National Environmental Research Institute
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Annual status report 2004

Report commissioned by Elsam Engineering A/S

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2005

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Data Sheet

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Contents

National Environmental Research Institute

Synopsis

The aim of the project is to assess the collision risk between birds and wind turbines at the Horns Rev wind farm. The study 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 bird species. The study was based on data from spring 2004. The Horns Rev area lies in a region known to be of importance 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 that enter the wind farm is crucial to our assessment of collision risk. Having entered into the wind farm area, the risk is assumed to be highest for birds flying in the altitude of the turbine rotors. Consequently, flight altitude is another critical factor in the assessment of collision risks for the species that enter the wind farm.

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 were available to which the present data could be compared.

All observations of birds were performed from a transformer station situated to the north of the turbine in the northeastern corner of the wind farm. Mapping of bird movements was undertaken using radar surveillance both at day and night time. Visual observations were performed during daytime along four transects, two transects were located north and east of the wind farm, one along the eastern row of turbines and the last transect crossed diagonally through the wind farm in a southwestern 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 and radar observations were performed during March, April, May and August 2004. Data from the time of peak occurrence of staging divers in the area in February were not obtained as the programme was initiated in March. Due to major maintenance of the turbines, the programme was temporarily closed in September 2004, as this period did not represent normal operating conditions of the wind farm. To avoid a seasonal bias, data collected during August 2004 were not included in the present report.

Radar tracks of flying birds/bird flocks 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 pattern of bird movements around the wind farm, expressed as the relative migration intensity of both northbound and southbound migration;
- the pattern of horizontal bird avoidance towards the wind turbines, expressed as changes in flight direction of migrating birds approaching the wind farm;
- the probability of birds flying into the wind farm from the outer edge to measure the overall response of passage birds to the presence of the wind farm;
- in combination with visual observations, to describe the species-specific responses (flight direction and speed) to the wind farm;
- the behaviour of birds/radar echoes in relation to distance to the wind turbines.

During spring, bird movements generally followed a northerly orientation, but a substantial southwesterly migration also occurred. During the spring of 2004, bird tracks that entered the wind farm were only recorded at the eastern gate of the wind farm and constituted 29% of the tracks. Given the small sample size obtained in 2004, this percentage does not seem different from the 21% recorded during autumn 2003. As also observed in 2003, the majority of tracks approaching the wind farm from northerly directions, changed their orientation and passed to the west around the wind farm, which is comparable to the 2003 pattern. At the eastern side of the wind farm a higher proportion of birds in 2004 performed a northerly deflection at distances of 300-1000 m from the turbines, whereas in the autumn of 2003 birds coming from this direction showed a southward deflection. These different patterns at the eastern rows may have been due to the differences in seasons compared, as more birds tend to deflect northwards during spring migration than during autumn migration, when birds generally are moving south. Of northward migrating birds during spring 2004, deflection towards the wind farm in migration orientation occurred at distances of more than 2 km from the wind farm.

As also recorded in 2003, many radar tracks of birds disappeared from the radar within close range of the wind farm, e.g., due to change of flight direction, or landing on water. This is confirmed through the behavioural observations of Common Scoters approaching the wind farm during spring 2004. Whatever the precise nature of these disappearances, the loss of tracks on the radar screen in all probability reflects a behavioural response to the wind farm by approaching birds. Since most bird tracks disappeared at distances of about 400-500 m from the outer turbines of the wind farm this distance may represent a threshold distance for several bird species. This change in migration orientation in relation to the wind farm may have started at much longer distance, as seen for northward migrating birds. As expected, no collisions were observed.

Birds that flew in closer than ca. 400 m from the wind farm during southward movements showed an adjustment in orientation to make a perpendicular passage in between the rows of turbines, either flying south or west when approaching the north and east side of the wind farm, respectively. As recorded during autumn 2003, birds that passed in between turbines during daytime generally tended to make more precise adjustment in relation to the orientation of turbine rows than birds that passed in between turbines during night. Consequently, the risk of collision seems to be higher during periods of low visibility, i.e. during night or foggy conditions, compared to situations when birds have visual contact with the turbines.

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 bevægelser i området.

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 ved 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 radar overvågning 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 radar overvågning og visuelle observationer om dagen gav oplysning om artsspecifikke fuglebevægelser, flyveretninger og flyvehøjder. Visuelle observationer og radar undersøgelser blev gennemført i marts, april, maj og august 2004. Der blev således ikke indsamlet data i februar, hvor det største antal lommer er tilstede ved Horns Rev, idet undersøgelserne først blev igangsat i marts 2004. På grund af større reparationsarbejde på vindmøllerne blev undersøgelsesprogrammet midlertidig lukket i september 2004, da denne situation ikke repræsenterede en operationel møllepark. For at undgå at sammenstille data fra både forår og efterårsperioden i analyserne blev data indsamlet i august ikke medtaget i nærværende rapport.

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:

- fuglenes overordnede trækbevægelser omkring vindmølleparken, udtrykt som den relative trækintensitet af både nord- og sydtrækkende fugle;
- horisontal 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 -hastighed) på vindmølleparken;
- adfærden hos fugle/radar ekkoer i relation til afstand til vindmølleparken.

Igennem foråret registreredes flest nordtrækkende fugle ved Horns Rev, men en markant andel af sydtrækkende fugle blev også registreret. I foråret blev der, med udgangspunkt i det anvendte selektionskriterium, kun fundet radarspor der gik ind i mølleparken ved den østlige side af parken. Disse udgjorde 29% af radarsporene. Under hensyn til det lille materiale indsamlet i 2004, var dette resultat ikke markant forskellig fra 21% registreret i efteråret 2003. Som i 2003 viste langt de fleste radarspor af fugle, der nærmede sig mølleparken fra nordlige retninger en ændring i trækretning, og de fleste fløj uden om mølleparken, primært vest for parken. På den nordlige side af mølleparken var dette mønster sammenligneligt med det mønster, der blev registreret i 2003. På den østlige side af mølleparken viste flere fugle en afbøjning mod nord på en afstand af ca. 300-1.000 m fra møllerne sammenlignet med en generel afbøjning mod syd i efteråret 2003. Denne forskel i afbøjning ved den østlige mollerække kan være et resultat af, at flere fugle afbøjer mod nord under forårstrækket (hvor hovedtrækket er mod nord) end under efterårstrækket, hvor fuglene generelt trækker mod syd. Det nordgående træk i foråret 2003 viste, at en afbøjning i trækretning skete på mere end 2 km afstand af mølleparken.

Som registreret i 2003, forsvandt mange radarspor fra radarskærmen i området nær mølleparken, f.eks. på grund af at fuglene ændrede flyveretning, eller at de landede på vandet som beskrevet for sortænder i foråret 2004. 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 mølleparken. Da de fleste radarspor forsvandt ca. 400-500 m fra de yderste vindmøller mod nord og ca. 1.000 m fra de yderste mod øst, kan denne afstand til møllerne repræsentere en generel reaktionsafstand, selv om fugle kan reagere på vindmølleparken på langt større afstande som registreret for det nordgående træk. Som forventet blev der ikke registreret kollisioner.

I området nord for vindmølleparken var fuglenes generelle flyveretning sydvestlig på afstande større end 400 m fra vindmølleparken. Der var ikke forskel i fuglenes orientering mellem dag og nat og under forskellige vindretninger.

Fugle, der fløj mod syd, ændrede deres trækretning når de kom tættere på møllerne end ca. 400 m. Inden for denne afstand fløj de vinkelret ind i mølleparken imellem de enkelte møllerækker. Fugle, der fløj ind mod mølleparken fra nord, passerede parken i sydlig retning, mens fugle, der fløj ind i parken fra øst, passerede parken i vestlig retning. Som registreret i 2003, var fuglenes ændring i trækretning mere præcis i forhold til møllerækkerne om dagen end om natten. Risikoen for kollisioner mellem fugle og møller vil derfor sandsynligvis være højere under forhold med lav sigtbarhed, f.eks. om natten og i tåget vejr, end under forhold, hvor fuglene har mulighed for tydelig at se møllerne.

1 Introduction

1.1 Background

In February 1998, the Ministry of the Environment gave Elsam A/S and Eltra A.m.b.a. approval to erect a wind farm, capable of producing 160 MW of electric power, at Horns Rev, west of Blåvandshuk off the west coast of Jutland (Fig. 1). Construction activities at Horns Rev started in September 2001 and were finished in summer 2002.

The project was organised as a demonstration project to assess the technical, economic and environmental constraints on the future development of electric power production in Danish offshore environments. For detailed background information, see Elsamprojekt A/S (2000).

Within the framework of the environmental programme, performed since 2002, bird studies have been performed to assess the risk of bird colliding with wind turbines. This report presents the data compiled during spring 2004 and analyses the potential effects on birds present at Horns Rev during commercial operation of the Horns Rev wind farm. Due to the remoteness of the area it has not been possible to obtain base-line investigation of bird occurrence and behaviour at the wind farm site in relation to assessments of collision risks.

The bird studies at Horns Rev have been set up to describe the potential effects of the wind farm on birds under two main headings:

1) risk of collision (mortality);
2) risk of disturbance effects (displacement, equivalent to habitat loss).

In relation to collision risk, it has not been assumed that the present study would be able to detect incidences of collisions between birds and wind turbines, since collisions probably would occur at very low frequencies. Likewise, collisions most probably will occur during periods of poor visibility, i.e., during dark nights, fog, rain- or snowshowers, and/or during unpredictable conditions when birds may be attracted to the lights mounted on the turbines for traffic safety reasons.

For further details on the main headings and previous results, see the earlier series of reports (Noer et al. 2000, Christensen et al. 2001, Christensen et al. 2002, Christensen et al. 2003, Christensen et al. 2004, Petersen et al. 2004).

