.5	0.1
22 September 2003	211	13.1	22.0	9.3
23 September 2003	307	14.6	17.9	9.7
24 September 2003	290	9.7	16.7	4.3
25 September 2003	228	10.9	13.0	9.0
13 October 2003	113	5.6	10.8	2.6
14 October 2003	69	6.1	8.1	4.7
15 October 2003	62	4.9	6.1	3.1
16 October 2003	73	3.5	4.9	0.5
11 November 2003	135	9.2	14.0	5.7
12 November 2003	146	11.9	14.1	9.9
13 November 2003	-	-	-	-

Appendix 3

Species and numbers recorded during counts on the transect 'Southwest' on specific days at Horns Rev during 2003.

	Date																		
Species	30 Apr. 2003	1 May 2003	12 May 2003	13 May 2003	14 May 2003	15 May 2003	6 Aug. 2003	7 Aug. 2003	8 Aug. 2003	29 Aug. 2003	27 Aug. 2003	22 Sept. 2003	23 Sept. 2003	24 Sept. 2003	25 Sept. 2003	15 Oct. 2003	11 Nov. 2003	12 Nov. 2003	Total
Gannet							1												1
Cormorant									1		1			1	1	1			5
Common Scoter																		2	2
Arctic Skua			3	2	2	1													8
Common Gull	7	2								4				4		16		10	43
Herring Gull	1		3	1			17	6	2	4	1	4	5	13	3	12			72
Lesser Black-backed Gull	1	1	1		11		2	3						1	4				24
Great Black-backed Gull	5	2			7	1	4	16	2	2		1	34	45	13	4			136
Black-headed Gull	17	15							1						2				35
Little Gull	1																16	4	21
Kittiwake	1	1	5	4	13						1	1	19	10	1		1		57
Gull sp.													1						1
HerringGull/ Great Black-backed Gull												82	2	58	14	2			158
Arctic/Common Tern		3							15	2			2	2					24
Tern sp.			1							2						1			4
Sandwich Tern	23	11	163	37	192	36	25	9		7	2								505
Razorbill/Guillemot																	1		1
Starling																1	2	10	13
Passerine sp.													5					1	6

Appendix 4

Species and numbers recorded during counts on the transect 'South' on specific days at Horns Rev during 2002 and 2003.

Species	Date																							
	28 Aug 2002	29 Aug. 2002	30 Aug. 2002	28 Apr. 2003	29 Apr. 2003	30 Apr. 2003	1 May 2003	12 May 2003	13 May 2003	14 May 2003	15 May 2003	6 Aug. 2003	7 Aug. 2003	8 Aug. 2003	29 Aug. 2003	27 Aug. 2003	22 Sept. 2003	23 Sept. 2003	24 Sept. 2003	25 Sept. 2003	15 Oct. 2003	11 Nov. 2003	12 Nov. 2003	Total
Gannet	1											1												2
Cormorant												1				2								3
Heron												1												1
Eider					1																			1
Common Scoter									1									1	1				4	7
Velvet Scoter																					1			1
Sparrowhawk														1							1			2
Curlew												3												3
Arctic Skua								6	9	2	1					1								19
Common Gull		11	2		22	6	2					1		1	2				12		6			65
Herring Gull	90	79	35	4	66	8	1	2			4	9		3	7	1	21	6	22	4	16	4	2	384
Lesser Black-backed Gull		2			6	4	1					2				1		5	2					23
Great Black-backed Gull	50	130	37	3	14	5	2	4		1		8	11	2	7	16	42	22	27	3	1			385
Herring/ Great Black-backed Gull												6		1	6	3	55	44	68	7	12		1	203
Black-headed Gull	39	57			2	7							3									1		109
Little Gull					19		2																1	22
Kittiwake	42	51	35		4	1	2	8	9	7	6			1	1		1	6	3					177
Gull sp. Gull										1		1			1	1	2	1	2				1	10
Arctic/Common Tern	29	22	15	1	162	3	7	3				13	1	6	3	2	5	1	1					274
Tern sp.	6	7						2				4	3	1	6			2						31
Sandwich Tern	153	40	72	10	27	7	13	234	212	377	166	20		4	21	7								1,363
Razorbill/Guillemot																			1					1
Starling																					1	1	49	51
Passerine sp.																		3	14		1		1	19

Appendix 5

Species and numbers recorded during counts on the transect 'West' on specific days at Horns Rev during 2002 and 2003.

