National Environmental Research Institute
Ministry of the Environment · Denmark

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NERI Report
Commissioned by DONG energy and Vattenfall A/S
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Data sheet

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Contents

Summary

This report presents data on monitoring investigations of birds carried out during 1999-2005 in relation to the construction of the world's first two large offshore wind farms at Horns Rev and Nysted in Denmark. We consider the hazards turbines posed to birds and the physical and ecological effects that these cause. We propose a series of hypotheses relating to these effects on birds at the two sites, testing to see if birds do indeed show reactions to the turbines once erected, relative to their "unaffected" behaviour we monitored during pre-construction baseline studies. In this way, the effects of the construction of the wind farms at sea could be predicted from our hypotheses and validated by post construction monitoring and data collection which was a condition of planning permission for the Danish projects. Throughout, we have restricted our studies primarily to waterbirds, because these are the species that exploit the offshore environment in general and the two study areas in particular, because Denmark has a special responsibility for the maintenance of their populations and the habitat that they use and because long lived birds with relatively low annual breeding success (which include many waterbirds) are those most susceptible to additional mortality. This does not mean that other species (such as many bird of prey and short-lived land birds that pass through the areas on migration) are not important, but their study was generally beyond the scope of these investigations.

In general terms, the potential effects of the construction of a wind farm on birds were considered to arise from three major processes:

1. A behavioural element caused by birds avoiding the vicinity of the turbines as a behavioural response to a visual (or other) stimulus. This can have two effects:
   - a barrier effect affecting bird movement patterns, potentially increasing costs
   - the displacement of birds from favoured distribution, equivalent to habitat loss
2. Physical changes due to construction (physical habitat loss, modification to bottom flora and fauna and creation of novel habitats, e.g. for resting on the static superstructure).
3. A direct demographic element resulting from physical collision with the superstructure (mortality).

We investigated each of these elements at both wind farms collecting data prior to and post construction as outlined under the following headings.

1a) At Horns Rev and Nysted, the barrier effect was studied by mapped bird migration routes combining radar techniques by day and night with specific species identification during daylight hours using telescopes. Radar tracks were entered to a GIS platform to compare the base-line with subsequent post-construction monitoring results. Emphasis was placed upon three key variables:

I. the orientation of migration routes for waterbirds and terrestrial species to measure potential avoidance responses and response distances,
II. the probability that waterbirds will pass through the wind farm area to measure waterbird responses to the entire wind farm,
III. migration intensity, measured by the number of bird flocks that pass into the wind farm area, to measure the effect of avoidance responses on the volume of migration within the wind farm area post construction.

Comparisons of these key variables between individual base-line years were undertaken by controlling for various factors such as weather conditions, season and time of day using multi-factor analysis of variance (ANOVA) and regression analyses.

Results showed birds generally avoided Horns Rev and Nysted wind farms, although responses were highly species specific. Some species (e.g. divers and Gannets) were almost never seen flying between turbines, others rarely (e.g. Common Scoter) whilst others showed little avoidance behaviour (e.g. Cormorants and gulls). Overall, at Horns Rev, 71-86% of all bird flocks heading for the wind farm at 1.5-2 km distance avoided entering into the wind farm between the turbine rows patterns confirmed at Nysted (78%), predominantly amongst waterbirds. There was considerable movement of birds along the periphery of both wind farms, as birds preferentially flew around rather than between the turbines. Such avoidance was calculated to add an additional period of flight equivalent to an extra 0.5-0.7% on normal migration costs of Eiders migrating through Nysted. Changes in flight direction tended to occur closer to the wind farm by night than day at both sites, but avoidance rates remained high in darkness, when it was also shown birds tend to fly higher. Few data on avoidance behaviours were available during conditions of poor visibility, because intense migration generally slows and ceases during such conditions.

1b) Comparison of pre- and post construction aerial surveys of waterbird abundance and distribution in and around the two Danish offshore wind farms generally showed that they avoided the turbines (at least during the three years following construction), although responses were highly species specific. Divers at Horns Rev showed complete avoidance of the wind farm area during the three years post construction period, despite being present in average densities prior to construction. Common Scoter were absent from Horns Rev pre-construction, but occurred in large numbers in the vicinity of the wind farm, but were almost never seen within the turbines despite up to 381,000 in the general area. Terns and auks also occurred in the area but were almost never seen within

the Horns Rev wind farm post erection. Long-tailed Ducks showed statistically significant reductions in density post construction in the Nysted wind farm (and in sectors 2 km outside) where they had shown higher than average densities prior to construction. This strongly suggests major displacement of this species from formerly favoured feeding areas, although the absolute numbers were relatively small and therefore of no significance to the population overall. No bird species demonstrated enhanced use of the waters within the two Danish offshore wind farms after the erection of turbines, but it was clear, for example amongst Cormorants at Nysted, that the wind farm area was used occasionally for social feeding by very large numbers of birds post construction. Although bird displacement (as a result of behavioural avoidance of wind farms) represents effective habitat loss, it is important to assess the relative loss in terms of the proportion of potential feeding habitat (and hence the proportion of birds) affected relative to the areas outside of the wind farm. For most of the species considered here, the proportion is relatively small and therefore likely of little biological consequence. However, the additional cost arising from the construction of many other such wind farms may constitute a more significant effect. Hence, consideration of such cumulative effects of many such developments along an avian flyway represents an important priority in the future.

2) Physical habitat loss and gain was considered trivial, since even accounting for the anti-scour structures, the extent of the change equated to less that 1% of the total area of marine substrate enclosed within the total wind farm. Their effects would therefore be small and difficult to distinguish from other distributional effects described by monitoring changes in bird densities, except for the arrival of new species (which was not observed during these two studies) attracted to novel habitats post construction.

3) The avoidance responses documented above mean that although turbine construction at sea has a major effect on the local (i.e. wind farm project level) distribution, abundance and flight patterns of birds, the corollary is that many fewer birds come within the risk zone of the rotor blade sweep zone. Radar study results demonstrated that birds may show avoidance responses up to 5 km from the turbines, and that >50% of birds heading for the wind farm avoid passing within it. Radar studies at Horns Rev and Nysted also confirm that many birds entering the wind farm reorientate to fly down between turbine rows, frequently equidistant between turbines, further minimising collision risk. The Nysted Thermal Animal Detection System (TADS a remote infra red video monitoring system) and radar studies confirmed that waterbirds (mostly Eider) reduced their flight altitude within the wind farm, flying more often below rotor height than they did outside the wind farm. A stochastic predictive collision model was developed to estimate the numbers of Eiders, the most common species in the area, likely to collide with the sweeping turbine blades each autumn at the Nysted wind farm. Using parameters (including those described above) derived from radar investigations and TADS, and 1,000 iterations of the model, it was predicted with 95% certainty that out of 235,000 passing birds, 0.018-0.020% would collide with all turbines in a single autumn (41-48 individuals), equivalent to less than 0.05% of the annual hunt in Denmark (currently c. 70,000 birds). With such a low level of probability of collision expected at any one turbine, it was predicted that the TADS monitoring system would fail to detect a single collision of a waterbird during more than 2,400 hours of monitoring that was undertaken at the site, and this proved to be the case. This level of monitoring resulted in a mere 11 bird detections well away from the sweep area of the turbine blades, 2 passing bats, two passing objects that were either small birds or bats, a moth and one collision of a small bird.

Dansk resumé

Denne rapport præsenterer data for de fugleundersøgelser, der er udført i perioden 1999-2005, i relation til etableringen af verdens to første større havvindmølleparker ved henholdsvis Horns Rev og Nysted i Danmark. Vi behandler de risici, som møllerne udgør for fuglene, og herunder de fysiske og økologiske effekter, som disse risikofaktorer afstedkommer. Vi lancerer en række hypoteser og heraf afledte forventninger vedrørende sådanne effekter på de to lokaliteter, og vi tester disse hypoteser for at se, om fuglene virkelig viser en reaktion pga. møllerne ved at sammenligne deres adfærd efter etableringen af mølleparkerne med det "upåvirkede" adfærdsmønster de havde, før møllerne blev etableret. Denne overvågning og dataindsamling var en betingelse for godkendelserne af de danske projekter. I denne udredning af effekter har vi fortrinsvis begrænset os til vandfuglene, fordi det er de arter, der generelt udnytter havområder, og i særdeleshed de to undersøgelsesområder. Danmark har desuden et særligt ansvar for at bevare vandfuglebestande og deres levesteder. Samtidig er der blandt vandfuglene mange arter, hvor individerne godt nok kan opnå en høj levealder, men en lav årlig ynglesucces. Det gør dem sårbare overfor den ekstra dødelighed, som vindmøller evt. kan påføre disse arter. Det betyder ikke, at andre arter (såsom mange rovfugle og landfugle med kort levealder, som passerer undersøgelsesområderne på træk) ikke er vigtige, men studier af disse artsgrupper har generelt ligget udenfor rammerne af undersøgelserne.

Overordnet set kan de mulige effekter fra etableringen af en vindmøllepark opstå fra tre hovedprocesser:

1) Et adfærdsmæssigt element, som forårsages af, at fugle undgår nærområdet til møllerne som en reaktion på syns- (eller andre) indtryk. Det kan have to effekter:

- en barriereeffekt, som påvirker fuglenes trækmønstre med mulige energetiske omkostninger til følge
- en forskydning af fuglenes fordeling væk fra deres foretrukne områder, svarende til et habitattab.

2) Fysiske ændringer som følge af etableringen af en vindmøllepark (fysisk habitattab, ændringer i den fastsiddende vegetation og bundfauna og dannelsen af nye habitater, for eksempel rastepladser på de faste elementer over vandlinjen).

3) Et direkte demografisk element, som kommer fra de fysiske kollisioner med de faste elementer over vandlinjen (dødelighed).