The present report only refers to analysis of the risk of collision based on data obtained during the spring of 2004. When relevant, the 2004 data are compared with the results obtained for the 2003 observations. Due to major maintenance activity in the wind farm, the programme was temporarily closed during autumn 2004. During this period, data were only collected during one trip in late August/early September. In order to prevent a seasonal bias in the analyses, the scarce data from the autumn period is omitted in the present report. This data will, however, be included and analysed in the final report. - The 2004 spring data were originally analysed and presented in a comprehensive note (Christensen & Hounisen 2004) commissioned by Elsam Engineering A/S for the meeting of the International Expert panel in Billund in September 2004. The present report includes additional data and analyses that were not presented in the previous note. Further the data have been subject to a more thorough quality control, which, however, did not alter the results or main conclusions from the previous note.

Figure 1. The location of the Horns Rev offshore wind farm in the Danish part of the North Sea.

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2 Methods

2.1 Study area

The wind farm is located in the North Sea ca. 14 km west-southwest of Blåvandshuk at water depths of ca. 6.5-14 m (Fig. 2). The wind farm comprises 80 turbines placed in 10 north-south orientated rows with each row containing 8 turbines. Further details on the wind farm are described in Elsamprojekt A/S (2000).

Observations of birds were undertaken from the transformer station situated north of the northeastern corner of the wind farm. Mapping of bird movements was undertaken using surveillance radar both during day and nighttime. Visual observations were performed during the daytime along four transects, two located north and east of the wind farm, respectively, one along the eastern row of turbines and one crossing diagonally through the wind farm in a south-westerly direction (Fig. 2). A combined use of radar and visual observations during the daytime provided an additional species-specific information on bird movements and orientations as well as data on flight speed. Radar observations covered an area extending 6 nautical miles (ca. 11 km) from the transformer station. No coverage of the area between ca. 355° and 95° was possible due to the structure of the transformer station (see Fig. 2).

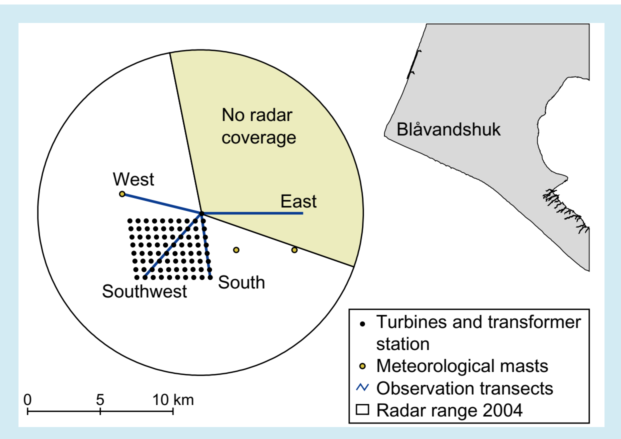

Figure 2. The study area displaying the location of the four transects (blue lines) used in the visual observation and the radar coverage.

2.2 Monitoring of migratory birds

Methods

Visual and radar observations were performed in March, April and May 2004 (Table 1).

Observations of bird migration intensity, species composition, flock size and migration routes were performed both during day and nighttime. The observations included 27 hours of visual observation and 82 hours and 25 minutes of radar observations (Table 1). The covered periods coincides with the aggregation of staging migrants and the main migration period of a substantial number of several species of waterbirds, which is the predominant species group during spring. Two observers were present to ensure maximum effectiveness in counting, and due to safety reasons.

During spring 2004, visual observation data were collected during daytime using a telescope (30x), and the data were recorded in 15-minute intervals. The results obtained from the daytime telescope observations allowed for a species-specific description of the abundance, phenology and behaviour of birds occurring within the area. Thus, the telescope observations made an essential contribution to the assessment of potential impacts by allowing for an estimation of the consequences at a species level.

The mean number of birds passing through each transect was calculated in 15-minute intervals (migration intensity). 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 and the 95% confidence limits. This approach is generally less sensitive to extreme observations of very large flocks, which may occur at a very low frequency, compared to calculation of simple averages.

To compile spatial data on bird migration at far distances and during periods of poor visibility, e.g. due to fog or darkness, a ship-radar (Furuno FR2125 or FR2110) was used. Each echo on the

Table 1. The period of effective observation (visual and radar) conducted from the transformer station at Horns Rev during spring 2004.

Period	Visual observations	Radar observations
24-27 March 2004	8 h 0 min	24 h 45 min
19-22 April 2004	9 h 0 min	24 h 55 min
11-14 May 2004	10 h 45 min	34 h 30 min
Total	27 h 45 min	82 h 10 min

radar monitor corresponded to a single bird or flock of birds in the study area, and in this way the spatial migration pattern could be described both during day and night. Sunset and sunrise defined the grouping of bird data into day and night.

Data

During spring 2004, the general orientation of bird migration is northwards, possibly with the exception of seabirds. Observations of seabirds, at Blåvandshuk, during spring often show substantial southward movements. Such behaviour may be related to seabirds avoiding low-pressures (cyclones) normally having a more northerly course when passing the North Sea (see Mouritsen 1991).

During spring 2004 a total of 595 southbound and 1,322 northbound tracks of birds were recorded. Even though more tracks were recorded of northbound birds/bird groups, the main focus of the present report is placed on southbound migration approaching the wind farm. The emphasis on the southbound migration was due to three reasons, 1) the radar positioned northeast of the wind farm has a much lower probability of detecting birds approaching the wind farm from southerly directions than birds approaching from the north, due to the initial further distances from the radar and to a 'shadow effect' on the radar from the wind turbines, 2) the results are directly comparable to those obtained during autumn 2003, and 3) the behaviour of birds approaching the wind farm is not assumed to deviate in relation to the direction of approach.

The migration routes were mapped by tracing the course of bird flocks from the radar monitor on to a transparency, digitised and transferred to a GIS-database. Only tracks longer than 1 km (arbitrary value) were included in the analysis, thereby excluding short tracks of local movements. When possible, species and flock size were recorded.

Following the methods employed for the 2003 study (Christensen et al. 2004), data were collected in the spring of 2004 in order to test the main hypothesis that migratory birds show a lateral avoidance response to the wind farm. In order to evaluate this hypothesis, data were processed and included in the following analysis 1) the overall migration intensity in the covered area, 2) an analysis of lateral changes in migration orientation, and 3) an analysis of the probability of birds passing the wind farm. In addition, a general analysis of the orientation of northward bird migration towards and around the wind farm is presented.

Time of day, season and wind direction has previously been shown to have significant impacts on the migration patterns in the study area (Christensen et al. 2004). Hence, these factors were incorporated in the analyses.

2.2.1 Relative migration intensity

Bird migration intensity in the covered area was calculated for both southbound and northbound migration as the total length (in metres) of all tracks occurring within squares of 500x500 m imposed on the total area. Data is processed as described in Christensen et al. (2004).

2.2.2 Lateral changes in migration routes

Analyses of lateral changes in the southward-oriented migration during spring were carried out for birds approaching the wind farm from the north and from the east. A total of 184 (north of the wind farm) and 92 (east of the wind farm) bird tracks were included. This excluded tracks that did not cross at least two of 15 transects lo-

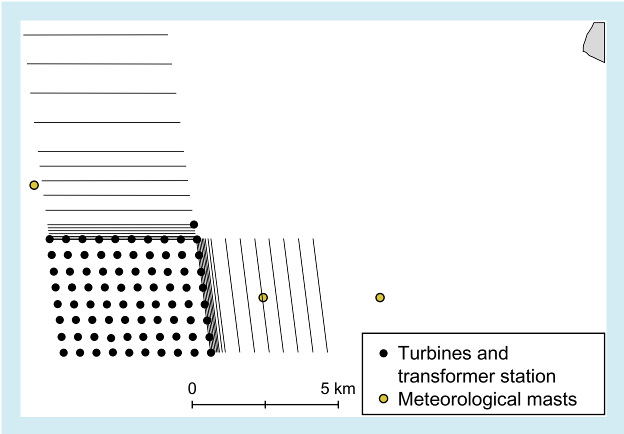

Figure 3. Location of transects north and east of the wind farm used in the analyses of lateral changes in migration orientation of birds during spring 2004.

cated in parallel to the most northern and eastern 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 north of the wind farm, and 50, 100, 150, 200, 250, 300, 400, 500, 1,000, 1,500, 2,000, 2,500, 3,000, 3,500 and 4,000 m east of the wind farm, see Fig. 3). Due to the blind angle of the radar, the covered area did only reach four kilometres east of the wind farm. The transects had the same orientation and length as the turbine rows (see Christensen et al. 2004 for details).

For each bird track that intersected two adjacent transects the migration course were calculated between intersection points. Subsequently, the mean migration course was calculated for all distance intervals relatively. To assess the lateral changes in migration orientation in relation to the wind farm, migration orientation was analysed (ANOVA) in relation to distance to the wind farm in combination with cross wind (classified as easterly and westerly wind directions in analyses of tracks north of the wind farm, and as northerly and southerly wind directions when considering tracks east of the wind farm) and time of day (day and night).

2.2.3 Probability of birds passing into the wind farm area

Analyses of the probability of birds entering the wind farm was performed on 49 and 31 tracks recorded north and east of the wind farm, respectively. These tracks were selected using the criteria set up by Christensen et al. (2004), comprising tracks that passed two transects located 1500 and 2000 meters from the wind farm. In the previous analysis of data from 2003, tracks with a length of less than 2 km were excluded from this analysis (Christensen et al. 2004). However, due to the low number of tracks recorded in 2004, we only excluded those that were shorter than 1 km in the present analyses of data from the spring of 2004.

The proportion of tracks that entered into the wind farm area from the north and east was calculated. The effect of cross winds, time of the day (day and night) and bird track orientation between 1,500 and 2,000 m from the wind farm was analysed using a logit model, i.e. the response variable was binary (presence/absence at the eastern edge), and the explanatory variables were all assigned to categories, except for distance measurements that were continuous.

