# Investigations of migratory birds during operation of Horns rev offshore wind farm: Preliminary note of analysis of data from spring 2004

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## Information Note

This information note summarises the framework for the two notes, concerning the preliminary analyses of bird studies conducted during spring 2004 in relation to the offshore wind farm at Horns Rev.

The two notes are:

Petersen, I.K. & Hounisen 2004. Investigation of birds during the operational phase of the Horns Rev offshore wind farm - preliminary note on the issue of potential habitat loss.

Christensen, T.K. & Hounisen, J.P. 2004. Investigations of migratory birds during operation of Horns Rev offshore wind farm: Preliminary note of analysis of data from spring 2004.

It must be emphasised that the two notes were prepared to provide a preliminary update on the results from the bird studies carried out during spring 2004 to be used by authorities in the screening process of potential new wind farm sites in the Horns Rev area.

For this reason, the notes cannot be considered as final reports. Analyses are not exhaustive and results must be considered as very preliminary to await further consideration before submission of the annual status report for 2004 in March 2005.

# Contents

# 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 entire project has been 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, bird investigations have been carried out in relation to the risk of collision between birds and wind turbines since 2002. To provide the latest update on the results from the bird investigations, this note presents results compiled during spring 2004 and deals with a preliminary analysis of 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.

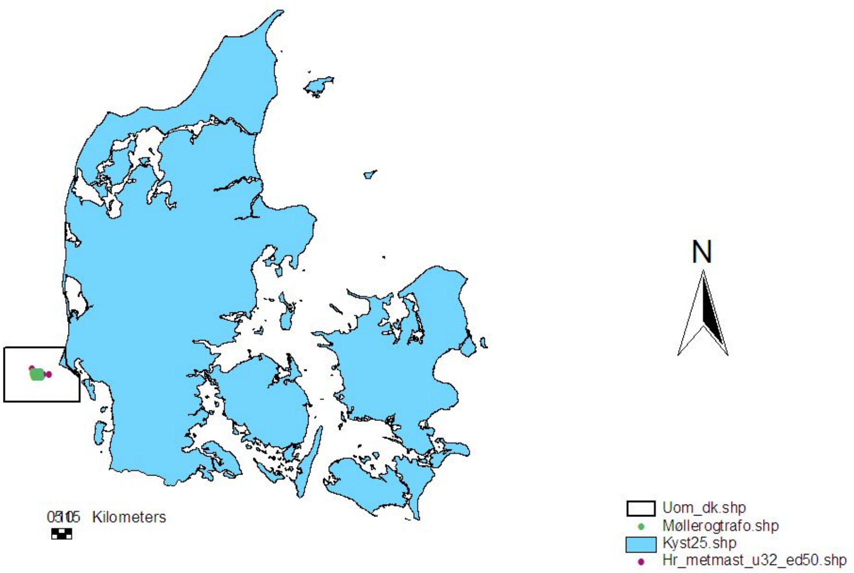


Fig. 1. The location of the Horns Rev offshore wind farm in the Danish part of the North Sea.

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) Disturbance effects (displacement, equivalent to habitat loss).

The present note only refers to investigations of the risk of collision. 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).

# 2. Methods

## 2.1 Study area

The wind farm is located in the North Sea c. 14 km west-southwest of Blåvandshuk at water depths of c. 6-12 m (Fig. 2). The wind farm comprises 80 turbines placed in 10 north-south orientated rows with 8 turbines in each row. 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 northeasternmost turbine in the wind farm. Mapping of bird movements 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, respectively, one along the eastern row of turbines and one crossing diagonally through the wind farm in a south-westerly direction (Fig. 2). 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 speed. Radar observations covered an area extending 6 nautical miles (c. 11 km) from the transformer station, but did not cover the area between c. 360° and 95° due to the structure of the transformer station (see Fig. 2).