Vi har undersøgt hver af disse faktorer ved begge vindmølleparker ved at indsamle data før og efter etableringen under følgende overskrifter:

1a) Ved Horns Rev og Nysted blev barriereeffekten undersøgt ved kortlægning af fuglenes trækruter, som er undersøgt ved brug af radar døgnet rundt og artsbestemmelse ved hjælp af teleskop i dagtimerne. Radarspor blev integreret på en GIS-platform med henblik på at sammenligne resultaterne i en før (base-line) og efter undersøgelse. Der er lagt vægt på tre nøglefaktorer:

I. Orienteringen af trækruter hos vandfugle og landlevende arter for at måle en evt. undvigerespons samt reaktionsafstand,

II. sandsynligheden for at vandfugle vil passere gennem vindmølleområdet for at måle deres reaktion på hele vindmølleparken,

III. trækintensitet målt som antallet af fugleflokke, der passerer gennem vindmølleområdet for at måle effekter af undvigeresponser på det samlede trækvolumen i vindmølleområdet efter etableringen.

Sammenligning af disse nøglefaktorer med de enkelte base-line år som reference blev foretaget ved at inkorporere forskellige andre faktorer som f.eks. vejrforhold, sæson og tidspunkt på døgnet ved at bruge varians- (ANOVA) og regressionsanalyser.

Resultaterne viste, at fuglene generelt undgik vindmølleparkerne ved Horns Rev og Nysted, dog var denne reaktion specifik for de enkelte arter. Nogle arter (for eksempel lommer og suler) blev næsten aldrig set flyvende mellem møllerne, andre sjældent (f.eks. sortand), mens andre igen udviste en svag reaktion (for eksempel skarv og måger). Samlet set undlod 71-86% af alle fugleflokke, som var orienteret mod vindmølleparken på Horns Rev, at flyve ind mellem møllerne i en afstand af 1,5-2 km. Dette mønster blev bekræftet ved Nysted (78%) hovedsageligt omfattende vandfugle. Der var en betydelig trafik af fugle langs kanten af begge vindmølleparker, fordi fuglene foretrak at flyve rundt om parkerne snarere end ind mellem møllerne. Denne undvigerespons blev beregnet til at udgøre ekstra flyvetid i størrelsesordenen 0,5-0,7% af de normale omkostninger for edderfugle, der trækker ved Nysted. Ændringerne i flyveretningen var tilbøjelig til at foregå tættere på begge mølleparker om natten i forhold til om dagen, men stadigvæk forblev undvigeresponsen også markant om natten, hvor fuglene også til en vis grad fløj højere. Datagrundlaget var sparsomt i perioder med lav sigtbarhed, fordi intense trækbevægelser reduceres eller indstilles under sådanne forhold.

1b) Sammenligning af før og efter undersøgelserne af vandfugles antal og fordeling fra fly i og omkring de to danske havvindmølleparker viste i de tre år efter etableringen som er undersøgt, at de generelt undgik møllerne, men at reaktionsmønstrene var artsspecifikke. Lommer ved Horns Rev undgik fuldstændigt mølleparken, til trods for at denne art var til stede i hele området med gennemsnitlige tætheder som før etableringen af parken. Sortænder var ikke til stede på Horns Rev før etablering af parken, men forekom i stort antal i nærheden af vindmølleparken efter dens etablering,

men blev næsten aldrig observeret mellem møllerne, selvom der var op til 381.000 individer i det samlede område. Terner og alkefugle forekom også i området, men blev næsten aldrig set inde i mølleparken på Horns Rev efter etableringen. Havlit viste en statistisk signifikant reduktion i tætheder efter etableringen af mølleparken ved Nysted (hvilket også gjaldt for et område ud til 2 km fra parken), hvor de ellers før etableringen forekom i tætheder over gennemsnittet. Det tyder stærkt på, at der er sket en forskydning væk fra denne arts foretrukne fourageringsområder. I absolutte tal var denne forskydning af en lille størrelsesorden og derfor ikke af betydning for bestanden som sådan. Ingen fuglearter viste en øget forekomst på vandfladen i de to danske havvindmølleparker efter deres etablering, men det står klart, at f.eks. skarv ved Nysted lejlighedsvis udnyttede mølleområdet med store antal i forbindelse med kollektiv fouragering. Forskydninger i fuglenes fordeling (som følge af en adfærdsmæssig undvigerespons) kan således give et habitattab, selvom habitaten stadigt fysisk er til stede. Men det er i den forbindelse vigtigt at vurdere det relative tab udtrykt som andelen af mulige fourageringshabitater (og på den måde andelen af fugle), der påvirkes udenfor vindmølleområdet. For de fleste af de behandlede arter er denne andel relativt lille og derfor er den biologiske påvirkning sandsynligvis også lille. Men de samlede biologiske omkostninger af mange påvirkninger fra vindmøller kan udgøre en mere betydningsfuld effekt, som er vigtig, når kumulative effekter skal vurderes for mange sådanne anlæg langs en trækkorridor.

2) Det fysiske habitattab, henholdsvis –tilvækst, anses at have lille betydning, selvom den specielle konstruktion, der modvirker skader fra isskruninger, indregnes. Således udgør ændringen mindre end 1% af det totale marine substrat i vindmølleparkerne. Fundamenternes effekt vil derfor være små og vanskelige at skelne fra effekter på fuglefordelingerne, som er beskrevet ved ændringer i fugletætheder. Dog er her undtaget tilstedeværelsen af nye arter (som imidlertid ikke blev observeret i de to undersøgelsesområder), som tiltrækkes af et nyt levested efter etableringen af parkerne.

3) Undvigeresponserne, som er dokumenteret ovenfor, betyder, at selvom etableringen af havvindmøller har stor effekt på de lokale (dvs. det enkelte vindmølleprojekt) fordelinger, antal og trækmønstre hos fugle, så er den logiske følge, at betydeligt færre fugle kommer ind i kollisionsrisikozonen omkring møllevingerne end det samlede antal, der trækker gennem området. Resultaterne fra radarstudierne har demonstreret, at fugle kan udvise en undvigerespons op til 5 km fra møllerne, og at mere end 50% af fuglene, som har kurs mod vindmølleparken, undlader at passere ind igennem den. Radarstudier fra Horns Rev og Nysted bekræfter også, at mange fugle, som flyver ind i parkerne justerer kursen for at flyve langs med møllerækkerne ofte med samme afstand til møllerne. Dermed minimerer de kollisionsrisikoen. Undersøgelser ved Nysted med det såkaldte "Thermal Animal Detection System" (TADS, et fjernstyret varmefølsomt videokamera) samt radarstudierne har desuden bekræftet, at vandfugle (hovedsagelig edderfugl) reducerede deres flyvehøjde indeni mølleparken, således at de oftere fløj i højder under møllevingernes rækkevidde, end de gjorde udenfor vindmølleparken. En stokastisk model, som forudsiger kollisioner ved Nysted, blev udviklet med henblik på at estimere antallet af edderfugle, der kan tænkes at kollidere med de roterende møllevinger hvert efterår. Ved at bruge parametre (inklusiv dem som er beskrevet ovenfor) udledt fra radarundersøgelserne og TADS, samt 1.000 gentagne modelleringer, er forventningen (med en statistisk sikkerhed på 95%), at ud af de 235.000 fugle, der passerer området, vil 0,018-0,020% af dem kollidere med møllerne i ét efterår (41-48 individer). Antallet af kollisioner svarer dermed til mindre end 0,05% af det årlige jagtudbytte på edderfugl i Danmark (for øjeblikket 70.000 fugle). Med så lavt et niveau for den forventede kollisionssandsynlighed var forudsigelsen også, at TADS-overvågningssystemet ikke ville være i stand til at opfange én eneste kollision blandt vandfugle i de 2.400 timers overvågning, der er foretaget på lokaliteten. Denne forventning blev bekræftet. Overvågningsindsatsen resulterede i blot 11 fugleregistreringer et godt stykke væk fra de roterende møllevinger, således 2 passerende flagermus, 2 passerende objekter, som enten var små fugle eller flagermus, en natsværmer og én kollision af en lille fugl eller flagermus.

1 Introduction

Tony Fox, Thomas Kjær Christensen, Johnny Kahlert, Ib Krag Petersen

1.1 Background

The increasing awareness of the potential role of CO_2 emissions from fossil fuel combustion in climate change, and its potential consequences for maintenance of current lifestyles, has focussed attention on methods of energy generation in the last two decades as never before. As early as 1995, The Untied Nations Intergovernmental Panel on Climate Change recognised major reductions in CO_2 emissions from fossil fuel combustion were needed to avoid major climate change (IPCC 1995). That report also noted that in the face of increasing demand, renewable energy (including wind energy) offered a means of reducing increasing reliance upon final energy resources in the future as well as reducing a major source of greenhouse gases.

In 1996, as part of the rolling plan of energy policy development, the Danish Government published "Energy 21" a national energy action plan aimed at reducing CO_2 emissions by 20% over 1988 levels by 2005. This required that renewable energy contributed 12-14% to total Danish energy consumption and also established an annual 1% increase in the contribution of renewable energy to the Danish energy system as the goal for the period 2005 to 2030, achieving approximately 35% by the end of this period. Most significantly this could only be achieved with a significant increase in offshore capacity, potentially up to 4,000 MW by 2030.

One of the major preparatory studies for "Energy 21" was a survey of the possibilities of construction of offshore wind farms. A number of options were assessed to selecting suitable marine areas for the development of offshore wind farms, considering such factors as scenic value, nature conservation interests, raw material extraction, marine archaeology, fisheries, shipping routes, military areas and the interests of a wide range of other user groups. Based on this initial assessment, five areas were identified as representing the most suitable sites for the initial development of offshore wind farms (Fig. 1).

Such a major infra-structure development in the offshore marine environment represented a substantial pioneer development, and for this reason, the five initial projects were designed from the outset as demonstration projects. Although planned as commercial entities, their purpose was also to test:

- the engineering challenges
- to examine the economic potential, and
- to assess the effects on the environment.