2.2.4 Northward migration

With the radar located north of the wind farm, analyses of the northward bird migration at Horns Rev is markedly impeded by the reduced detectability of birds by the radar at far distances, and by the presence of the turbines making radar shadows in the area south and west of the wind farm. Thus, analyses of northward bird migration should be considered indicative and not conclusive.

For these reasons, the present report only makes a general approach in assessing the possible effect of the wind farm on northward bird migration by analysing the mean orientation of migration in separate zones around the wind farm. These zones are represented by 48 2,750x2,000 meter grid cells centred around the wind farm (see Fig. 18). In each grid cell the mean orientation of migration was calculated based the orientation between start and end point from all individual track segments present within separate grids, after transformation of track orientation into values of between -90° (westerly orientation) and +90° (easterly orientation). The analyses included all 1,316 tracks of northward migrating birds recorded by radar. The number of track segments ranged between 2 and 210 per grid cell, totalling 2,921 segments.

2.3 Weather data

Weather conditions were included in the documentation of effects of the wind farm on migration routes to increase confidence in the conclusions. Data on wind conditions from the vicinity of the wind farm area were obtained from the meteorological mast placed ca. 1.5 km northeast of the wind farm (see Fig. 2), as was the case in 2003. Every sample of weather data was assigned to bird observations to minimise the time span between weather and bird records. This was done with an accuracy of 15 minutes.

3 Results

3.1 Migratory birds

3.1.1 Migration routes, species composition, numbers and flock size

During spring, the area at Horns Rev is exploited by both staging and migrating waterbirds (e.g. Christensen et al. 2002, Petersen et al. 2004). Most of the bird migration in spring was orientated in a northerly direction, although substantial southward movements were also recorded. In the following paragraphs, the data collected on the most numerously occurring species are presented. Appendix I-IV and V give a full species list as well as total numbers observed during visual observations and of miscellaneous observations of passerine species, respectively.

During spring 2004 a total of 577 southbound and 1,316 northbound bird tracks were recorded. Most tracks, of both northbound and southbound birds/bird flocks, were recorded north and east of the wind farm, although some tracks were also recorded west and south of the wind farm. The fact that fewer tracks are recorded in the latter areas is to some extent caused by a radar shadow effect of the individual wind turbines and from the decrease in detectability by the radar at progressively longer distances. The relative density of southbound and northbound bird tracks is shown in Fig. 4 and Fig. 5, while the original tracks are shown in Fig. 6. As data are obtained from a horizontally oriented radar, the vertical distribution of the bird migration is not known and the tracks presented constitute bird migration occurring both in between turbines and above the wind farm.

During spring 2004, the species composition of visually observed birds recorded during transect counts was comparable with the species composition recorded in spring 2003. As in 2003, Common Scoter, gulls and terns were the numerically dominant species. In 2004 divers occurred in numbers comparable to numbers recorded in 2003, whereas Common Scoter, Gannets and terns occurred in lower numbers. Gulls were generally recorded in higher numbers in spring 2004 than in 2003, except for Great Black-backed Gull, which occurred in lower numbers.

In the following paragraph the most numerously occurring species, and species of special interest recorded at Horns Rev are considered with regards to flight intensity, flock size or flight behaviour relevant to wind farm issues. Results reported for 2003 are taken from Christensen et al. (2004).

Divers Gavis arctica/stellata

A total of 14 divers were recorded east and north of the wind farm. No divers were recorded within

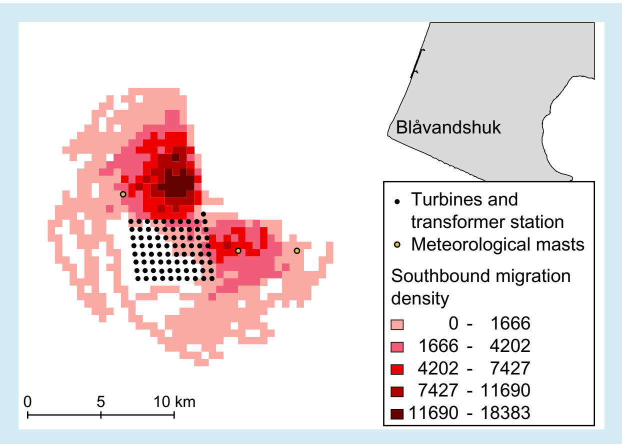

Figure 4. Spatial density of 577 tracks of the southbound bird migration at Horns Rev during spring 2004, expressed as total metres of radar tracks per 500x500 m grid square.

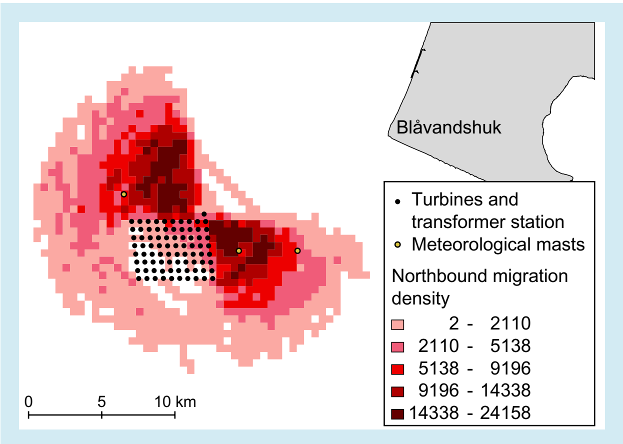

Figure 5. Spatial density of 1,316 tracks of the northbound bird migration at Horns Rev during spring 2004, expressed as total metres of radar tracks per 500x500 m grid square.

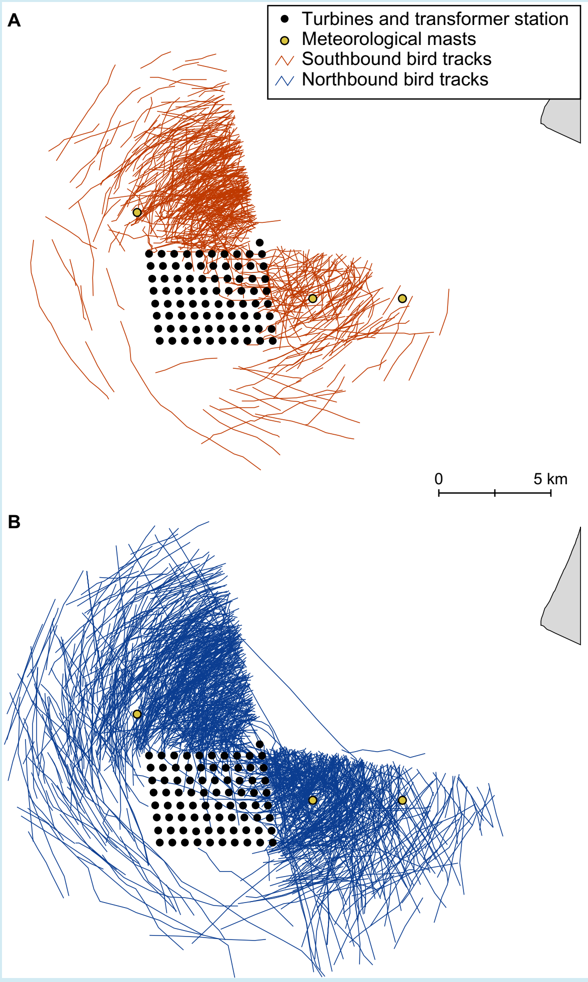

Figure 6. Radar registration of 577 tracks of birds/bird flocks migrating southwards (A) and northwards (B) at Horns Rev during spring 2004. The vertical position of migrating birds is not known.

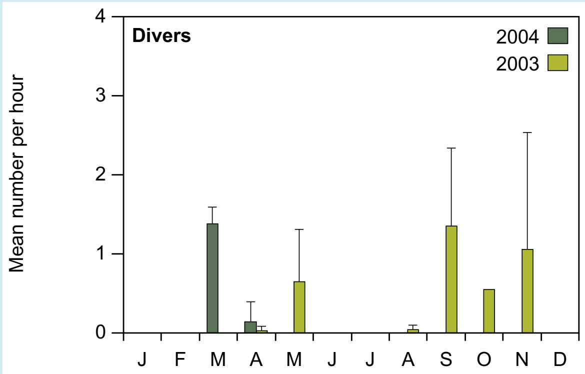

Figure 7. The number of divers recorded per hour of observation (± SD) during March, April and May 2004 and during 2003.

the wind farm. The mean migration intensity of 0.23 individuals per 15-minutes is not different from the intensity of 0.13 birds per 15 minutes recorded in 2003 (Table 2). Migration intensity was highest in March (Fig. 7), which probably reflects the fact that the highest number of staging divers in the area occur during late winter (see Christensen et al. 2003, Petersen et al. 2004). The peak period of occurrence of divers in February was not covered by the present study. Compared to data obtained during 2003, migration intensity in March is comparable to migration intensity in autumn. The low numbers of divers recorded during peak migration of divers in April and May in 2004 may be a result of a low activity of divers in the study area or the fact that the ob-

Table 2. 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). The species are divers, Gannet and Common Scoter recorded visually during the spring 2003 and 2004 crossing four transects located east and north of the wind farm, along the eastern row of turbine (In/Out) and crossing the wind farm (Within). The data set was log-transformed before the means and confidence limits were calculated.

		Spring 2003				Spring 2004			
		L	M	U	N	L	M	U	N
Divers	East-transect	0.04	0.13	0.23	17	0.04	0.23	0.45	11
	North-transect	-	-	-	0	-0.02	0.06	0.15	3
	In/Out	-	-	-	0	-	-	-	0
	Within	-	-		0	-	-	-	0
Gannet	East-transect	0.42	0.64	0.9	134	0.13	0.40	0.74	21
	North-transect	0.13	0.28	0.44	35	-0.01	0.08	0.18	4
	In/Out	-	-	-	0	-0.03	0.03	0.08	1
	Within	-	-	-	0	-	-	-	0
Common Scoter	East-transect	5.68	9.72	16.19	34,950	6.37	13.18	26.30	1,222
	North-transect	0.03	0.17	0.32	26	43.09	95.20	208.89	20,760
	In/Out	-0.01	0.01	0.04	1	0.55	1.50	3.01	113
	Within	-	-	-	0	1.13	3.32	7.76	522

servation periods did not cover days of substantial migration of these species. Divers were mainly observed as solitary individuals, as overall mean flock size was 1.21 individuals (Table 4).