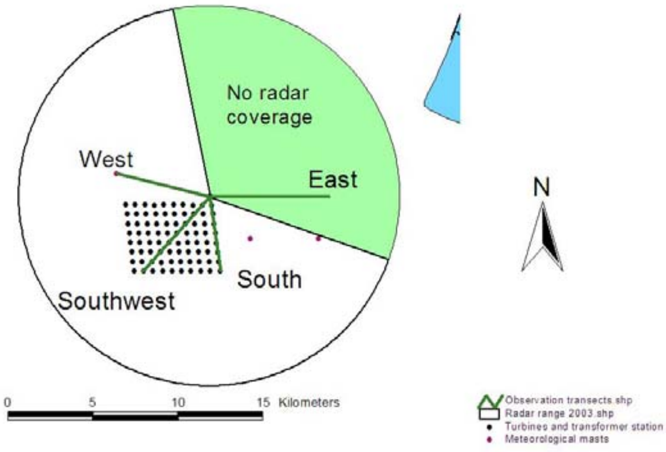


Fig. 2. The study area with location of the four transects used in the visual observation and the areas covered/not covered by radar.

## 2.2 Monitoring of migratory birds

Visual and radar observations were performed in March, April and May 2004. Observations of the bird migration intensity, species composition, flock size and migration routes were performed day and night totalling 27 hours of visual transect observation and 82 hours and 25 minutes of radar observations. 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, and for safety reasons.

During spring 2004, visual data were collected during daytime using a telescope (30x), and data were recorded by 15-minute periods. The results obtained from the daytime telescope observations made possible a species specific description of the abundance, phenology and behaviour of birds occurring in the area. The telescope observations thereby made an important contribution to the assessment of potential impacts and their consequences at a species level.

The mean number of birds passing the transects was calculated per 15-minute period (migration intensity) for separate transects and for each period of observation. 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 long distance and during periods of poor visibility due to fog or darkness a ship-radar (Furuno FR2125 or FR2110) was used. Each echo on the 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.

During spring, the mean orientation of bird migration is northwards. However, observations at Blåvandshuk during spring often show substantial southwards movements by seabirds, which may be related to birds avoiding low-pressures (cyclones) normally having a more northerly course in passing the North Sea (see Mouritsen 1991). Thus some southbound migration was expected as well.

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 note is placed on southbound migration approaching the wind farm for three reasons, 1) the radar, positioned northeast of the wind farm, have a much lower probability of detecting birds approaching the wind farm from southerly directions than birds approaching from the north, due to longer distances from the radar and to some shadow effect from the wind turbines, 2) the results are directly comparable to those obtained during the autumn 2003, and 3) a detailed analysis of northbound migrating birds must await a revised methodological approach that will be developed and subsequently presented in the main 2004 annual report.

The migration routes were mapped by tracing the course of bird flocks from the radar monitor on to a transparency. 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. Afterwards, the tracks on transparencies were digitised and entered into a GIS-database.

Following the methods used in 2003 (Christensen et al. 2004), data were collected in spring 2004 in order to test the main hypothesis that migratory birds show a lateral avoidance response to the wind farm. In order to assess 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.

Time of day, season and wind direction has previously been shown to have significant effects 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

The 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, excluding tracks that did not cross at least two of 15 transects located 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, Fig. 3). 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 Christensen et al 2004 for details).

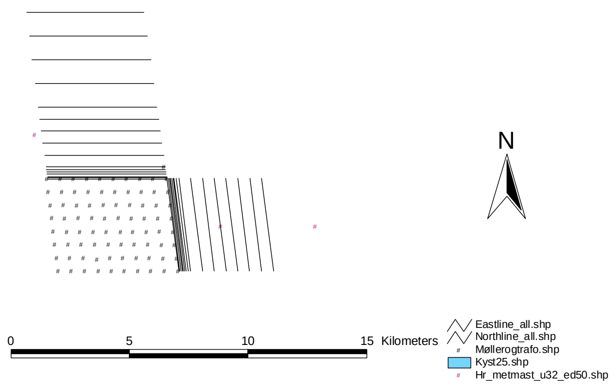


Fig. 3. Location of transects north and east of the wind farm used in the analyses of lateral changes in migration orientation of birds during the spring 2004.