Species	Date																							Total
	28 Aug 2002	29 Aug. 2002	30 Aug. 2002	28 Apr. 2003	29 Apr. 2003	30 Apr. 2003	1 May 2003	12 May 2003	13 May 2003	14 May 2003	15 May 2003	6 Aug. 2003	7 Aug. 2003	8 Aug. 2003	29 Aug. 2003	27 Aug. 2003	22 Sept. 2003	23 Sept. 2003	24 Sept. 2003	25 Sept. 2003	15 Oct. 2003	11 Nov. 2003	12 Nov. 2003	
Red/Black-throated Diver																		3	3		1		7	14
Podiceps sp.																					2			2
Fulmar																		1						1
Gannet					7	1	1		5	6	15				1			13	1	1				51
Cormorant	1											2				1								4
Whooper Swan																							27	27
Greylag Goose																							53	53
Dabbling duck sp.																							8	8
Tufted Duck										2														2
Common Scoter		22		1	3		1	2		19			15	3			2	135	25	45	10		99	382
Velvet Scoter																							2	2
Oystercatcher			2			1							3											6
Golden Plover														2										2
Curlew																			4					4
Bar-tailed Goodwit			3																					3
Redshank												1												1
Greenshank												1												1
Ruff												2												2
Arctic Skua		3							10	8	7													28
Skua sp.		2																						2
Common Gull	1	26	1		10	2									1		1		3	1	9		8	63
Herring Gull	24	131	25	2	53	5	10	3		2	1	10		1	2	3	20	2	24		15	2	1	336
Lesser Black-backed Gull	1	5	1		3	2	5			2		1			3				1	18				42

Appendix 5 continued

Species	Date																							Total
	28 Aug 2002	29 Aug. 2002	30 Aug. 2002	28 Apr. 2003	29 Apr. 2003	30 Apr. 2003	1 May 2003	12 May 2003	13 May 2003	14 May 2003	15 May 2003	6 Aug. 2003	7 Aug. 2003	8 Aug. 2003	29 Aug. 2003	27 Aug. 2003	22 Sept. 2003	23 Sept. 2003	24 Sept. 2003	25 Sept. 2003	15 Oct. 2003	11 Nov. 2003	12 Nov. 2003	
Great Black-backed Gull	10	68	38		17	4	4	1	2	6	5	3	1		17	16	12	51	78	23				356
HerrringGull/ Great Black-backed Gull																	80	2	51	20	13			166
Black-headed Gull		11			1	2	15			1									11					41
Little Gull					2	8				3												15	35	63
Kittiwake	9	58	80		4	5	18	5	37	26	18		1			5	2	62	15	2			6	353
Gull sp.																6		1					4	11
Arctic/Common Tern	2	3	6	1	56	5	5	7		1		1	6	6	10	7	1	4	1					122
Tern sp.														3	12								2	17
Sandwich Tern	15	51	33	12	74	75	27	105	59	246	145	113	6		13	2			1					977
Razorbill/Guillemot									1												4		2	7
Guillemot																			1					1
Passerine sp.																		49	300					349

Appendix 6

Species and numbers recorded during counts on the transect 'East' on specific days at Horns Rev during 2002 and 2003.

Species	Date																						Total
	29 Aug. 2002	30 Aug. 2002	28 Apr. 2003	29 Apr. 2003	30 Apr. 2003	1 May 2003	12 May 2003	13 May 2003	14 May 2003	15 May 2003	6 Aug. 2003	7 Aug. 2003	8 Aug. 2003	29 Aug. 2003	27 Aug. 2003	22 Sept. 2003	23 Sept. 2003	24 Sept. 2003	25 Sept. 2003	15 Oct. 2003	11 Nov. 2003	12 Nov . 2003	
Red/Black-throated Diver					1		1	8	5	2				1	1		15	13	4	2		3	56
Red-necked Grebe																				6			6
Fulmar		1												1			1						3
Sooty Shearwater		1												1									2
Storm Petrel																			1				1
Gannet	1	2		19	25	36	3	3	33	15	15	2	1	3	2	1	24	2	2				189
Cormorant					1												1				1	132	135
Heron	1																						1
Greylag Goose																						66	66
Pink-footed Goose							7													135			142
Dabbling duck sp.														1									1
Tufted Duck																				1			1
Eider																						5	5
Common Scoter	18	22	152	3370	333	1813	1068	20891	6378	785	9	43	2	67	2	2	114	138	62	40	30	49	35388
Velvet Scoter						8	26	45	67	14													160
Red-breasted Merganser						2																	2
Sparrowhawk													1										1
Oystercatcher											1		13										14
Golden Plover														7									7
Redshank											1												1
Calidris sp.													2										2
Great Skua																	2						2
Arctic Skua		1					9	9	15	7				2			5						48
Skua sp.																		1					1
Common Gull	5	16		12	4	4						1	2		1			2		1	1	7	56