Two divers were recorded by radar. One was flying southward east of the wind farm towards the meteorological mast (met-mast). At a distance of ca. 1 km north of the met-mast this bird made a U-turn and flew back north. The second diver was flying northeast from a point south of the wind farm. This bird passed the southeastern turbine at a distance of ca. 900 metres and proceeded northeast.

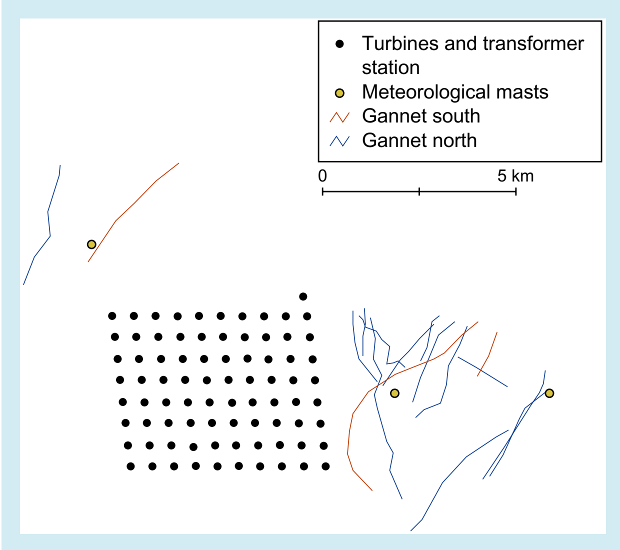

Figure 9. Radar tracks of 16 individuals/flocks of Gannets migrating southwards and northwards at Horns Rev during spring 2004.

Gannet Sula bassanus

During spring 2004, a total of 26 Gannets were counted. Most Gannets were recorded to the east and north of the wind farm, and only one individual was recorded inside the wind farm. The mean migration intensity was lower in spring 2004 than in 2003 (Table 2). The number of Gannets recorded in April and May was lower than in the same period in 2003 (Fig. 8). Mean flock size in 2004 was comparable to mean flock size in 2003 (Table 4). All recorded radar tracks of southbound and northbound Gannets showed that these birds generally kept clear of the wind farm (Fig. 9). One bird approaching the wind farm from the northeast clearly reacted to the presence of the wind farm by deflecting southwards (see Fig. 9).

Common Scoter Melanitta nigra

A total of 22,617 Common Scoters were recorded during spring 2004. The vast majority (92%) of the Common Scoters was observed north of the wind farm and during April and May (Table 2, Fig. 10). A relatively large number of birds were recorded within the wind farm in spring 2004 (635 individuals; 2.81%) compared to spring 2003 (9 individuals; 0.025%). Of these birds, most were occurring at the transect crossing the wind farm and fewer at the eastern part of the wind farm (Table 2). Compared to spring 2003 when most Common Scoters were recorded as migrating east of the wind farm, the occurrence in 2004 probably reflects the fact that high numbers of scoters consistently were present in the area just north of the wind farm in 2004, whereas in 2003, scoters were staging further north of the wind farm. The mean flock size in 2004 was comparable to the

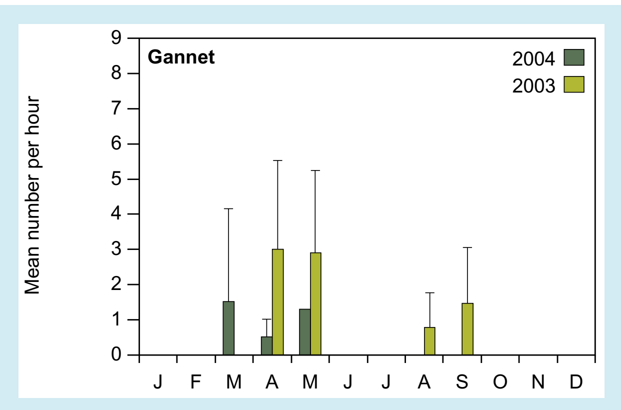

Figure 8. The number of Gannets recorded per hour of observation (± SD) during March, April and May 2004 and during 2003.

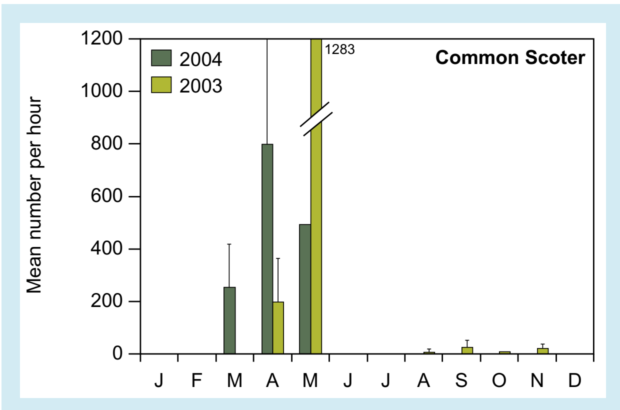

Figure 10. The number of Common Scoter recorded per hour of observation (± SD) during March, April and May 2004 and during 2003.

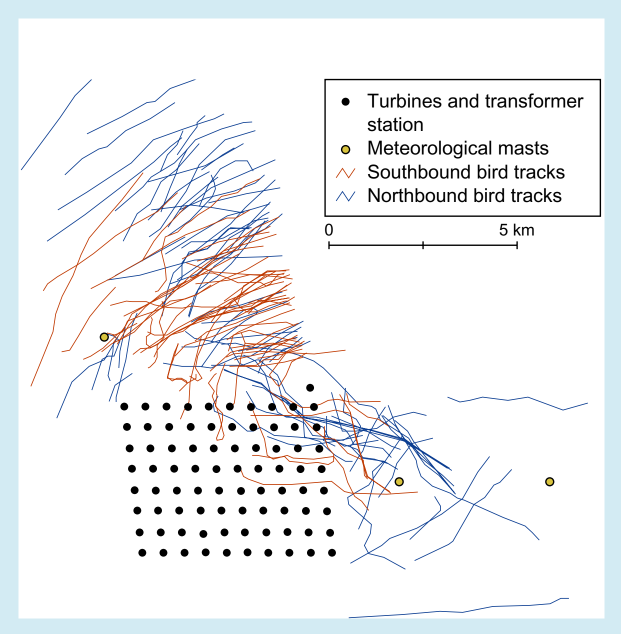

Figure 11. Radar tracks of 138 individuals/flocks of Common Scoter migrating southwards (N = 62) and northwards (N = 76) at Horns Rev during spring 2004.

mean flock size in 2003 (Table 4). All recorded radar tracks of southbound and northbound Common Scoters are shown in Fig. 11. As evident from Fig. 11, Common Scoters were frequently observed flying within the northeastern area of wind farm, as was confirmed by visual observations. These movements were clearly related to birds flying to and from the common roosting and foraging area just north of the wind farm, which was used at least by approximately 3,000-3,500 Common Scoters during April and May 2004 (cf. Petersen et al. 2005).

Gulls Laridae

During spring 2004, a total of 1,250 gulls were counted, of which 33% could not be identified to the species level. Of the identified birds the most numerously occurring species was Herring Gull (28%) and Common Gull (18%). Except for Black-headed Gull (N = 6), all identified species were

Table 3. Mean number (M) of birds per 15-minute visual observation period with 95% lower (L) and upper (U) confidence limits and total number of individuals (N). The species are Herring Gull, Great Black-backed Gull, Arctic/Common Tern and Sandwich Tern and the group 'other gulls' (all other identified and unidentified gulls, except Kittiwake) recorded visually during the spring 2003 and 2004. These are observed crossing four transects located east and north of the wind farm, along the eastern row of turbine (In/Out) and crossing the wind farm (Within). The data set was log-transformed before the means and confidence limits were calculated.

		Spring 2003				Spring 2004			
		L	M	U	N	L	M	U	N
Herring Gull	East-transect	0.17	0.32	0.48	51	0.71	1.51	2.69	97
	North-transect	0.22	0.43	0.47	76	0.81	1.71	3.05	145
	In/Out	0.23	0.53	0.89	85	0.31	0.75	1.33	37
	Within	-0.01	0.05	0.12	5	0.62	1.41	2.58	78
Great Black-backed Gull	East-transect	0.24	0.41	0.6	67	0.09	0.29	0.53	13
	North-transect	0.17	0.31	0.47	39	0.05	0.31	0.64	24
	In/Out	0.11	0.27	0.45	29	-0.4	0.04	0.14	2
	Within	0.06	0.16	0.27	15	-0.02	0.12	0.29	5
Other gulls	East-transect	0.38	0.61	0.88	119	1.33	2.50	4.27	143
	North-transect	0.17	0.35	0.56	56	1.41	3.41	7.07	541
	In/Out	0.29	0.56	0.89	72	0.17	0.67	1.38	66
	Within	0.1	0.31	0.55	56	0.18	0.72	1.52	47
Arctic/Common Tern	East-transect	0.24	0.50	0.82	154	0.23	0.88	1.87	96
	North-transect	0.11	0.32	0.58	75	-0.02	0.14	0.32	9
	In/Out	0.26	0.64	1.12	176	-0.08	0.08	0.26	6
	Within	-0.03	0.03	0.08	3	-	-	-	0
Sandwich Tern	East-transect	1.18	1.66	2.24	490	0.24	0.74	1.44	55
	North-transect	1.59	2.36	3.37	743	0.37	1.20	2.52	195
	In/Out	4.35	6.91	10.71	1,048	0.35	1.00	1.98	86
	Within	0.96	1.60	2.44	462	0.13	0.57	1.18	37

Table 4. Mean flock size (M) with 95% lower (L) and upper (U) confidence limits, and total number of flocks (N) observed during spring 2003 and 2004. Data were log-transformed.