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 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) in statistical analyses (ANOVA).

### 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. However, due to the low number of tracks, tracks that were longer than 1 km was included as opposed to the 2 km criteria used in the 2003 analyses (Christensen et al 2004).

The proportion of migration tracks that entered into the wind farm from the north and east was calculated. The effect of cross winds, time of the day (day and night) and bird track orientation at 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.

## 2.3 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 was obtained from the meteorological mast placed c. 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 while minimising the time span between weather and bird records. This was done with a 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 a site 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. For reasons mentioned above, the present notes will mainly focus on southward movements of birds. As this note presents only the preliminary results of the spring 2004, it mainly includes observations of the most numerously occurring species recorded. Data on, for instance, passerine occurrence is not included, but these will be presented later in the annual report for 2004.

During spring 2004, a total of 578 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. That fewer tracks are recorded in the latter areas is to some extent affected by a shadow effect of the individual wind turbines and from the reduction 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.

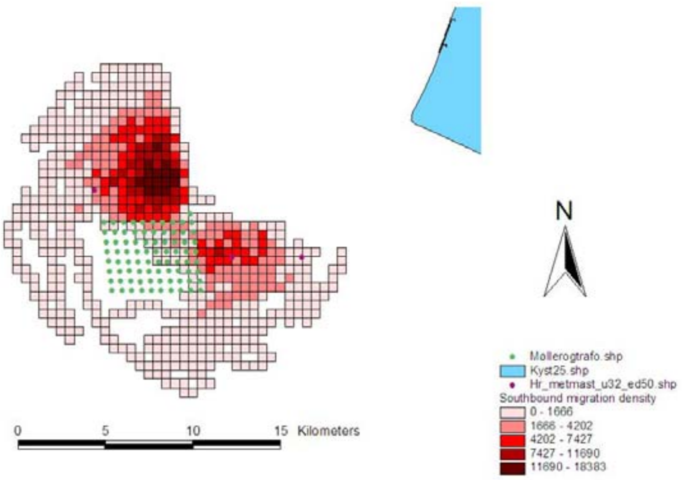


Fig. 4. Spatial density of 578 southbound bird migration at Horns Rev during spring 2004, expressed as total meters of radar tracks per 500x500 m grid square.

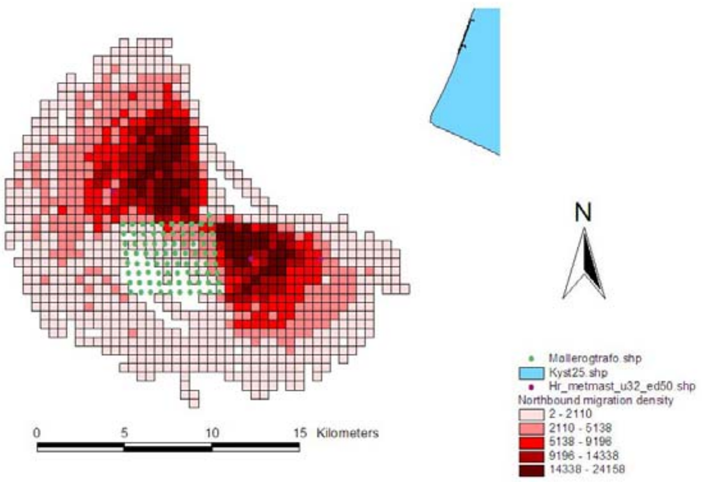


Fig. 5. Spatial density of 1,316 northbound bird migration at Horns Rev during spring 2004, expressed as total meters of radar tracks per 500x500 m grid square.

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 Common Scoter and divers occurred in numbers comparable to numbers recorded in 2003, whereas Gannets and terns occurred in lower numbers. Gulls were generally recorded in higher numbers in the spring 2004 than in 2003, except for Great Black-backed Gull, which occurred in lower numbers.