In February 1998, in the first step towards the fulfilment of the goals set by "Energy 21", the Minister of Environment and Energy announced plans to start the programme and invited tenders to undertake the first of the projects. In June 1999, the Ministry of the Environment and Energy gave outline planning permission to erect two offshore wind farms in Danish waters, each with a capacity of up to 150 MW. Amongst the conditions imposed on the developments were those specifying that full environmental impact assessments (EIAs) relating to the projects must be undertaken and others explicitly requiring the establishment of before-after monitoring programmes to enable comparisons to demonstrate any potential environmental impacts.

Migratory birds figure prominently amongst any assessment of the environmental impacts of offshore constructions because of the international law, agreements and conventions which relate to, and protect them, and their habitat. The inner Danish waters, including the eastern parts of the North Sea, constitute major staging and wintering grounds for huge numbers of water- and seabirds. It is thought that at the very least 5-7 million individuals of more than 30 bird species winter in these areas, and that even larger numbers exploit them for staging on migration. In several cases, these concentrations constitute the entire breeding- or flyway populations of northwest Palearctic species and are of major international importance (Rose & Scott 1994, 1997, Laursen et al. 1997). As a consequence, Denmark has special obligations under international legislation and as a signatory to international conventions, such as the African - Eurasian Migratory Waterbird Agreement under the Bonn Convention, the Ramsar Convention and the EU Bird directive (see Christensen et al. 2006). Such agreements and legislation require states to protect the habitats of, and maintain the populations of, migratory birds using the territory of those states. For this reason, a full investigation of the potential impacts of constructing offshore parks of wind turbines on water- and seabirds in Denmark was made a requirement of the construction projects.

This report documents the results of extensive ornithological studies undertaken in association with the construction and operation of these two offshore wind farms which were established as a result, these being the large-scale demonstration facilities at Horns Rev (in the North Sea some 14 km off the west coast of Jutland near Blåvandshuk) and at Nysted (Rødsand in the Baltic some 10 km south of Nysted on Lolland in southern Denmark).

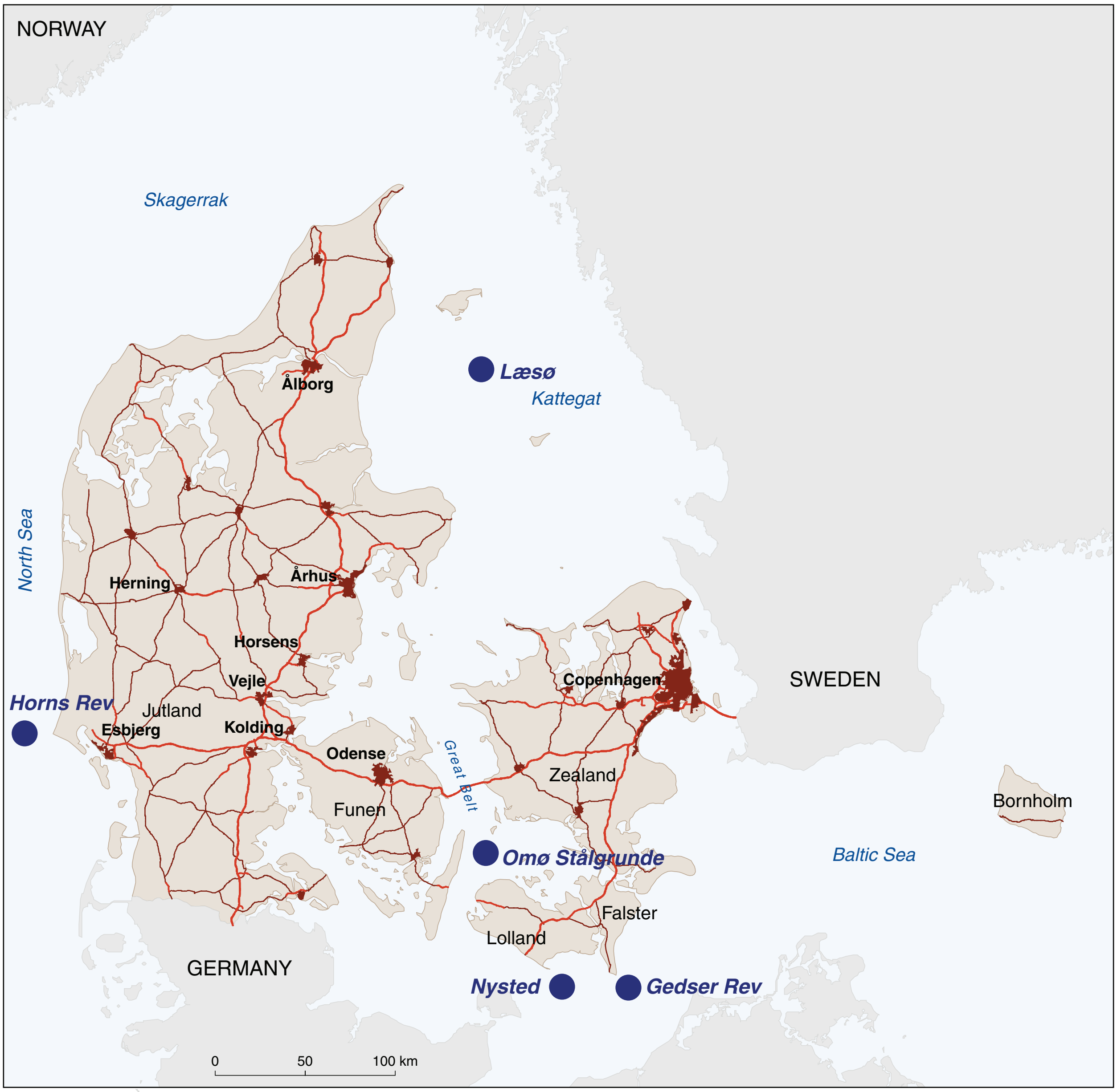

Figure 1. The five main areas initially proposed for the development of offshore wind turbines in Danish waters under the original Energy 21 proposals.

1.2 Nysted

1.2.1 Area description

The Nysted offshore wind farm is situated in the Danish Baltic, south of Nysted on Lolland and west of the town Gedser on the south tip of Falster. It is placed south of a long chain of shallow shoals, some 25 km long that runs from Hyllekrog (on Lolland) in the west to the southern tip of Gedser in the east. These shallows break the surface in two narrow barrier-islands, western Rødsand and eastern Rødsand, which separate the shallow inland Rødsand Lagune from the deeper Femer Bælt outside. Between the two barrier-islands lies Øster Mærker channel, which is approximately 5.5 km wide and on average 3.5 m deep in the deepest parts. The wind farm is positioned some 2 km south of the barrier-islands (see Fig. 2). The seabed in the vicinity of the wind farm is gently sloping and consists of sorted glacier deposits (especially moraine clays) covered by thin layers of clean medium sand, containing very little organic fraction, silts or clays, generally below waters of 6-10 m (Danish Geotechnical Institute, 1999 a, b). These waters experience little effects of lunar tides, but water levels are subject to influence from the wind.

1.2.2 Human Activities

The inner Danish waters are popular for yachting, especially in the summer, and the vicinity of Nysted is no exception (Water Consult 2000). In the late 1990s, an estimated 8000 pleasure boats passed through Øster Mærker every year. The Nysted offshore wind farm lies within 82 km of five active harbours, but because of the shallow waters it is not close to especially active shipping routes. A major east-west shipping lane lies 8 km south of wind farm which typically experiences

48,000 ships per annum. The area was not and is not used for other recreational purposes, such as diving or hunting to any great degree (Water Consult 2000).

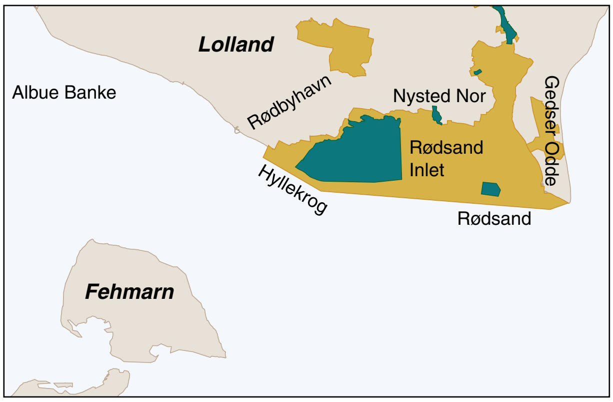

Figure 2. Map of the marine areas south of Lolland and Falster in southeastern Denmark with the location of the Nysted Offshore Wind Farm and the marine part of Special Protection Area (SPA) no. 83, Special Area of Conservation (SAC) no. 152, Ramsar Area no. 25 (yellow signature), and the same protection categories, which in addition are designated as wildlife reserves (blue signature: Hyllekrog, Nysted Nor and Rødsand) – partly after Kahlert et al. 2005.

1.2.3 Conservation areas

The Nysted offshore wind farm is situated just outside an area protected as a Special Protection Area (SPA) under the EC Birds Directive, as a Special Area of Conservation (SAC) under the EC Habitats Directive and as a wetland of International Importance under the Ramsar Convention, collectively gathered together as "International Protection Area" no. 173 (Fig. 2). The area from Gedser to Hyllekrog, including the Rødsand Lagune, Bøtø Nor and Guldborg Sund, is designated as Ramsar area no. 25 and SPA no. 83 for the presence of breeding species including Marsh Harrier (*Circus aeruginosus*), Avocet (*Recurvirostra avosetta*), Arctic Tern (*Sterna paradisaea*), Common Tern (*Sterna hirundo*), Little Tern (*Sterna albifrons*) and Sandwich Tern (*Sterna sandvicensis*), and for migrating birds including Mute Swan (*Cygnus olor*), Whooper Swan (*Cygnus cygnus*), Brent Goose (*Branta bernicla*), Bean Goose (*Anser fabalis*), Goldeneye (*Bucephala clangula*) and Coot (*Fulica atra*) which use the area outside of the breeding season (Skov- og Naturstyrelsen 1995). The EC Habitat Areas (SAC) are designated to protect several environmental features of importance at the European level. These include sandbanks which are slightly covered by sea water all the time; mudflats and sand flats not covered by seawater at low tide; large shallow inlets and bays; perennial vegetation of stony banks, *Salicornia* and other annual plants colonizing mud and sand; Atlantic salt meadows (*Glauco-Puccinellitalia maritimae*); Harbour Porpoises (*Phocoena phocoena*); Grey Seal (*Halichoerus grypus*); Harbour Seal (*Phoca vitulina*); shifting dunes along the shoreline with *Ammophila arenaria* (white dunes) and fixed dunes with herbaceous vegetation (grey dunes). Three areas within Rødsand Inlet, Hyllekrog, Nysted Nor and Rødsand, are all designated wildlife reserves under Danish domestic hunting and wildlife legislation.