	Spring 2003				Spring 2004			
	L	M	U	N	L	M	U	N
Divers	1.01	1.39	1.90	11	0.97	1.21	1.50	11
Gannet	1.09	1.16	1.22	137	0.95	1.18	1.47	19
Common Scoter	4.38	4.63	4.88	1,205	3.85	4.11	4.38	1,292
Herring Gull	1.08	1.13	1.18	183	1.13	1.18	1.23	279
Great Black-backed Gull	1.07	1.13	1.19	126	1.04	1.18	1.33	34
Black-headed Gull	1.39	2.51	4.52	15	0.55	1.32	3.15	4
Common Gull	1.08	1.19	1.32	55	1.21	1.30	1.40	154
Little Gull	1.44	1.84	2.35	27	1.54	1.89	2.31	56
Kittiwake	1.11	1.17	1.23	191	1.08	1.29	1.54	34
Arctic/Common Tern	1.79	2.04	2.32	139	1.68	2.15	2.75	38
Sandwich Tern	1.25	1.27	1.29	1,962	1.53	1.65	1.78	186

recorded within the wind farm, although numbers were generally lower on transects within the wind farm than on transects outside the wind farm (see Table 3). Compared to spring 2003, migration intensity of gulls was higher in 2004, except for Great Black-backed Gull that showed lower migration intensity (Table 3). The mean flock size of gulls ranged between 1.18 and 1.89 individuals, being highest for the Little Gull, and was fully comparable to flock sizes recorded in spring 2003 (Table 4). All recorded radar tracks of southbound and northbound gulls are shown in Fig. 12. Gulls were frequently observed within the wind farm area.

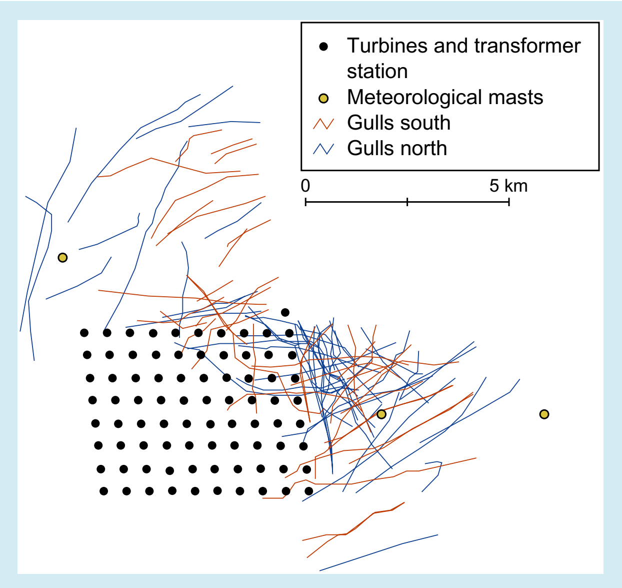

Figure 12. Radar tracks of all 89 individuals/flocks of Gulls migrating southwards (N = 39) and northwards (N = 50) at Horns Rev during spring 2004.

Terns Sterna spp.

A total of 498 terns were recorded during the spring of 2004, of which 2.8% could not be identified to the species level. Of the identified birds the Common/Arctic Tern represented 22% (N = 111), while Sandwich Tern constituted 75% (N = 373) of all recorded terns. Mean migration intensity ranged between 0.08 and 0.88 individuals per 15-minute periods for the Common/Arctic Tern and between 0.57 and 1.20 individuals per 15-minute periods for the Sandwich Tern. Generally, migration intensity of both species was lower in 2004 than in 2003 (Table 3), and most terns were recorded on transects outside the wind farm. The mean flock size was slightly higher for the Common/Arctic Tern (2.15 individuals) than for the Sandwich Tern (1.65 individuals), but comparable to flock sizes recorded in 2003 (Table 4). All recorded radar tracks of southbound and northbound terns are shown in Fig. 13.

Other species

During the afternoon of May 13 2004, a substantial migration of shorebirds was recorded. All flocks were initially identified by the radar, and most were observed in the area to the south and east of the wind farm. Most flocks (N = 20) were only recorded by radar and not visually identified, but 12 flock were identified as Knot *Calidris canutus*, including 2,150 individuals. Flight speed of identified flocks of Knots was similar to the flight speed of unidentified flocks, as were the main direction and echo appearance on the moni-

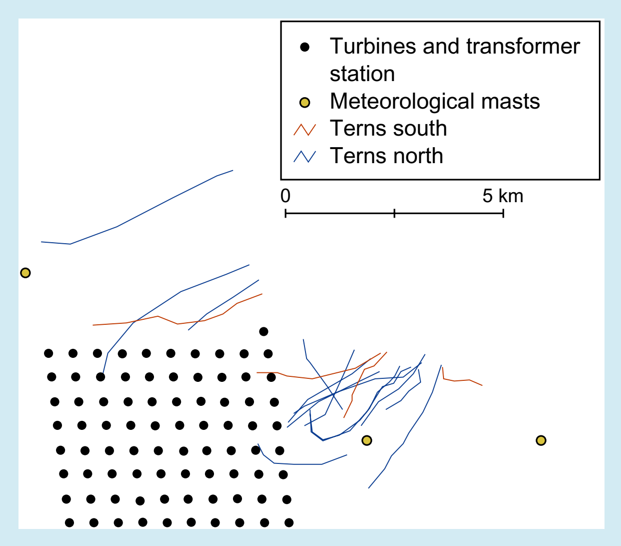

Figure 13. Radar tracks of all 18 individuals/flocks of terns migrating southwards and northwards at Horns Rev during spring 2004.

tor. Given this it was assumed that most unidentified flocks represented Knots. The flight altitude of one flock was estimated to be ca. 398 metres above sea level, which corresponded well with the observers impression of most flocks flying at high altitudes (assessed to >300 m above seas level and high above the turbines) and very difficult to locate. All recorded tracks of migrating shorebirds are shown in Fig. 14, including two separate flocks of Curlew *Numenius arquata* recorded on March 25 and May 11, respectively.

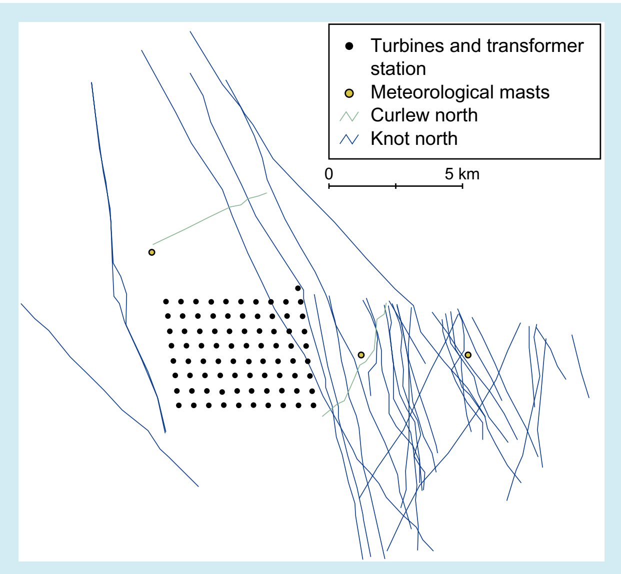

Fig. 14. Radar tracks of Knot (N = 12), Curlew (N = 2) and unidentified shore birds (N = 20, probably Knots) migrating northwards at Horns Rev during spring 2004. No records were obtained on southward migration.

During April and May two to three Shags *Phalacrocorax aristotelis* were frequently observed to perch and rest on the meteorological mast east of the wind farm, and on the wind turbines. One bird was observed foraging close to wind turbines inside the wind farm and around the transformer station.

3.1.2 Lateral changes in migration routes

The 184 selected tracks (see methods) of migrating waterbirds that moved in a southerly direction (towards the northern border of the wind farm area) exhibited a migration orientation between 175° and 224° (Fig. 15). This range is comparable to the range recorded in the autumn 2003 (185°-232°). Migration orientation changed significantly from a southwesterly direction to a southerly direction close to the wind farm (ANOVA: $F_{54,354} = 2.60$, $P < 0.0001$, $R^2 = 0.28$; N = 409 track segments). The migration orientation was significantly related to distance to the wind farm (ANOVA: $F_{14} = 6.79$, $P < 0.0001$) and to the interaction between time of day and direction of the wind (ANOVA: $F_{1} = 7.68$, $P < 0.01$). As recorded in autumn 2003, a shift in orientation was evident at a distance of approximately 400-500 metres from the wind farm (Fig. 15), although not so marked as the change recorded in 2003.

Separate analyses performed on track segments recorded at distances of more than 400 m from the wind farm showed that the mean orientation

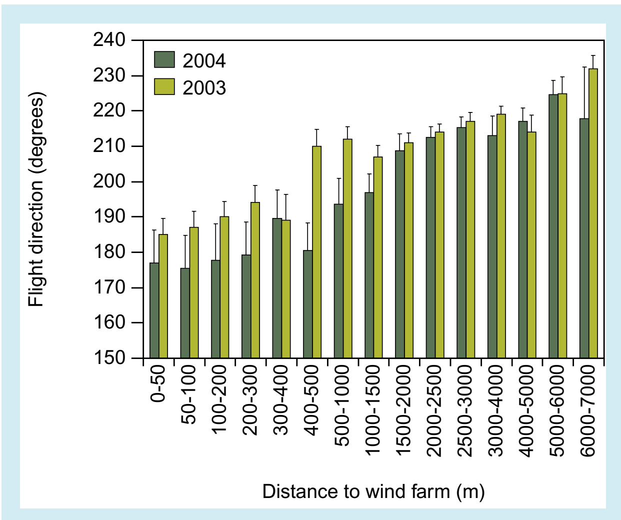

Figure 15. Mean orientation (± SE) of 184 southbound tracks of migrating birds recorded by radar north of the wind farm in spring 2004 and autumn 2003 in relation to distance to the wind farm.