In the following paragraph a suite of selected species occurring at Horns Rev are considered with regards to flight intensity, flock size or flight behaviour relevant to wind farm issues. When referred to results from 2003, see Christensen et al. (2004).

Table 1. 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 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 | 1222 |
| | 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 |

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) for 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 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 3. 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 |

**Divers** *Gavis arctica/stellata*

A total of 14 divers were recorded east and north of the wind farm. No divers were recorded within the wind farm. The mean migration intensity of 0.06-0.23 individuals per 15-minute is not different from the intensity (0.13 bird/15 min) recorded in 2003 (Table 1). Migration intensity was highest in March and declined during April and May (Fig. 6), which probably reflects that the highest number of staging divers in the area occur during late winter (see Christensen et al. 2003, Petersen et al. 2004). 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 that the observation 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 3).

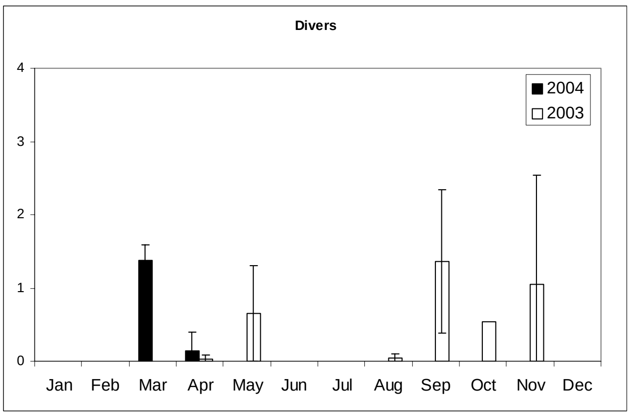


Fig. 6. The number of divers recorded per hour of observation (± SD) during March, April and May 2004 and during 2003.

**Gannet** *Sula bassanus*

During spring 2004, a total of 26 Gannets were counted. Most Gannets were recorded 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 1). The numbers of Gannets recorded in April and May was lower than in the same period in 2003 (Fig. 7). Mean flock size in 2004 was comparable to mean flock size in 2003 (Table 3).

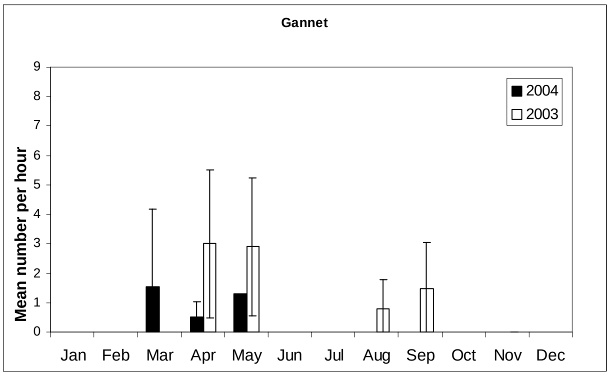


Fig. 7. The number of Gannets recorded per hour of observation (± SD) during March, April and May 2004 and during 2003.

**Common Scoter** *Melanitta nigra*

A total of 22,617 Common Scoters were recorded during the spring 2004. The vast majority (92%) of the Common Scoters were observed north of the wind farm and during April and May (Table 1, Fig. 8). A relatively large number of birds were recorded within the wind farm in spring 2004 (635 individuals; 2.81%) compared to the spring 2003 (9 individuals; 0.025%; N = 35,779). Of these birds, most were occurring on the transect crossing the wind farm and fewer at the eastern part of the wind farm (Table 1). Compared to spring 2003 where most Common Scoters were recorded as migrating east of the wind farm, the occurrence in 2004 probably reflects 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. Mean flock size in 2004 was comparable to mean flock size in 2003 (Table 3).