Although not relevant to the ornithological interest, a seal sanctuary has been designated since 1978 around the western tip of the Rødsand sandbank (54º35'N, 11º49'E), east of the channel to Nysted, where access is prohibited between March 1 and September 30 (Ministry of the Environment and Energy 1993).

1.3 Nysted Offshore Wind Farm

The wind farm is located south of Rødsand, ca. 10.5 km west-southwest of Gedser Odde and ca. 11.5 km south of Lolland (Fig 2).

1.3.1 Construction

Timeline of events

Approval in principle	15 June 1999
EIA Report submitted	July 2000
Permission to start construction	19 June 2002
Establishment of the sub-station	30 March 2003 (start date)
Establishment of the foundation:	
- Start of excavation work	June 2002
- Placement of foundations	October 2002-June 2003
Erection of wind turbines	10 May 2003 – 27 July 2003
Wind farm Commissioned	1 December 2003

1.3.2 Technical specification

Owners of the Nysted Wind Farm
ENERGI E2 A/S (50%), DONG (30%) and E.ON Sweden (formerly Sydkraft (20%).

Operator
ENERGI E2 A/S.

Wind turbines

Manufacturer:	BONUS (three wings, clockwise rotation
Power:	2.3 MW
Number of turbines:	72
Total power:	165.5 MW
Hub height:	69 m
Wing length:	41 m
Total height:	110 m
Colour:	Light grey

Foundations

Type:	Gravitation foundation
Material:	Concrete
Shape:	Conical
Max. diameter (platform):	10.34 m
Min. diameter (shaft):	4.24 m
Situation method:	Excavation and levelling

Sub-station (Owned and operated by SEAS-NWE a.m.b.a)
Foundation: Same gravitation foundation as turbines, however platform diameter is 11 m and shaft diameter is 5 m

Situation method: Excavation and levelling

Dimensions

Max. water depth:	9.5 m
Min. water depth:	6 m
Distance between turbines:	
- North-South:	480 m
- East-West:	850 m
Area:	24 km^2
Nearest distance to shore:	10 km

Aviation and navigation light (during the study)
A red light is situated on top of each of the turbines for aviation safety. The red lights on the eastern- and westernmost rows are flashing. Some of the outer turbines are also fitted with yellow light (iso) to warn ship traffic in the area. The sub-station is fitted with flashing white light.

Navigation
The navigation corridor used during construction has been maintained throughout the operational phase.

Meteorology masts
Two east and two west of the wind farm.

Further information
At the web-site: www.nystedhavmoellepark.dk you can find more information about the project or alternatively contact Charlotte Boesen (ccx@e2.dk), Pernille Holm Skyt (pnh@e2.dk) or Steffen Andersen (san@e2.dk) if you have questions about the Nysted Wind Farm.

1.4 Horns Reef

1.4.1 Area description

The wind farm area is located in the Danish part of the North Sea, c. 14 km west-south-west of Blåvands Huk, and c. 35 west of the town of Esbjerg. The wind farm is placed on the shallows shoals of Horns Rev, which have an east-westerly orientation and which continues c. 20 km west of the wind farm (Fig. 3).

Geomorphologically, the Horns Rev formation is a terminal moraine ridge, consisting of relatively well sorted sediments of gravel and sand (Danish Hydraulic Institute 1999). The water depth range between 2 and 15 m along the reef, and one major channel, Slugen, c. 7 km east of the wind farm, separates the reef from the shallow coastal waters of Blåvands Huk. The wind farm is placed in a deeper basin in the central eastern part of the reef, on water depths varying between 6.5 m to 13.5 m.

The area is characterised by a clear tidal cycle, which results in marked directional changes in the water currents, shifting between a northward and southward direction, as well as changing water levels. The difference between high and low tide is approx. 1.5-1.8 m.

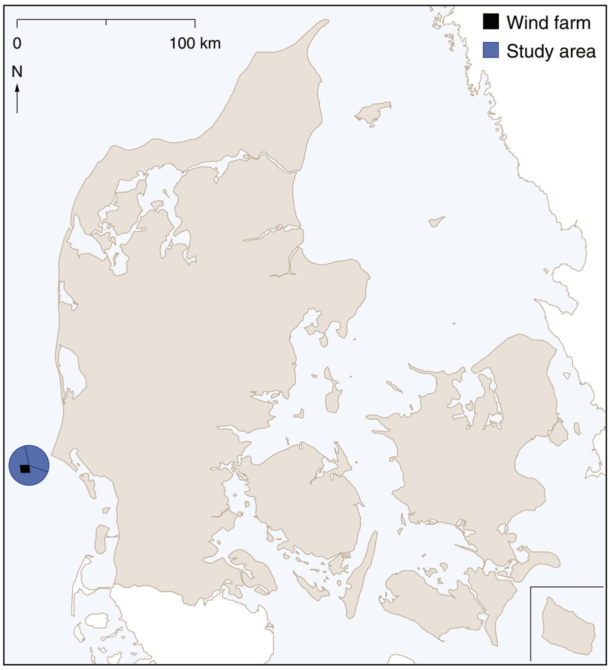

Figure 3. The location of the Horns Rev offshore wind farm in the Danish part of the North Sea.

1.4.2 Human activities

The generally exposed offshore environment (strong winds and currents) in combination with the shallow shoals of Horns Rev has probably put natural limits on human activities in this area. Recreational activities are definitely rare, with the possible occurrence of a few sport fishermen during calm weather conditions during summer, and maybe a few sport hunters during autumn and winter.

The level of commercial fishing activity over the shallows of Horns Rev is unknown. Shrimp fishery may take place in the area, but the coastal areas north of Blåvands Huk, and along Skallingen and in Esperance Bay, south-southeast of Blåvands Huk, are probably more important for this type of fishery and for commercial fishery in general.

The important harbour in Esbjerg generates some traffic from ferries and commercial shipping vessels in the area. The main route taken by these ships is, however, located several kilometres south of the wind farm. Some traffic, mainly coasters and trawlers, passes through the channel of Slugen east of the wind farm area.

1.4.3 Conservation and restriction areas

The offshore location of the Horns Rev wind farm is not encompassed by any restriction or conservation area of neither national nor international importance. The adjacent coastal zone south from Blåvands Huk constitute, however, the northern part of the Wadden Sea that has been appointed as a Special Protection Area (SPA) under EC Birds Directive (SPA no. 57), a Special Area of Conservation (SAC) under the EC Habitats Directive (SAC no. 78), and a wetland of international importance under the Ramsar Convention (Ramsar Area no. 27), and which is commonly known as the International Protection Area no. 89. The designation of this area as a SPA is based on a long list of both breeding and staging/migrating species, of which Common Scoter *Melanitta nigra* occurs at Horns Rev. In relation to the Ramsar Convention, an area is classified as being of international importance to a species if 1% of its flyway population is present regularly at some time of the annual cycle (Prater 1981). According to this 1%-criterion, the area around Horns Rev is of international importance to Red- and Black-throated Diver *Gavia arctica/G. stellata* and to Red-necked Grebe *Podiceps grisegena* (Laursen et al. 1997).

In 2004, an area south of the Horns Rev was designated as a SPA under the EC Bird Directive (SPA no. 113). This area has been designated for the occurrence of Red- and Black-throated Diver and Little Gull *Larus minutus*.

1.5 Horns Rev Offshore Wind Farm

The geographical coordinates of the four corners of the Horns Rev wind farm and of the transformer station are shown in Table 1.

Table 1. Coordinates of the four corner turbines of the Horns Rev wind farm and of the transformer station. Coordinates in UTM32/WGS84.

	Easting (x)	Northing (y)
Northwestern turbine	423.974	6.151.447
Northeastern turbine	429.014	6.151.447
Southeastern turbine	429.492	6.147.556
Southwestern turbine	424.452	6.147.556
Transformer station	428.946	6.152.003

1.5.1 Construction

Timeline of events	
Approval in principle	15 June 1999
EIA Report sumitted	July 2000
Permission to start construction	19 June 2002
Establishment of the sub-station	30 March 2003 (start date)
Establishment of the foundation:	
- Start of excavation work	March 2002
- Mounting of monopoles	April 2002-June 2002
Erection of wind turbines	10 May 2003 – 27 July 2003
Wind farm Commissioned	1 December 2003

1.5.2 Technical specification

Owners of the Horns Rev Wind Farm
Vattenfall A/S (60%), Dong A/S (40%)

Operator
Vattenfall A/S

Wind turbines

Manufacturer:	Vestas (V80-2 MW, three wings)
Power:	2.0 MW
Number of turbines:	80
Total power:	160 MW
Hub height:	70 m
Wing length:	40 m
Total height:	110 m
Colour:	Pale grey (RAL 7035)

Foundations

Type:	Monopile foundation
Material:	Steel
Shape:	Cylindrical
Max. diameter:	4.0 m
Depth into sediment:	c. 25 m
Scour protection:	Stones (appr. 10 m belt around monopile)

Transformer station (Owned and operated by Energinet.dk)

Foundation:	3 monopiles
Dimensions:	c. 25m x 25m x 25m (LxWxH)

Dimensions

Max. water depth:	13.5 m
Min. water depth:	6.5 m
Distance between turbines:	
- North-South:	560 m
- East-West:	560 m
Area:	20 km^2
Nearest distance to shore:	14 km

Aviation and navigation light
All wind turbines are equipped with yellow lanterns as navigational lighting. In addition, all wind turbines positioned at the outer edge of the wind farm are equipped with two medium intensity flashing red lights situated on the top of the nacelles. The lights operate with a frequency of 20 to 60 flashes per minute, and have a variable effective intensity (±25%) of up to 2000 candela. When visibility in the area exceeds 5 km, the intensity is automatically reduced to 200 candela.