Table 5. Analysis of variance of effects from distance from the wind farm, time of the day (day/night), wind direction and the combined effects (*) on the orientation of migrating birds approaching the wind farm from the north. This was made separately on bird tracks at distances of less than 400 metres and more than 400 metres from the wind farm.

	< 400 m			> 400 m		
Factor	F	DF	P	F	DF	P
Distance	0.36	5	0.874	3.12	8	0.002
Day	1.62	1	0.205	2.52	1	0.114
Wind	0.25	1	0.620	1.30	1	0.255
Distance*Day	0.49	5	0.785	1.26	7	0.271
Distance*Wind	0.72	5	0.609	0.56	7	0.785
Day*Wind	7.65	1	0.007	2.53	1	0.113
Distance*Day*Wind	0.08	4	0.988	1.11	6	0.356

of migration (207° ± 1.7 SE) was significantly related to distance to the wind farm, but not to other factors (Table 5). At distances less than 400 m from the wind farm the orientation of migration averaged 181° ± 4.1 SE, and was significantly related to the interaction terms time of day and wind direction (Table 5). During daytime and easterly wind directions mean migration orientation was more southerly (183° ± 4.9 SE, N = 67) than during nighttime and westerly wind directions (200° ± 8.2 SE, N = 21). Due to small sample sizes (less than 5 individual tracks), data on other combinations are not presented.

Compared to lateral deflection patterns recorded during autumn 2003, the present observations do not deviate markedly, although some differences do exist. The general pattern is that birds flying close to the wind farm adjusted their orientation to enter the wind farm perpendicular to pass in between separate turbine rows, and that this adjustment in orientation was more precise during daytime than during nighttime. This pattern seems to be consistent between years.

The 92 selected tracks of migrating waterbirds that moved in a southerly direction (towards the eastern border of the wind farm area) showed a mean orientation between 180° and 349°. This range is somewhat broader than recorded during autumn 2003 (233°-256°), and is mainly related to a northerly orientation in tracks at distances of between 300 m and 1,000 m from the wind farm (Fig. 16). Mean orientation showed significant variation (ANOVA: $F_{56,303} = 1.91$, $P < 0.001$, $R^2 = 0.26$; N = 360 track segments), being significantly affected by distance to the wind farm and from the combined effects of day and wind.

At distances of less than 1,000 metres from the wind farm, the effect of distance disappeared, and only wind direction and the combined effect of day and wind significantly affected bird orientation (Table 6). At distances of more than 1,000 metres, mean orientation was not affected by any factor included in the model (Table 6).

There is no obvious explanation to the differences in orientation between 2003 and 2004, but it may relate to comparison of data collected during autumn (2003) and spring (2004). Thus the tendency for a northerly deflection during the spring 2004 would arise if tracks of northerly migrating birds are erroneously included in this sample of southward moving bird tracks, as may be indicated by the huge variation observed at all distance inter-

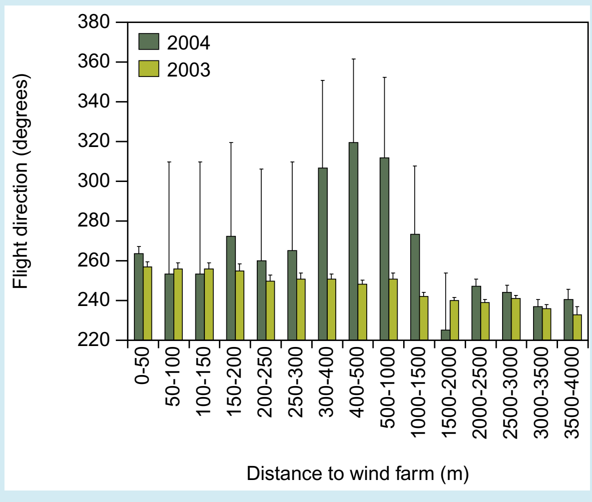

Figure 16. Mean orientation (± SE) of 92 southbound tracks of migrating birds recorded by radar east of the wind farm in spring 2004 and autumn 2003 in relation to distance to the wind farm.

Table 6. Analysis of variance of effects from distance from the wind farm, time of the day (Day), wind direction and the combined effects (*) on the orientation of migrating birds approaching the wind farm from the east. This is made separately on bird tracks at distances of less than 1,000 metres and more than 1,000 metres from the wind farm.

	< 1,000 m			> 1,000 m		
Factor	F	DF	P	F	DF	P
Distance	0.44	9	0.911	0.95	4	0.439
Day	3.65	1	0.058	0.01	1	0.925
Wind	6.86	1	0.010	0.90	1	0.345
Distance*Day	0.31	9	0.982	0.55	4	0.698
Distance*Wind	1.23	9	0.282	0.94	4	0.441
Day*Wind	12.58	1	0.001	0.03	1	0.863
Distance*Day*Wind	0.49	6	0.816	0.56	6	0.690

vals compared to similar data from 2003 and to data from the area north of the wind farm. Potentially, the increased variance may be a result of an increase in northward deflection which would be the result of movements of, i.e., Common Scoters, between near-coast areas and the large concentration that appeared along the end of Horns Rev during spring 2004. That more birds turn northward may also occur if the northward migrating birds (that have followed the coastal zone) have turned into a southerly direction when passing Blåvandshuk are ending up at the wind farm, where they adjust to their original northward orientation. However, the occurrence of both locally staging and migrating birds of the same species, makes it difficult to make a clear assessment of this diverting pattern. Alternatively, this pattern may originate if birds show some strong deflective response to the wind farm.

In the analyses of bird deflection there was a substantial decrease in the number of tracks with decreasing distance to the wind farm both to the north and east of the wind farm. 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 disappeared on the screen.

3.1.3 Probability of birds passing into wind farm area

The number of bird tracks that complied with the selection criteria was very low at both the northern (N = 49) and eastern (N = 31) side of the wind farm. Consequently, the present results should be taken only as indications and not considered as conclusive.

During spring 2004, none of the 49 tracks selected in the area north of the wind farm passed into the wind farm. Of the 31 tracks directed towards the eastern side of the wind farm, 9 tracks (29%) entered the wind farm. This percentage was slightly higher, but comparable to the 21% recorded in autumn 2003.

In order to describe the probability of bird flocks passing into the wind farm area in further detail, logistic regression models were applied including different cross wind situations (northerly (271°-90°) and southerly (91°-270°)), day and night, and direction of migration measured as the mean orientation between track-points located 1,500 m and 2,000 m from the wind farm.

Including wind direction in the model was not valid for statistical reasons. Thus, the final model included only time of day and mean migration orientation. The logistic regression models did not

Table 7. Maximum Likelihood Analysis of Variance of effects from time of the day (Day), flight direction between 1,500 and 2,000 m from the wind farm, and the combined (*) effects of the two factors on the presence of tracks at the eastern gate of the wind farm area during spring 2004 (N = 31 tracks).

Factor	χ^2	DF	P
Day	3.24	1	0.072
Direction	0.93	1	0.334
Direction*Day	3.40	1	0.065

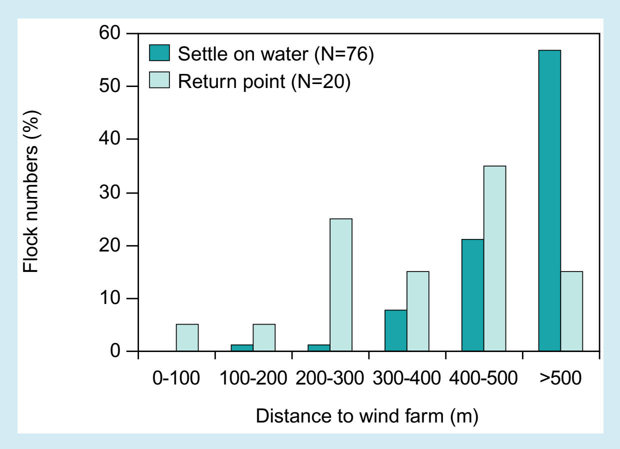

Figure 17. The percentage of flocks in relation to distance to the wind farm of Common Scoter approaching the wind farm from the north that settle on the water or turn away from the wind farm.

show any significant effects from the factors included, although the effect of day (day/night) was almost significant (Table 7). Thus, there were no indications that the probability of birds of flying into the wind farm differed between day and night or was affected by the mean orientation. However, it should be considered that the sample sizes are small and this may influence the sensitivity of the test.

3.1.4 Disappearance of radar tracks: Common Scoter as an example

As recorded in the autumn 2003, several bird tracks disappeared from the radar long before entering the wind farm, and these disappearances may reflect a potential reaction towards the wind farm.

Disappearance of birds on the radar monitor may have several explanations (see Christensen et al. 2004). First, echo disappearance may occur when birds stop flying to land on the sea surface. Secondly, as birds turn to avoid or pass around the wind farm, the cross-sectional area of the birds may be to small to be detected by the radar, e.g., birds seen from the front or behind generally provide a smaller area for the radar to detect, compared with the area provided if the birds are 'seen' from the side.

In the area to the north of the wind farm, a total of 96 flocks of Common Scoters were observed visually while approaching the wind farm from the north. Of these, 76 flocks landed on the sea surface, with a total of 52 flocks (57%) landing on the water at a distance of more than 500 metres from the nearest turbines. Only two flocks (2.6%) were observed landing on the water closer than 300 metres from the turbines (Fig. 17).

The remaining 20 flocks approaching the wind farm were observed to react to the wind farm by changing flight direction. The vast majority of flocks (90%) changed their flight direction at distances of more than 200 metres from the turbines, while only two flocks (10%) flew in closer than 200 metres from the turbines before they changed flight direction (Fig. 17).

None of the 96 flocks of Common Scoter were observed to fly into the wind farm during these observations.