Appendix 6 continued

	Date																						
Species	29 Aug. 2002	30 Aug. 2002	28 Apr. 2003	29 Apr. 2003	30 Apr. 2003	1 May 2003	12 May 2003	13 May 2003	14 May 2003	15 May 2003	6 Aug. 2003	7 Aug. 2003	8 Aug. 2003	29 Aug. 2003	27 Aug. 2003	22 Sept. 2003	23 Sept. 2003	24 Sept. 2003	25 Sept. 2003	15 Oct. 2003	11 Nov. 2003	12 Nov . 2003	Total
Herring Gull	121	140	8	21	1	11	7	1		2	12		1	2		25	6	44	4	59	13	17	495
Lesser Black-backed Gull	3	1		4	7	16	12	5	4	1	2				3	1	4	4					67
Great Black-backed Gull	84	90	6	11	5	13	17	1	5	9	9	2		35	63	15	44	60	3	5		1	478
Great/Lesser Black-backed Gull															2	3	2						7
HerringGull/ Great Black-backed Gull											1	2	7	13	17	6	76	104	2	29			257
Black-headed Gull		1		4	1	1							7					17		5			36
Little Gull			1	7	16	2															26	35	87
Kittiwake	6	82		3		6	9	11	36	3	1				7	7	34	6		1		5	217
Sabines Gull.																	1						1
Gull sp.								2	13	3	1			3			5			1	6	9	43
Arctic/Common Tern	11	80	2	113	18	18			3		42	32	61	20	2	13	2	11					428
Tern sp.											17	65	52	12	5	8	1	3					163
Sandwich Tern	42	93	24	83	110	93	56	16	62	46	41	3		19	4		1	1					694
Razorbill																		1					1
Razorbill/Guillemot							1	1										4		20		4	30
Guillemot										1							6	2					9
Swallow				2																			2
Meadow Pipit																		2					2
White Wagtail	1																						1
Starling																						54	54
Passerine sp.																	80	269		2		1	352

Appendix 7

Miscellaneous observations of bird species recorded at the transformer station at Horns Rev during August 2002 – November 2003. The list is considered to accurately reflect those species, which had occurred, but numbers recorded should be considered as minimum, as some observations may not have been noted. Numbers in brackets are those additionally found dead on the transformer station and are not included in total numbers.

Species	Scientific name	N
Sparrowhawk	*Accipiter nisus*	6
Peregrine Falcon	*Falco peregrinus*	1
Merlin	*Falco columbarius*	1
Turtle Dove	*Streptopelia turtur*	1
Collared Turtle Dove	*Streptopelia decaocto*	3 (2)
Wood Lark	*Lullula arborea*	1
Swallow	*Hirundo rustica*	14
Hooded Crow	*Corvus cornix*	1 (1)
Jackdaw	*Corvus monedula*	2
Wren	*Troglodytes troglodytes*	5
Redstart	*Phoenicurus phoenicurus*	(1)
Whinchat	*Saxicola rubetra*	1
Wheatear	*Oenanthe oenanthe*	1
Ring Ouzel	*Turdus torquatus*	(1)
Blackbird	*Turdus merula*	1
Fieldfare	*Turdus pilaris*	1
Redwing	*Turdus iliacus*	10
Song Trush	*Turdus philomelos*	2
Reed Warbler	*Acrocephalus scirpaceus*	1
Blackcap	*Sylvia atricapilla*	2 (1)
Garden Warbler	*Sylvia borin*	1
Whitethroat	*Sylvia communis*	1
Lesser Whitethroat	*Sylvia curruca*	1
Willow Warbler	*Phylloscopus trochilus*	3
Goldcrest	*Regulus regulus*	2
Meadow Pipit	*Anthus pratensis*	56
Yellow Wagtail	*Montacilla flava*	12 (1)
White Wagtail	*Montacilla alba*	2
Starling	*Sturnus vulgaris*	29 (8)
Greenfinch	*Carduelis chloris*	3
Linnet	*Carduelis cannabina*	4 (1)
Twite	*Carduelis flavirostris*	1
Crossbill	*Loxia curvirostra*	1
Chaffinch	*Fringilla coelebs*	1

National Environmental Research Institute

The National Environmental Research Institute, NERI, is a research institute of the Ministry of the Environment. In Danish, NERI is called *Danmarks Miljøundersøgelser (DMU)*.
NERI's tasks are primarily to conduct research, collect data, and give advice on problems related to the environment and nature.

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