Meteorological masts
During the entire study period, one meteorological mast has been located 2 km north-northwest of the wind farm. Two additional masts were placed east of the wind farm, at a distance of 2 km and 6 km, respectively.

Further information
At the web-site: www.hornsrev.dk you can find more information about the project or alternatively contact Jette Kjær (jette.kjaer@vattenfall.com) or Jesper Kyed Larsen (jesperkyed.larsen@vattenfall.com) if you have questions about the Horns Rev Wind Farm.

1.6 Birds at the Nysted area

1.6.1 Avian migration patterns during spring and autumn

The area between Hyllekrog and Gedser Odde has long been known as one of the most prominent migration sites in Denmark, from which substantial migration of many species groups can be observed. The area lies on the northern trajectory of the Fehmarn Belt migration bottleneck, which is part of the important African-Eurasian migration route. The present significance of the area for migrating birds has been confirmed through extensive studies commissioned by SEAS Wind Energy Centre (SEAS) on behalf of Energi E2 A/S in the context of the wind farm project (Desholm *et al.* 2001, 2003 and Kahlert *et al.* 2000, 2002, 2004, 2005).

The migration comprises many different species groups, showing different migration strategies and routes. Firstly, there are high concentrations of waterbirds on their westerly and southwesterly migration from breeding areas in Fenno-Scandia and Russia mainly en route to the western fringe of the Baltic Sea or travelling onwards to the North Sea in the autumn and returning in the opposite direction during spring. This is reflected in a strong coastal migration of waterbirds south of Lolland and Falster both during day- and nighttime (Fig. 4). Secondly, Gedser Odde and Hyllekrog are two of the southernmost points amongst the Danish islands to which many terrestrial bird species are funnelled on their southbound migration during the autumn, in an attempt to avoid crossing extensive stretches of water. On the broader stretches of coasts between these points, there is also broad-front migration of mainly terrestrial bird species, coming from the south coast of Lolland, especially during nighttime (Desholm et al. 2001, Hill & Hüppop 2004), (Fig. 4). During spring, intensive broad-fronted northbound migration (presumably mostly passerines) occurs from the German coast towards the shores of Lolland and Falster. However, this migration is rarely registered visually, either because it occurs at nighttime and/or at high altitude (Blew et al. 2006, present study).

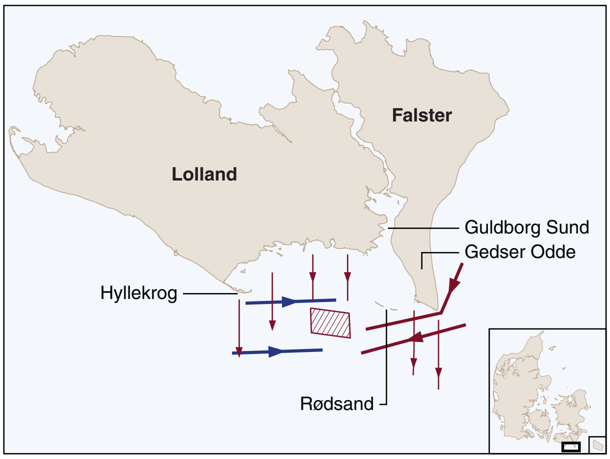

Figure 4. The wind farm area and study area south of Lolland and Falster in southeastern Denmark. Names of locations referred to in the text are indicated. The hatched area represents the Nysted Offshore Wind Farm, thin and thick arrows indicate the schematic direction of terrestrial and waterbird migration, respectively. Blue arrows indicate spring migration and red arrows autumn migration.

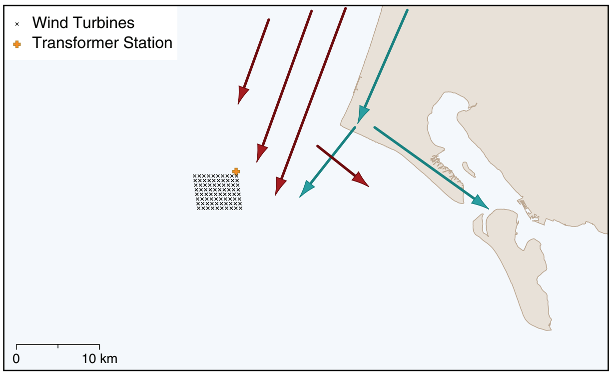

Figure 5. Schematic presentation of the main routes of bird migration at Blåvands Huk during autumn. Red arrows indicate seabirds and waterbirds and blue arrows terrestrial species, i.e., raptors and passerine birds.

1.7 Birds at the Horns Rev area

1.7.1 Staging and migrating birds during spring and autumn

The area around Horns Rev constitutes an important area for staging and migrating birds, especially to Black- and Red-throated diver, Red-necked Grebe and Little Gull. In addition to these species, Guillemot *Uria aalge* and Razorbill *Alca torda*, which are listed on the Danish Red-list as breeding species that are uncommon or immediately threatened (Stoltze & Pihl 1998), occur at Horns Rev. Of species that have been recorded in high, but not in nationally or internationally important numbers, at Blåvands Huk, are Gannet, skuas, Common Scoter and several species of gulls and terns, based on visual observations from the coast (Kjær 2000, Jakobsen in print), and from data sampled by means of aerial and ship surveys (see Laursen et al. 1997).

During the periods of bird migration, the area at Blåvands Huk constitutes one of the most important points for both marine and terrestrial migratory bird species. This has been documented by systematic bird counts, especially during autumn periods, at Blåvands Huk since 1963 (Kjær 2000, Jakobsen in print). During autumn the coastline north of Blåvands Huk acts as a boundery line that accumulate both terrestrial bird species that are reluctant to fly over the open sea, and marine species that are reluctant to fly over terrestrial habitats. Depending on the direction and force of the wind, which have a drifting effect on the general direction of bird migration and on the volume as well, the effect of the coastline reaches far north of Blåvands Huk, and hence results in the high numbers of southward migrating birds occurring at this location. Thus the effects of wind direction on bird migration at Blåvands Huk generally result in an accumulation of marine bird species during periods of westerly winds, and in an accumulation of terrestrial bird species during periods of easterly winds. For southbound migrating terrestrial species, some are seen migrating in a south-westerly direction over the sea from the outermost western point of the coast, whereas others are recorded to follow the coastline towards southeast. The general pattern of bird migration at Blåvands Huk is shown in Fig. 5. For more detailed descriptions of the occurrence of species at Blåvands Huk see Kjær (2000) and Jakobsen (in print), and references herein.

1.8 Scope of the investigations

1.8.1 Potential and anticipated effects and impacts of offshore wind farms upon birds

Almost any form of human activity, but especially the construction of large artificial moving objects, has some physical effect on the natural world. At the most trivial, the presence of a man-made moving object may cause a bird to temporarily cease feeding, look at the source of the disturbance and resume feeding assured of a lack of threat. More seriously, persistent disruption to feeding may cause more long term loss of feeding time or even displace birds from their preferred optimal feeding distribution, causing an ecological effect. When birds are precluded from feeding where they would choose to do so, food intake is reduced below the optimal levels and where birds take to the air to escape the immediate vicinity of the disturbance stimulus, energy expenditure is enhanced, so engendering an extra energetic cost which if substantial enough, potentially could affect reproduction and survival. Birds displaced from optimal feeding opportunities may risk poorer foraging opportunities and greater competition where densities are enhanced. In the extreme, a fast moving object may kill or mortally injure an individual bird adding to the death rate which would occur under normal circumstances.

The studies presented here are the result of conditions placed upon the consent procedures for the wind farms at Horns Rev and Nysted. Because both projects were "demonstration modules" designed to test economic feasibility, engineering challenges and environmental impacts of offshore wind farms, implicit in the project designs were predictive assessments of the potential impacts and post construction monitoring, which made these processes rather different from normal environmental impact assessment procedures. Nevertheless, it is worth considering the needs of the EIA process under existing European legislation.

Under Article 2 of Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment (as amended by Directive 97/11/EC) European Union Member States "...shall adopt all measures necessary to ensure that, before consent is given, projects likely to have significant effects on the environment by virtue inter alia, of their nature, size or location is made subject to an assessment with regard to their effects." Article 5 and Annex II lists energy generation installations as projects which "...shall be made subject to an assessment, in accordance with Articles 5 to 10, where Member States consider that their characteristics so require."

Hence, European legislation requires some form of assessment of the effects of large scale wind farm construction on the environment be made, specifically with respect to the fauna of the area. This is taken to mean that a consideration of such effects at local (i.e. wind farm project level) geographical scale is required, in the context of the present report assessed with regard to the avian populations involved. The Directives also specify the requirement for some assessment of the cumulative effects and impacts arising from each proposal in conjunction with other projects (which may include other wind farms but also other human development activities) that may impinge upon the same population at another point in the same flyway. Hence, in considering the hazards presented to birds by wind farms it is important to consider the relative importance of the different types of effects such as those outlined above and to be able to undertake a comparative assessment of the relative strengths of these effects on the relevant bird populations concerned. It is also important to be able to distinguish between (but also compare) local effects (such as small scale redistribution) and large scale impacts (defined here as changes at the population level), if we are to assess cumulative consequences for long distance migratory birds.