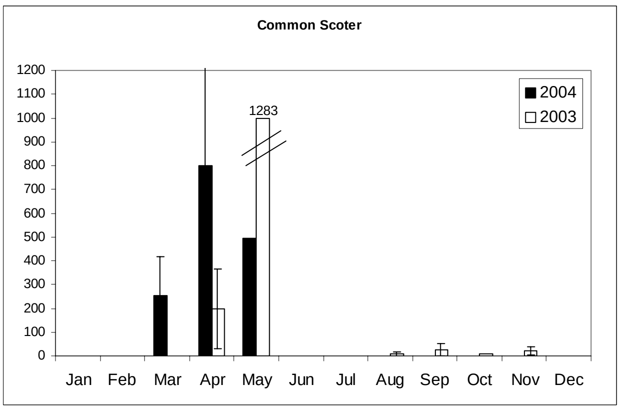


Fig. 8. The number of Common Scoter recorded per hour of observation (± SD) during March, April and May 2004 and during 2003.

**Gulls** *Laridae*
During spring 2004, a total of 1,250 gulls were counted, of which 33% could not be identified to species. The most numerously occurring species was Herring Gull (28%) and Common Gull (18%). Except for Black-headed Gull (N = 6), all identified species were recorded within the wind farm, although numbers were generally lower on transects within the wind farm than on transects outside the wind farm. Compared to spring 2003, migration intensity of gulls was higher in 2004, except for Great Black-backed Gull that showed lower migration intensity (Table 2). The mean flock size of gulls ranged between 1.18 and 1.89 individuals, being highest in Little Gull, and was fully comparable to flock sizes recorded in spring 2003 (Table 3).

**Terns** *Sterna spp.*
A total of 498 terns were recorded during spring 2004, of which 2.8% could not be identified to species. Common/Arctic Tern constituted 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 period in Common/Arctic Tern and 0.57 and 1.20 individuals per 15-minute period in Sandwich Tern. Generally, migration intensity of both species were lower in 2004 than in 2003 (Table 2), and most terns were recorded on transects outside the wind farm. The mean flock size was slightly higher in Common/Arctic Tern (2.15 individuals) than in Sandwich Tern (1.65 individuals), but comparable to flock sizes recorded in 2003 (Table 3).

**Other species**
During 13 May 2004, a substantial migration of Knot *Calidris canutus* was recorded. Migrating flocks of Knots were found on radar in the area south and east of the wind farm. Several flocks were not found by visual observation, but flocks that were identified accounted for 2,150 individuals. Most flocks were flying at high altitudes (assessed to >300 m above seas level).

During April and May 2-3 Shags *Phalacrocorax aristotelis* was frequently observed to rest on the meteorological mast east of the wind farm, and on wind turbines. One bird was observed foraging close to wind turbines inside the wind farm and around the transformerstation.

### 3.1.2 Lateral changes in migration routes

The 184 selected tracks of migrating waterbirds moving in a southerly direction towards the northern border of the wind farm area showed a orientation of the migration that ranged between 175º and 224º (Fig. 9). This range is fully comparable to the range recorded in the autumn 2003 (185º - 232º). Migration orientation changed significantly from a south-westerly 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). Migration orientation was significantly affected by distance to the wind farm (ANOVA: $F_{14} = 6.79$, $P < 0.0001$) and from the interaction between time of day and wind (ANOVA: $F_1 = 7.68$, $P < 0.01$). As recorded in the autumn 2003, a shift in orientation was evident at a distance of approximately 400-500 metres from the wind farm (Fig. 9), 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 of migration (207º ± 1.7 SE) was significantly affected by distance to the wind farm, but not by other factors (Table 4). At distances less than 400 m from the wind farm the orientation of migration averaged 181° ± 4.1 SE, and was significantly affected by the interaction term time of day and wind direction (Table 4). During daytime and easterly wind directions mean migration orientation was more southerly (183° ± 4.9 SE, N = 67) than during night time and westerly wind directions (200° ± 8.2 SE, N = 21). Due to small sample sizes (less than 5 individual tracks), data on other combinations is not presented.