3.1.5 Northward migration

The mean direction of northward bird migration in separate zones around the wind farm at Horns Rev is shown in Fig. 18. In the area to the north and east of the wind farm, the mean direction of migration is between north and northeast, whereas in the area to the south and west of the wind farm the overall direction of migration is

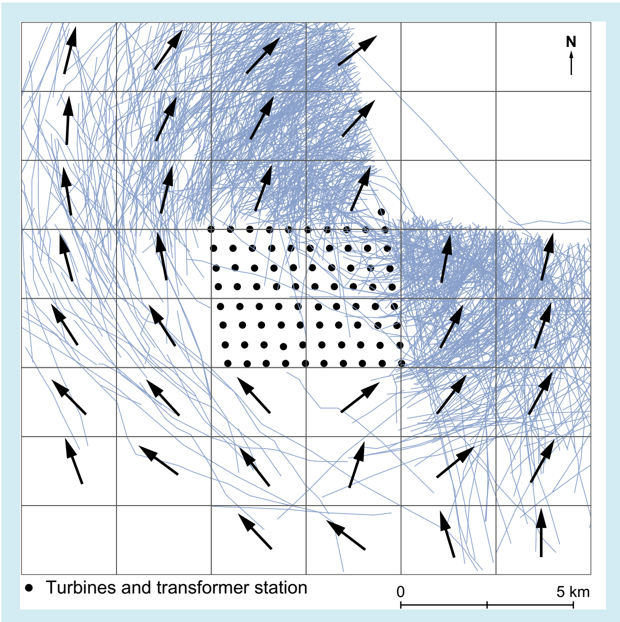

Figure 18. Mean orientation (arrows) of northward bird migration at Horns Rev during the spring 2004. Orientation is calculated in separate grid squares of 2,750x2,000 metres centred around the wind farm and is based on a total of 1,316 bird tracks recorded by radar.

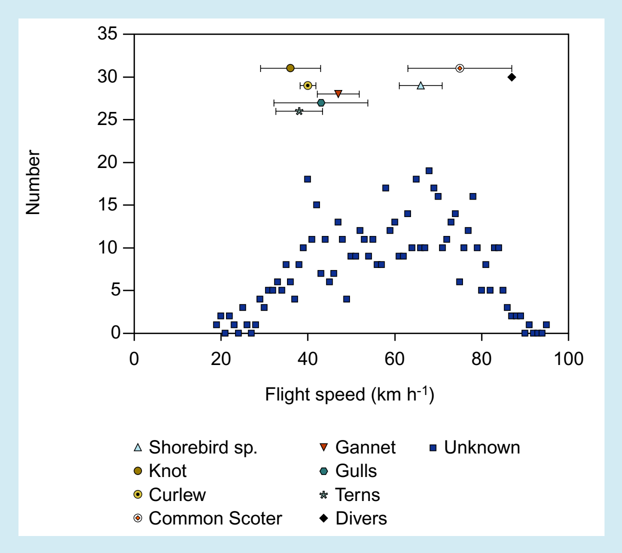

Figure 19. The frequency distribution of flight speed measurements of unidentified species recorded during spring 2003. Flight speed of selected species identified is shown separately as mean and SE.

northwest. This pattern indicates that northward migrating birds tend to avoid flying through the wind farm, and that they adjust their orientation at some distance to the wind farm. Tentatively assessed from individual tracks south of the wind farm (Fig. 18), deflection in most tracks seems to have occurred at distances of between 4 and 6 km from the wind farm.

Despite the fact that detection of birds by radar is reduced in the area to the south and west of the wind farm, the present data suggest that a substantial part of the spring migrants deflect westwards around the wind farm, even though they approach the wind farm from south-easterly directions. As this deflection only occurs south and southwest of the wind farm, and the orientation of migration change towards the north after passage of the wind farm, the present data suggest that the presence of the wind farm generate a deflection in bird migration in the Horns Rev area. This occurs at a considerable distance from the wind farm. A corresponding eastward deflection in northward migration east of the wind farm is not as marked as in the areas to the south and west of the wind farm. This is probably related to inclusion of local bird movements in this area, especially by gulls and terns, which due to their small size are not detected by radar in the area south and west of the wind farm.

3.1.6 Flight speed

Flight speed measures were obtained on a total of 712 tracks of birds during the spring 2004, of which 126 were identified to the species level. In figure 19 the data is presented graphically including the measures of selected species (divers N = 1, Common Scoter N = 47, Gannet N = 9, Gulls N = 27, Terns N = 3, shorebirds sp. N = 17, Knot N = 12 and Curlew N = 2).

The distribution of unknown species show a tendency of a bimodal pattern with peak number of birds having a flight speed of about 40-45 km/h and 60-70 km/h, respectively, which compares to the identified species. The identified species display a division between slowly flying gulls, terns, Knot, Gannet and Curlew, and faster flying Common Scoter, divers and unidentified shorebirds.

Even though the present data show that various overlaps in flight speed exist between species, it can also be seen that separation between some species or groups of species may be possible on the basis of flight speed.

4 Discussion and conclusions

4.1 Assessing effects of wind farm operation on migratory birds

The importance of the study area at Horns Rev for migrating and staging waterbird species was confirmed during spring 2004. Gulls and terns dominated the count results in the area. The Common Scoter was the most numerous species recorded, as a result of a substantial number of staging birds in the area during April and May.

Autumn bird migration patterns at the nearby coast of Blåvandshuk is well described (Kjær 2002, Jacobsen in prep.), documenting the southward autumn migration along the coast of Jutland of many waterbirds and terrestrial species. In spring, the observations from Blåvandshuk are more sporadic. Nevertheless, it has been documented that a substantial part of waterfowl and seabird migration during spring actually is heading south, probably as a result of bird avoidance of low pressure systems crossing the North Sea north of the Horns Rev area (see Mouritsen 1991). In the present study, we found substantial northbound bird movements at Horns Rev, suggesting that northbound migration is dominating at Horns Rev during spring. However, southbound bird migration still comprised 30% of all recorded tracks.

In spring 2004 almost equal proportions of tracks were recorded during day- and nighttime. Although detectability of birds/groups of birds by radar is affected by weather conditions and by the distance to the birds, the most intensive bird movements were recorded to the north of the wind farm.

It must be stressed that direct comparison between bird numbers, activity of bird movements 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 generate an echo, whereas visual observations would be able to register such birds.

Of the focal waterbird species (divers, Gannet, Common Scoter, gulls and terns), only gulls and terns were observed regularly within the wind farm area. In spring 2004, Common Scoters were also recorded occasionally within the wind farm, but the total of 635 individuals comprise only 2.8% of all birds recorded during transect counts. In April and May 2004, several thousand Common Scoters were consistently recorded exploiting the area just a few hundred metres north of the wind farm (see Petersen & Hounisen 2004), and the birds were observed to make substantial movements to and from this area. During such local movements, some flocks of Common Scoters were observed to fly into the wind farm, even though the main movements occurred further northeast.

No divers and only one Gannet were observed inside the wind farm. Although relatively few individuals of these species were recorded, the observed flight behaviour followed the same pattern of passing around the wind farm that was observed during autumn 2003. The majority of observed flocks of Common Scoters that were flying toward the wind farm showed a similar tendency of avoiding the wind farm by making turns at distances of between 100 m to 400 m from the wind farm. However, the observations of bird flight behaviour suggest that divers, Gannets and Common Scoters actively avoided the wind farm area and only occasionally enter the wind farm.

The migration intensity of divers in March 2004, which coincided with the late staging period of wintering divers, was higher than during the migration periods in April and May. Thus, the present observations support previous records showing that during spring divers peak in their occurrence in the Horns Rev area during February and March (see Christensen et al. 2003).

Gulls and terns generally showed higher flight intensities outside the wind farm than within the wind farm and, with the exception of Sandwich Tern, also showed lower flight intensities within than at the outer (eastern) row of turbines. Compared to flight intensities during spring 2003, only Herring Gull showed a marked increase in flight intensity within the wind farm. Marked behavioural reactions to the wind farm and single turbines were not observed in gull and tern species.

Avoidance behaviour was recorded in Arctic/Common Terns during spring 2003, but these species were almost not present in 2004. Likewise, markedly lower numbers of Sandwich Terns were recorded in 2004.

As in 2003, very few radar tracks were recorded within the wind farm. This probably reflects the fact that few birds actually occurred within the wind farm compared to immediately outside. However, the turbines themselves caused radar shadows 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 for several bird echoes that moved behind turbines as these showed disrupted tracks. This resulted in a reduced detectability as birds moved farther than two or three turbine rows into the wind farm (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 the spring 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 to the north and east of the wind farm area.

Southbound bird migration tracks recorded during spring 2004 of waterbird movements showed a general southwesterly orientation at some distance from the wind farm. Generally, most bird tracks approaching the wind farm showed avoidance of the turbines by turning around the wind farm. However, a marked change in flight direction was, however, found in those birds flying in close to the wind farm from both the north and from the east. In both areas these modifications to flight direction ultimately resulted in an almost perpendicular entrance through the first row of wind turbines.

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. At short range the orientation of bird movements north of the wind farm was significantly affected by the combination of 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, mean track orientation of birds that entered the wind farm during night was 200° ± 8.2 SE, whereas mean orientation during daytime was 183° ± 4.9 SE, which is comparable to the results from autumn 2003 (195° ± 2.6 SE during night and 177° ± 4.9 SE during daytime). This suggests that while birds are able to see the rows of turbines more clearly during day time 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 turbine rows when passing through the wind farm area.

In the area east of the wind farm, the pattern of orientation of migrating birds showed a marked deviation at distances between 300 m to 1,000 m from the wind farm, having a northerly orientation. There is no obvious explanation, but this pattern may probably relate to the dominance of a northerly orientation in bird migration during springtime as compared to data compiled from the autumn 2003.