The purposes of impact assessment are to evaluate whether or not a stress (in this case wind turbine construction) has changed the environment, to determine which components are adversely affected, and to estimate the magnitude of the effects. Evaluating such change is difficult, because it is often unclear in advance which environmental components will be affected and in which fashion by the stress and because natural variation in biological systems is also extremely high. It is therefore essential to define the spatial and temporal extent of changes to the environment caused by the development, the organisms that will be affected by it and the manner in which they are affected, in order to adequately design a test to measure the effects. Having established this definition, the assessment of an environmental impact necessitates a comparative study of an expected change in an indicator variable (such as bird density) that could be correlated in some way with the start of the new human-related activity. The two best possible ways to account for such change are to compare such an indicator variable (i) in the same area before and after the start of new activity and (ii) in the impact area and in a similar (usually spatially close to, but independent of, the development). Hence, the tendency has been to combine both approaches in an attempt to account for large scale variation in natural systems (e.g. inter-annual and seasonal variation). This "combined" design is often referred to as a Before–After Control-Impact (or BACI) design and where possible, this is the approach we have adopted throughout this investigation. This involves comparison of baseline pre-construction data with that post construction, allowing for major spatial and temporal variations in patterns with reference to before-after comparisons of the same variable indicators in areas well away from the windfarm construction area.

The potential effects of the wind farm on birds can be considered to arise from three major processes (see Fig. 6):

1. A direct demographic element resulting from physical collision with the superstructure (mortality);
2. A behavioural element caused by birds avoiding the vicinity of the turbines as a behavioural response to a visual (or other) stimulus. This can have two effects:
    - the displacement of birds from favoured distribution, equivalent to habitat loss
    - a barrier effect affecting bird movement patterns, potentially increasing energetic costs
3. Physical changes due to construction (physical habitat loss, modification to bottom flora and fauna and creation of novel habitats, e.g. for resting on the static superstructure).

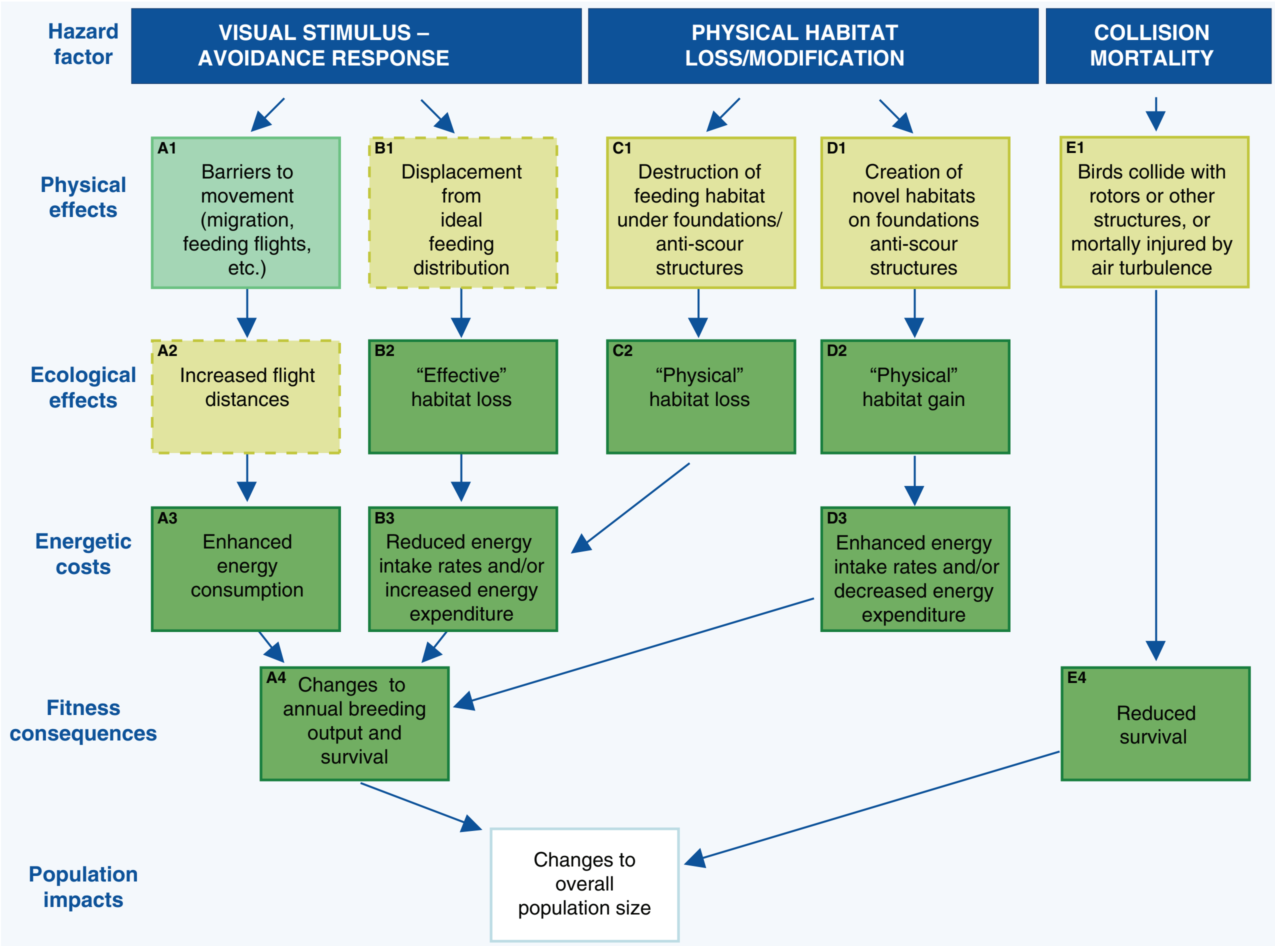

Figure 6. Flow chart describing three major hazard factors (blue boxes) presented to birds by the construction of offshore wind farms, showing their physical and ecological effects on birds, the energetic costs and fitness consequences of these, and their ultimate impacts on the population level (white box). The yellow boxes indicate potentially measurable effects, the dark green boxes indicate processes that need to be modelled (see text for details).

Under the objectives set for the Danish offshore wind farm projects, each of these effects needs to be predicted and their magnitude assessed as a contribution to the Environmental Impact Assessment process, and then measured, compared with the pre-construction predictions and re-assessed based on the post-construction monitoring programmes. The challenge is to be able to assess these local effects in a way that will enable comparison of impacts at the population level, since only by making this transition does it become possible to determine a suitable common currency to compare between effects and different developments and make assessments of cumulative effects. If we are to be able to measure cumulative effects, it is essential that we establish a common currency for the measurement. For instance, in theory, it is relatively easy to measure the numbers of Common Eider deaths resulting from collisions with turbines in a year and compare this with the numbers known to die from other causes of Man-induced mortality (e.g. the annual hunting kill, or the estimated numbers that drown in fishing nets every year). But if birds are displaced from normal migration routes and fly longer distances to reach breeding areas, what is the relative cost of this? If birds are reticent to feed near turbines and effective habitat loss occurs, how serious is this and how do we compare this with extra flight costs or elevated mortality rates? We need to be able to directly compare these effects on birds if we are to establish a common currency to assess environmental impacts of single and multiple developments, but also if we are to make balanced judgements about the relative impacts of different projects on bird populations.

Let us consider each of the three major effects of wind farms on birds outline above.

1. Collisions

Collisions increase mortality rates in bird populations, and it is known that wind turbines can cause enhanced local bird mortality (*e.g.* Barrios & Rodrígues 2004). At the level of a flyway population, the sensitivity to additional mortality caused by collisions with wind turbines will depend on the population dynamics of the species. Long-lived species with a low reproduction rate such as many waterbirds are likely to be more sensitive to small changes in adult mortality compared to passerines that suffer a high annual mortality (in some species more than 50%) and have a correspondingly high reproductive output (Noer *et al.* 1996, Morrison *et al.* 1998).

Precise predictions of bird collision rates were not possible prior to the construction of the turbines. It is possible to use remote sensing techniques, such as radar and infra-red video monitoring equipment to map the cross-sectional densities of flying birds within the air space of a proposed wind farm prior to construction (Desholm et al. 2006). It is also feasible to model the probability of a collision of a moving object (assuming that birds show no cognisant avoidance actions, e.g. Band et al. 2006). However, we know very little about the ability of birds to undertake last minute avoidance action in the close vicinity of a turbine, which makes *a priori* predictions of collision rates, especially species-specific rates, extremely difficult (Chamberlain et al. 2006). Nevertheless, the subject has been given attention in the present report as collision risk is highly dependent on a number of factors, into which insight can be gained by compiling data before and after the erection of the wind farm. This specifically focuses upon the avoidance response at a range of spatial scales by flying birds, which may either deflect laterally as they approach a wind farm or may climb to attain sufficient height to avoid it altitudinally. Such avoidance responses are likely to be species-specific, which may result from the differing ability of various species to manoeuvre, their sensitivity to the presence of large offshore constructions and interactions with weather factors. Furthermore, displacement from regular migration patterns will indirectly affect the collision risk, as the precise position of the local migration routes is a major determinant of the number of potential bird encounters at a wind farm.

With respect to collision risk, the present report mainly deals with the description of species, occurrences and flight trajectories on a temporal and spatial scale. This also involves investigating the effects that the presence of the wind farm may have upon migration patterns, together with natural factors such as weather conditions and time of the day. A separate project, which deals with the development of reliable methods to estimate collision frequency at the Nysted wind farm, has been undertaken. This project includes recordings from video cameras, using infrared sensing and further analysis of bird occurrences and flight trajectories in order to develop a much improved model to predict bird collision rates.