Compared to lateral deflection patterns recorded during the autumn 2003, the present results do not deviate markedly, although some differences 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 they do this more precisely during daytime than during night time. This pattern seems to be consistent between years.

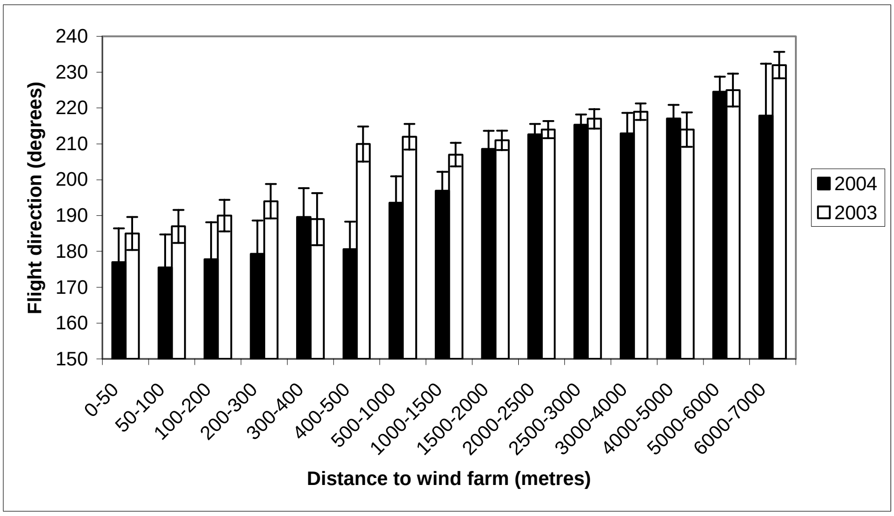


Fig. 9. Mean orientation (± SE) of southbound tracks of migrating birds recorded by radar north of the wind farm in spring 2004 and autumn 2003 in relation to distance to the wind farm.

Table 4. 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 north, made separately on birds 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 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Disatance*Day*Wind | 0.08 | 4 | 0.988 | 1.11 | 6 | 0.356 |

The 92 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 which ranged between 180º and 349º. This range is somewhat larger than recorded during the autumn 2003 (233º - 256º), and is mainly related to a northerly orientation in tracks at distances between 300 m and 1,000 m from the wind farm (Fig. 10). 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 5). At distances of more than 1000 metres, mean orientation was not affected by any factor included in the model (Table x).

There is no obvious explanation to this deviating pattern, but it may be due to erroneous inclusion of tracks of northerly migrating birds in this sample, as may be indicated by the huge variation found at all distance intervals compared to data from 2003 and to data from the area north of the wind farm. Alternatively, this pattern may originate if birds show some strong deflective response to 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 Scoter, between near-coast areas and the large concentration that appeared along the end of Horns Rev during spring 2004. The aspect of deflection will be analysed in detail in the annual report.

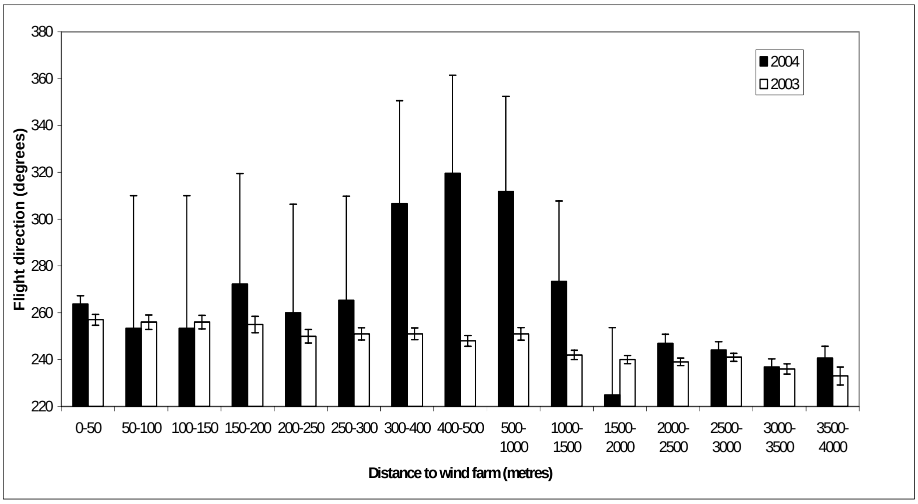


Fig. 10. Mean orientation (± SE) of southbound tracks of migrating birds recorded by radar east of the wind farm in spring 2004 and autumn 2003 in relation to distance to the wind farm.