The change in flight orientation north of the wind farm recorded in spring 2004 was less distinct than in 2003. In 2003 a marked change in orientation occurred ca. 400 m north of the wind farm. However, within 400 m from the wind farm, migration orientation did not display changes, suggesting that birds have adapted their orientation to the presence of the wind turbines at this distance.

As in autumn 2003, visibility was not markedly reduced by the presence of heavy fog or misty conditions in spring 2004. Thus, the recorded flight direction of birds that approached the wind farm almost exclusively included bird movements during daytime or during clear night conditions. Under these circumstances, the birds were probably able to visually detect the wind farm, either directly during daytime or at nighttime by the flashing red lights located on turbine nacelles.

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 normal visibility exceeded 2 km for the vast majority of the main migration periods during spring 2004, the present results support the tentative conclusions of the 2003 study that the risk of collisions may be slightly higher during night than during daytime. This may be because the birds seem able to adjust their flight orientation more precisely during daytime.

4.1.2 Probability of birds passing into the wind farm area

Of the very few tracks that were selected for this analysis, the percentage of the waterbirds that passed through the northern and eastern gates of the wind farm area during spring 2004 was 0% and 29%, respectively.

In the area to the east of the wind farm, the probability of entering the wind farm was not affected by time of day (day/night) or by the orientation of the birds measured between 1,500 and 2,000 m from the wind farm, although differences between day and night were almost significant ($P = 0.072$). The effect of cross wind was not included in this analysis, as inclusion of this factor violated the model.

The results from spring 2004 is comparable to the results obtained in autumn 2003, where no effect was observed by either of the included factors. Thus, the probability of birds flying into the wind farm does not seems to be markedly affected by time of day, by wind direction, and by the migratory orientation of the birds.

4.1.3 Flight speed

Flight speed was recorded routinely during radar observations with the aim to subsequently assign unidentified radar tracks to species groups or to species based on known flight speeds of identified birds. In spring 2004, flight speed measures of unidentified birds tended to show a bimodal distribution, indicating that at least two groups of birds could be separated on the basis of flight speed: one group of slow flying birds including gulls, terns, Gannet and some shore birds (Curlew, Knot), and one group of fast flying bird species including divers, Common Scoter and some unknown shore bird species (probably Golden Plover).

4.2 Concluding remarks

This report presents the results derived from the study on birds and collision risk at the Horns Rev offshore wind farm based on data obtained during the spring of 2004. The analyses presented here employed the same methodological approaches as applied to the data collected in 2003, and mainly considered southbound migration. A rough analysis of northbound bird migration during spring 2004 has been developed describing the orientation and deflection in bird migration skirting the wind farm. A more detailed analysis of northbound bird migration is not applied since the ability of the radar to track bird movements in the area south and west of the wind farm is reduced considerably due to long distances and radar shadow effects from the turbines.

As expected, no actual collisions were observed during the three periods of observation (27 hours of visual observation) performed at the wind farm site during spring 2004.

Generally very few birds were recorded inside the wind farm. Gulls and terns were the most frequently occurring species recorded in between turbines, but mainly observed at the edge of the wind farm and far less in the central parts of the wind farm. During April and May thousands of Common Scoter were present in the area close to the wind farm, and flocks of this species were occasionally seen flying inside the wind farm. The low number of seabirds and waterfowl recorded inside the wind farm and the general tendency of deflection around the wind farm by migrating birds recorded by radar, indicate that most bird species generally exhibit an avoidance reaction to the wind turbines, which reduces the probability of collision.

As recorded during autumn 2003, most birds that actually entered the wind farm seemed to adjust flight orientation to pass through the wind farm in parallel with turbine rows and not to cross several rows. Even though more data on both occurrence and behaviour still needs to be sampled during periods of poor visibility, a less accurate adjustment of flight orientation was recorded during night time, suggesting that a higher risk of collision may be associated with migration during periods of darkness and therefore also of low visibility.

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Appendix I

Species and numbers recorded during counts on the transect 'Southwest' on specific days at Horns Rev during spring 2004.

	Date							
Species	24 March 2004	25 March 2004	26 March 2004	20 April 2004	21 April 2004	22 April 2004	12 May 2004	Total
Common Scoter		29	4	5	479		5	522
Common Gull					27	3		30
Herring Gull	2	4	2	10	57	3		78
Lesser Black-backed Gull						2		2
Great Black-backed Gull		1			1	3		5
Little Gull					1			1
Kittiwake					4		1	5
Gull sp.					12			12
HerrringGull/Great Black-backed Gull				2				2
Sandwich Tern					34	2	1	37
Passerine sp.					21		1	22

Appendix II

Species and numbers recorded during counts on the transect 'South' on specific days at Horns Rev during spring 2004.

Species	24 March 2004	25 March 2004	26 March 2004	20 April 2004	21 April 2004	22 April 2004	12 May 2004	Total
	Date							
Gannet	1							1
Shag							1	1
Merlin					1			1
Oystercatcher							1	1
Eider		1						1
Common Scoter	1	28	4	2	37	5	36	113
Common Gull		4	45		3	3		55
Herring Gull	3	6	9		18	1		37
Great Black-backed Gull							2	2
Herrring/Great Black-backed Black-headed Gull		1			1			2
Little Gull					1			1
Kittiwake		8					1	9
Gull sp.					7		1	8
Arctic/Common Tern							6	6
Sandwich Tern					77		9	86
Passerine sp.		1		1	18			20

Appendix III

Species and numbers recorded during counts on the transect 'West' on specific days at Horns Rev during spring 2004.

	Date							
Species	24 March 2004	25 March 2004	26 March 2004	20 April 2004	21 April 2004	22 April 2004	12 May 2004	Total
Red/Black-throated Diver	2	1						3
Gannet							4	4
Cormorant		2			7			9
Common Scoter	508	995	52	10	14,237	116	4,842	
Curlew		2	1					3
Arctic Skua							2	2
Skua sp.							3	3
Common Gull	3	13	6	1	35	11		69
Herring Gull	9	11	3	33	85	2	2	145
Great Black-backed Gull				6	17	1		24
Herrring Gull/Great Black-backed Gull				13	156	6		175
Black-headed Gull	1				1			2
Little Gull			47		83			130
Kittiwake	6				20		2	28
Gull sp.					145	18	2	165
Arctic/Common Tern					2		7	9
Sandwich Tern				5	183		6	194
Passerine sp.					2			2

Appendix IV

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

Species	24 March 2004	25 March 2004	26 March 2004	20 April 2004	21 April 2004	22 April 2004	12 May 2004	Total
Red/Black-throated Diver		5	3		3			11
Gannet	7				4	1	9	21
Common Scoter	34	473	79	12	503	69	52	1222
Golden Plover					2			2
Arctic Skua							4	4
Common Gull	2	17	13		37	5		74
Herring Gull	2	11	12	27	41	4		97
Great Black-backed Gull					6	1	6	13
Herrring Gull/Great Black-backed Gull		23						23
Black-headed Gull		4						4
Little Gull	2				3	12	3	20
Kittiwake	1	1			2	2	4	10
Gull sp.		2	7		10		3	22
Arctic/Common Tern					11		85	96
Tern sp.							14	14
Sandwich Tern					49	2	4	55
Razorbill/Guillemot							2	2
Guillemot							1	1
Starling		1						1
Passerine sp.		1	1		23	2		27

Appendix V

Miscellaneous observations of bird species recorded at the transformer station at Horns Rev during August 2002 - November 2003 and March-May 2004. The list is considered to accurately reflect the occurrence of species, whereas 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 (2002-2003)	N (spring 2004)
Shag	*Phalocrocorax aristotelis*		2-3
Sparrowhawk	*Accipiter nisus*	6	1
Peregrine Falcon	*Falco peregrinus*	1	
Merlin	*Falco columbarius*	1	
Woodcock	*Scolopax rusticola*		1
Caspian Tern	*Sterna caspia*		1
Wood Pigeon	*Columba palumbus*		1
Turtle Dove	*Streptopelia turtur*	1	
Collared Turtle Dove	*Streptopelia decaocto*	3 (2)	1
Short-eared Owl	*Asio flammeus*		1
Skylark	*Aluada arvensis*		1
Wood Lark	*Lullula arborea*	1	
Swallow	*Hirundo rustica*	14	4
Hooded Crow	*Corvus cornix*	1 (1)	2
Jackdaw	*Corvus monedula*	2	4
Wren	*Troglodytes troglodytes*	5	2
Redstart	*Phoenicurus phoenicurus*	(1)	2
Whinchat	*Saxicola rubetra*	1	
Wheatear	*Oenanthe oenanthe*	1	
Ring Ouzel	*Turdus torquatus*	(1)	
Blackbird	*Turdus merula*	1	1
Fieldfare	*Turdus pilaris*	1	2
Redwing	*Turdus iliacus*	10	
Song Trush	*Turdus philomelos*	2	
Robin	*Erithacus rubecula*		1
Reed Warbler	*Acrocephalus scirpaceus*	1	
Blackcap	*Sylvia atricapilla*	2 (1)	
Garden Wabler	*Sylvia borin*	1	
Whitethroat	*Sylvia communis*	1	
Lesser Whitethroat	*Sylvia curruca*	1	
Willow Warbler	*Phyloscopus trochilus*	3	
Chiffchaff	*Phyloscopus collybita*		3
Goldcrest	*Regulus regulus*	2	2
Meadow Pipit	*Anthus pratensis*	56	16
Yellow Wagtail	*Montacilla flava*	12 (1)	
White Wagtail	*Montacilla alba*	2	17
Starling	*Sturnus vulgaris*	29 (8)	12
Greenfinch	*Carduelis chloris*	3	
Linnet	*Carduelis cannabina*	4 (1)	5
Twite	*Carduelis flavirostris*	1	
Redpoll	*Carduelis flammea*		1
Crossbill	*Loxia curvirostra*	1	
Chaffinch	*Fringilla coelebs*	1	1

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Investigations of migratory birds during operation of Horns Rev offshore wind farm

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