2a. Displacement of birds from the vicinity of turbines

Although it is not always clear why, birds do demonstrably avoid coming in the near vicinity of turbines, such that bird densities of different species are reduced at distances nearest to wind farms, both on land (e.g. Larsen & Madsen 2000) and at sea (e.g. Guillemette *et al.* 1999, Tulp *et al.* 1999). It is assumed that the visual (or other stimuli associated with the turbines) promotes an avoidance response in the same way as birds avoid other stimuli that may reflect a threat to their survival. If the area represents a feeding habitat, the feeding resource may remain largely intact and theoretically available; however the behavioural reaction of the birds renders an area within a certain distance of the turbine inaccessible by their response. This leads to "effective habitat loss" in the sense that a proportion of the habitat is still present, but is rendered unavailable by the reticence of birds to approach the wind farm. Clearly if birds avoid individual turbines by more than half the distance between them within a wind farm array, the entire area of the wind farm and a strip of that distance about the outer turbines are effectively lost as feeding area.

Bird species exploit offshore habitats for a number of different reasons, of which the most important is probably to exploit as a source of food. Different species exploit differing food resources, often in different seasons and for varying intervals of time. Hence, the potential ecological effects of bird displacement from the vicinity of turbines range from being insignificant (for example, where a surplus of alternative habitat is available) to being highly critical for some part of a population, where loss of key habitat could have a direct effect on reproductive output or the size of the total population.

The critical element in the EIA was therefore to determine the range of avian species present pre-construction, to compile information on their abundance, phenology and distribution, and to determine the way the site was being exploited by the most abundant and sensitive species. This has involved mapping bird abundance throughout the annual cycle, gathering data from more than one year (preferably at least three) to allow for major inter-annual variation in such biological patterns. The programmes have then focussed upon assessing the seasonal and (more important) spatial effects of the construction and operation of the turbines on bird numbers and distribution in a BACI-type approach, to see what numbers of birds show displacement responses to turbines and over what distances the effects extend for which species. Extended post-construction monitoring has also aimed to track whether there are any changes in this response with time, for instance do birds habituate to turbines (showing moderated responses within a season as a result of prolonged exposure to the same stimulus)? Or does the avoidance response diminish over a series of years post construction (e.g. as a result of the arrival of naive individuals with lower risk thresholds)? These questions have all formed part of the rationale behind the design of the investigations associated with the wind farms.

2b. The barrier effect to migrating birds

In the situation where migrating birds show large scale avoidance of wind turbines, the risk of collision is clearly diminished. Nevertheless, flying is the most energetically costly of all avian activities, so if the deflection in migration routes caused by such avoidance is significant, such a response could affect the energy budgets of migratory birds. Preliminary results suggested that for example Eiders at the Nysted Offshore Wind farm would based on known response distances make a detour of appr. 4.5 km, likely to equate to less than 1% of their total typical migration distance (Kahlert et al. 2005). In a migratory flight likely to be of many hundreds of kilometres duration, this extension is likely to be trivial, amounting to an extra energy cost that was equivalent to encountering severe head winds, and likely compensated easily by a short period of enhanced energy intake during foraging. There have been no reported instances of barrier effects so severe as to completely divert a migratory route along another course, although this possibility cannot be ruled out in the future. The broader question of cumulative effects of many such developments should also be considered. For the time being, the commitment in the EIA process has simply been to assess the potential extent of deflection of migrating birds and to assess the distance at which birds react and the extent of the displacement of the migratory corridor post construction compared to the pre construction base-line data.

3. Physical changes to habitat

Physical changes to avian habitats associated with the construction of the wind farm were judged to be of minimal importance. Even allowing for anti-scour structures that potentially extend out to 40 m from a turbine foundation, the total area of habitat loss under the new constructions within the total area of a wind farm was generally less than 1% of the whole. It was estimated that resettling of bottom fauna on the extended surface area provided by the foundations of the turbines would exceed the loss of bottom fauna caused by the establishment of turbines (DHI 2000). For this reason, it was considered that it would be difficult if not impossible to detect the effects of physical habitat loss on bird distribution and abundance, and in any case impossible to distinguish from "effective habitat loss" discussed above.

The presence of novel substrates (such as hard surface foundations in an area of sandy substrates) could attract new elements to the local flora and fauna. For instance, concrete foundations have attracted Blue Mussels *Mytilus edula* which could attract foraging Eiders to an area where previously sandy substrates offered no foraging opportunities. Furthermore, cormorants and gulls may use the static turbine superstructures for resting in areas where no such structures and therefore opportunities existed. The EIA was able to speculate about such processes, and the survey protocols to track displacement effects were designed to detect the appearance of new species or elevated densities of those species previously present.

1.8.2 Measuring variables against environmental threshold criteria

Consents to begin construction of the windfarm were given on the basis of a large number of conditions, including several relating to the environment and to birds in particular. The latter are, of course, highly relevant to the design of the research and monitoring programmes as well as supporting the EIA process. The full list of conditions can be found in the formal consent document provided by the Ministry for the Environment and Energy dated 29 March 2001 (journal number 6140-0002, ref SRN) but those that are directly relevant to this report are:

"The appropriate environmental agencies require that mitigation mechanisms be put in place, if on the basis of estimated population size and existing annual mortality, a birds species experiences a 1% increase in annual mortality as a result of collisions with turbines"

#27 "That the environmental impact assessment (including choice of measured parameters) be as broadly based as necessary to account for natural variation in environmental system, such that the assessment can separate such variation from that caused by the development"

#30 "That the best available methods are used to detect and measure bird collision rates..."

#31 "That an annual assessment be made of annual avian mortality caused by wind turbines to the environmental agencies"

1.8.3 Link to other programmes

The studies of migrating birds at Nysted and Horns Rev were supplemented by the studies done by Blew et al. (2006), who carried out visual and radar studies from a ship anchored close to the respective wind farms.

2 Methods

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2.1 Hypotheses

For the purposes of this entire investigation, it has been presumed that the major effects of the construction of offshore would fall into the three broad categories outlined in section 1.8.1. In essence, this entails two major factors that need to be assessed:

A. changes in distribution or flight routes as a result of avoidance/attraction, habitat loss or habitat gain
B. increase in death rate as a result of collisions

These factors can be manifest in different ways, depending on the reactions of the birds to the presence of the turbines post construction, relative to their behaviour prior to any physical presence in the impact area. For this reason, it is essential to construct a theoretical framework against which to test the responses shown by birds. Given the opportunity to gather base-line data on bird distributions in three dimensional space and their behaviour, the most appropriate method of addressing the assessment of the effects of offshore wind farm construction on birds is to construct a series of *a priori* hypotheses based on pre-construction states to enable predictions about post-construction states.

In terms of migratory birds (i.e. those which are passing through the air space associated with the offshore wind farm but which are not necessarily feeding in that area) therefore we might expect that birds may either show no reaction, react by avoiding the turbines or react by flying towards the turbines. Depending upon the biological knowledge available, each of these expectations would generate a series of different predictions which we could test by actual measurement in the field. In terms of birds that actually make use of the sea in the vicinity of the offshore wind farm, we could construct a similar set of expectations based on knowledge of their feeding ecology, behaviour, etc. Bird species that showed even distributions in the area pre-construction may choose to avoid the turbines, be attracted to them or show response post construction, each of which would generate a different set of predictions about bird distributions which could be tested by comparing data gathered in consistent ways pre- and post-construction. Finally, if one of the expectations is that birds do not avoid flying in the vicinity of turbines, and show no avoidance behaviour at all, then we would predict a number of birds will hit the turbine superstructure and be mortally injured or killed outright. Again, it is possible using mechanistic models and biological knowledge to make predictions about the likely magnitude of this source of additional mortality and measure this in the field under post construction conditions.

For convenience, we have bundled these effects into three major categories for ease of presentation in the report as follows: lateral displacement (or attraction) to migrating birds, lateral displacement (or attraction) to resting/feeding birds and collision mortality.

2.1.1 Lateral change in migration routes

Hypothesis: In previous studies, lateral avoidance has been considered the most frequent bird response to established wind farms (e.g. Winkelman 1992). An alternative hypothesis would be that birds are attracted.

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

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

2. The probability that birds cross the wind farm area after construction of turbines will decrease. If the change in flight direction occurs closer to the wind farm at poor visibility (see 1), the number of crossings is likely to be higher during these conditions;

3. The overall migration intensity in the wind farm will decrease after erection of the turbines. Assuming that it will be more difficult for migrating birds to detect the wind farm at night than by day, it is predicted that the decrease in migration intensity in the wind farm will be most pronounced during the day.

Based on the alternative hypothesis that migratory birds show a lateral attraction response to the wind farm, predictions will follow the opposite pattern as described above. Thus, a gradual and systematic deflection towards the wind farm will occur, the probability that birds cross the wind farm area after construction of turbines will increase, and the overall migration intensity in the wind farm will increase after erection of the turbines. Attraction effects may be species or time specific. For example, gulls and Cormorants can use the static turbine superstructure as a resting platform. Furthermore, the illumination of wind turbines may attract nocturnal migrants (for a review on the illumination topic, see Lensink *et al.* 1999).

2.1.2 Changes in distribution of feeding/resting birds

Hypothesis: Resting and feeding birds frequently respond to man-made features in the landscape by showing avoidance, including wind farms established on land (e.g. Larsen & Madsen 2000). It is therefore expected that if seabirds show a reticence to approach turbines at sea, they will show a displacement in their distribution post construction compared to that prior to construction. An alternative hypothesis would be that birds are attracted to man-made structures because of the perching possibilities these offer, or because of associated changes in potential food abundance that result from the constructions.

Based on the main hypothesis that resting or feeding birds show an avoidance response to the wind farm, the following predictions are made:

1. A displacement of birds will occur post construction with significant changes in the densities of birds within, and immediately adjacent to, the wind farm after the turbines have been erected compared to the densities recorded during the baseline.

Based on this prediction, we would expect bird densities within the windfarm and immediately adjacent to it to fall relative to the baseline and control areas away from the wind farm. Where observations failed to meet these expectations we may expect that birds show no displacement response to the erection of turbines. Where bird densities actually increase post construction in comparison to the baseline, and where the species has shown no similar increase in number in control areas, it may be concluded that the erection of turbines has attracted birds to their vicinity, although the reasons for such an effect would require further investigation. This conclusion is based on the assumption the food availability to birds had not changed.