Table 5. 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, made separately on birds 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 |
| Disatance*Day*Wind | 0.49 | 6 | 0.816 | 0.56 | 6 | 0.690 |

In the analyses of bird deflection there was a substantial decrease in the number of tracks with decreasing distance to the wind farm both north ands 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, for unknown reasons, 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. Given the small data samples, the selection criteria will be subject to evaluation in order to assess whether some alternative approach is possible in relation to optimise future analyses of the probability of bird passing into the wind farm.

During the spring 2004, none of the 49 tracks selected in the area north of the wind farm did pass into the wind farm. Of the 31 tracks directed towards the eastern side of the wind farm, 9 tracks (29%) passed into the wind farm. This percentage was slightly higher, but comparable to the 21.1% recorded in the 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. Thus, the final model included only time of day and mean migration orientation The logistic regression models did not show any significant effects on the probability of entering the wind farm from the factors included, although the effect of day/night was almost significant (Table 6). Thus, there were no indications that the probability of birds to fly into the wind farm was different between day and night and 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.

Table 6. Maximum Likelihood Analysis of Variance of effects from time of the day (Time), flight direction between 1,500 and 2,000 m from the wind farm and the combined (*) effects of the thwo factors on the presence of tracks at the eastern gate of the wind farm area during spring 2004 (N = 31 tracks).

| Factor | $?^2$ | DF | P |
|---|---|---|---|
| Day | 3.24 | 1 | 0.072 |
| Direction | 0.93 | 1 | 0.334 |
| Direction*Day | 3.40 | 1 | 0.065 |

As recorded in the autumn 2003, some tracks disappeared before entering the wind farm. These tracks probably represents birds that cease migration to sit on the water or represents birds changing flight course with the result of providing less cross-sectional area to reflect the radar signal. During spring 2004 some data has been collected to describe this aspect, but has not yet been processed. However, whatever the precise cause, these disappearances may reflect a potential reaction towards the wind farm.

### 3.1.4 Flight speed

Flight speed measures were obtained on a total of 712 tracks of birds during the spring 2004, of which 126 was identified to species during daytime. In figure 11 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. This difference in flight speed compares to identified species which show a similar division between slowly flying gulls, terns, Knot, Gannet and Curlew and faster flying Common Scoter, divers and unidentified shorebirds.

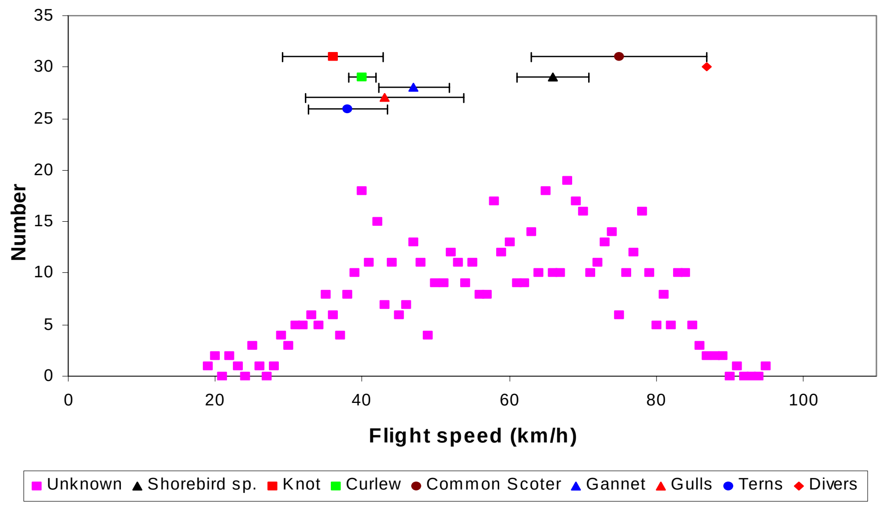

Fig. 11. The frequency distribution of flight speed measurements of unidentified species recorded during spring 2003. Flight speed of selected species identified is shown separately as mean and SE.

Even though the present data show that some overlap in flight speed exist between species, it can be seen that separation between some species or groups of species may be possible on the basis of measurements 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. The Common Scoter was the most numerous recorded species, as a result of substantial numbers recorded in April and May. Besides, gulls and terns dominated the count results in the area.

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, more sporadic observations exist from Blåvandshuk. However, 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 daytime and night-time. 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 north of the wind farm.

It must be stressed, that direct comparison between bird numbers and bird movements 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.

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 Scoter was 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 Scoter 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 this intensity of local movements, some flocks of Common Scoter were observed to fly into the wind farm, even though the main movements occurred further towards the 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 pattern of passing around the wind farm that was observed during the autumn 2003. The majority of observed flocks of Common Scoter that was flying towards the wind farm showed a similar tendency of avoiding of the wind farm by making rapid turns at distances of between 100 m to 400 m from the wind farm. Systematic observations of Common Scoter flocks approaching the wind farm were performed, but the data have not yet been analysed. However, the observations of bird flight behaviour suggest that divers, Gannet and Common Scoter actively avoided the wind farm area and only occasionally occurred inside 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 divers during spring 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 towards the wind farm and single turbines were not observed in gull and tern species. Some avoidance behaviour was recorded in Arctic/Common Terns during the spring 2003, but these species was 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 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 in several bird echoes that moved behind turbines and which showed disrupted tracks, resulting 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 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 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. A change in flight direction was, however, found in bird tracks approaching the wind farm from both the north and from the east. In both areas these modifications to flight direction resulted ultimately 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. However, at short range, the orientation of bird movements north of the wind farm was significantly affected by time of day and wind direction in combination. 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, the mean track orientation of birds that entered the wind farm during night was 200° ± 8.2 SE, whereas the mean orientation during daytime was 183° ± 4.9 SE. This result is comparable to the results from autumn 2003 (195° ± 2.6 SE during night and 177° ± 4.9 SE during daytime), and may suggest 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 of between 300 m to 1,000 m from the wind farm, having a northerly orientation. There may be several explanations to this pattern, some relating to deflection behaviour in the birds and some to erroneous categorisation of data. Hence, this pattern will be more fully analysed and assessed more carefully in the final full annual report of 2004.

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

As in the 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 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 normal visibility exceeded 2 km for the vast majority of the main migration periods during the spring 2004, the preliminary results do not affect the tentative conclusions of the 2003 study that the risk of collisions may be slightly higher during night than during daytime, as 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 analyses, 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 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, were no effect was found from either of the included factors. Thus, the probability of birds flying into the wind farm seems not to be markedly affected by time of day, and likewise not affected by wind direction either, nor 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 group or species from 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 light speed: one group of slowly flying birds including gulls, terns, Gannet and some shore birds (Curlew, Knot), and one group of faster flying bird species including divers, Common Scoter and some unknown shore bird species (probably Golden Plover).

## 4.2 Concluding remarks

The present note presents a rough preliminary outline of the results of the study of birds and collision risk at the Horns Rev offshore wind farm obtained during the spring period 2004. The analyses presented here in this note should only be considered preliminary as they may be subject to changes and improvements. In the present note we have used the same methodological approaches as used on data collected in 2003, mainly considering southbound migration. Analyses of northbound migration must await the application of a new methodological approach, and will be presented in the full annual report for 2004.

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 towards the wind turbines, which in turn 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 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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