2.1.3 Collision of flying birds

Hypothesis: Birds collide with many man-made features in the environment, causing fatal injury (e.g. Avery et al. 1978). As large unfamiliar objects (especially those with fast-moving components) in the marine environment, there is no reason to expect that birds will react differently to offshore wind turbines. Our hypothesis will therefore be that:

1. Birds which move habitually through the airspace within an offshore wind farm at altitudes swept by the turbine blades will collide with such structures if they show no avoidance responses.

The theoretical framework for the assessment of collision risk has therefore been to gather data to estimate the deterministic probability of a bird hitting the constructed superstructure given the known distribution of bird flights in time and space in the vicinity of the planned turbines, and then to monitor collision rate at the turbines to see how well these predictions perform against reality.

The rationale behind the overall investigations undertaken here have been to use remote sensing techniques, such as radar and thermal imagery, to track bird movements (principally migration but also local movements) prior to and after construction of the two offshore wind farms and to search for and describe the extent of avoidance behaviours at different spatial scales (from 2-6 km distance when birds likely first visually detect turbines down to a few cm where individuals avoid collision with the rotor blades at very short distances).

2.2 Selection of study areas

2.2.1 Aerial surveys

Given no a priori knowledge of the magnitude of potential disturbance from the wind farm on birds, the study areas at both Nysted and Horns Rev were designed to cover all potential zones of impact. For the specific detection of potential displacement effects, bird distributions were assessed in zones in the vicinity of the proposed wind farm to compare with those throughout the study area. These zones were chosen to include the following areas: 1) the wind farm, 2) the wind farm area and a 2 km zone (+ 2 km zone), around it, 3) the wind farm area and a 4 km zone (+ 4 km) around it.

Up to August 2002 the study area at Horns Rev covered a total area of approximately 1,700 km^2 around the wind farm, surveyed along 26 transect lines. From August 2002 four transect lines, number 27 to 30, were added east of the study area to cover the coastline area off the Wadden Sea.

The study area at Nysted for staging waterfowl covered an area of ca 1,350 km^2 including the planned wind farm of ca 23 km^2.

2.2.2 Migratory birds

Nysted
The observations of migrating birds at Rødsand were conducted from an observation tower placed 6 km south-west of Gedser Odde and 5 km north-east of the wind farm area. From this position it was possible to monitor bird migration by performing both visual and radar observations. Visual observations of birds were undertaken along a 6.9 km long transect between the observation tower and the buoy 'Schönheyders-Pulle' (see Fig. 11). Recordings of bird flocks by radar were compiled within a circular area of 388 km^2 radius around the observation tower. Specific counts of radar tracks were carried out the eastern and northern edge of the wind farm (hereafter referred to as eastern and northern gate). In figures related to radar observations, are only turbines within the radar range depicted. The

entire radar range is referred to as "the study area" with respect to migration studies.

Horns Rev

Observations of migrating birds were undertaken from the transformer station situated 560 metres north of the northeastern corner of the wind farm. Mapping of bird movements was undertaken using surveillance radar covered an area extending 6 nautical miles (c. 11 km) from the transformer station. 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 southwesterly direction (Fig. 7).

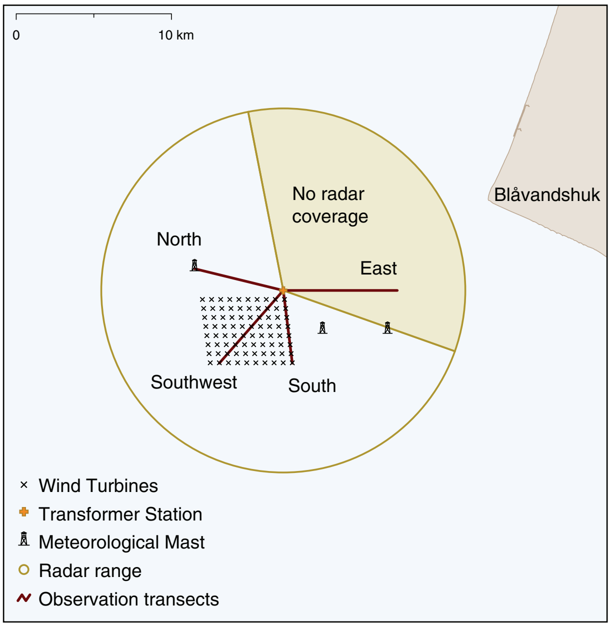


Figure 7. The study area displaying the location of the four transects (lines) used in the visual observation and the radar coverage. Note that some data actually were obtained by radar from the north-eastern area in late November 2005.

2.3 Aerial surveys at Nysted and Horns Rev

All aerial surveys were conducted from a high-winged, twin-engine Partenavia P-68 Observer, designed for general reconnaissance purposes. Surveys were performed from an altitude of approximately 76 m (250 feet) and with a cruising speed of approximately 185 km/t (100 knots).

The surveys were flown along pre-defined transect lines. End points or bends were defined as waypoints, which were entered into the GPS of the aircraft. The pilot navigated along the transect lines using these waypoints. Waypoints were in geographical coordinates as degrees, minutes and minutes/100. Datum was WGS84 (see Christensen et al. 2006 and Kahlert et al 2006). With a survey flight altitude of 76 m, and with wind turbines reaching 110 m it was necessary to slightly alter those transect lines intersecting the wind farm area in order to keep safe distance to the turbines. The transect lines illustrated in figures 9 and 10 are the modified ones. During the pre-construction surveys these transects were straight lines. During the surveys, two observers covered each one side of the aircraft. Only experienced observers were used. All observations were continuously recorded on Dictaphones, giving information on species, number, behaviour, transect band and time. The behaviour of the observed birds included the activities: sitting (on the water), diving, flushing or flying when detected.

During the aerial surveys a computer logged flight track data from a differential GPS at five seconds intervals. Each record contained longitude, latitude and time. Accuracy of GPS longitude and latitude was normally considered to be within 2 m. In situations where the GPS failed during track-logging, positions of each bird observation were calculated by interpolation. In these cases the spatial accuracy of the observation data is slightly reduced.

The majority of records were considered to have a temporal accuracy within four seconds. With a flight speed of 185 km/h the positional accuracy on the longitudinal axis was within 206 m. In the few situations where observers encountered high bird densities, grouping of observations in periods of up to 10 seconds has occurred, leading to an accuracy of observation positioning of up to 515 m. As the detection probability of birds is highly sensitive to weather conditions, surveys were not initiated when wind speed exceeded 6 m/s. Low visibility or glare also reduced detectability. In cases of severe glare, observations from one side of the aircraft were temporarily discontinued.

Observations were recorded using a modified line transect method (Buckland et al. 2001). A binned perpendicular distance from the survey track line was recorded, using three bins or transect bands. Directly underneath the aircraft was a blind strip extending out to 44 m either side of the track line where the observer was unable to effectively detect birds. The inner transect band (A) extended from 44 to 163 m, the middle band (B) from 163 to 432 m, and the most distant band (C) from 432 to 1000 m (Fig. 8). Transect bands were determined using an inclinometer, with break lines at predetermined vertical angles of 60°, 25° and 10° below the horizontal measured abeam flight direction. During the first surveys slightly different transect definitions were used. Transect widths for the individual surveys are shown in Christensen et al. (2006) and Kahlert et al. (2006). Destribution maps presented were based on cumulated numbers from alle transect bands.

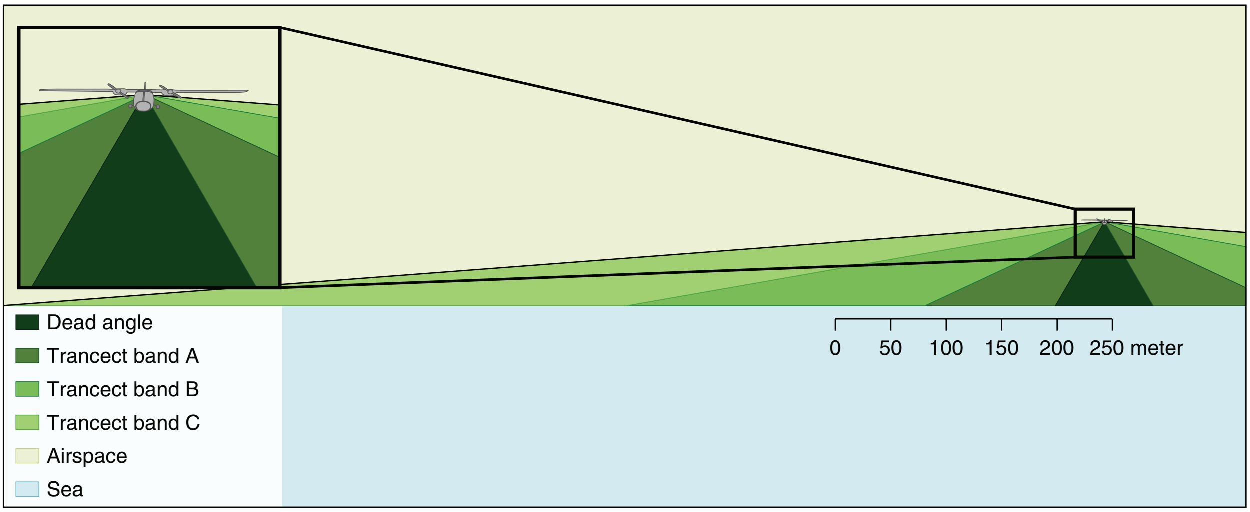


Figure 8. Head-on schematic diagram to scale of the aerial survey aircraft on transect, showing the flight altitude above the sea surface, showing the “dead angle” immediately below the aircraft that cannot be viewed by observers. The coloured angles illustrate the distances out from track line that define the transect bands. Inset shows the close up detail.

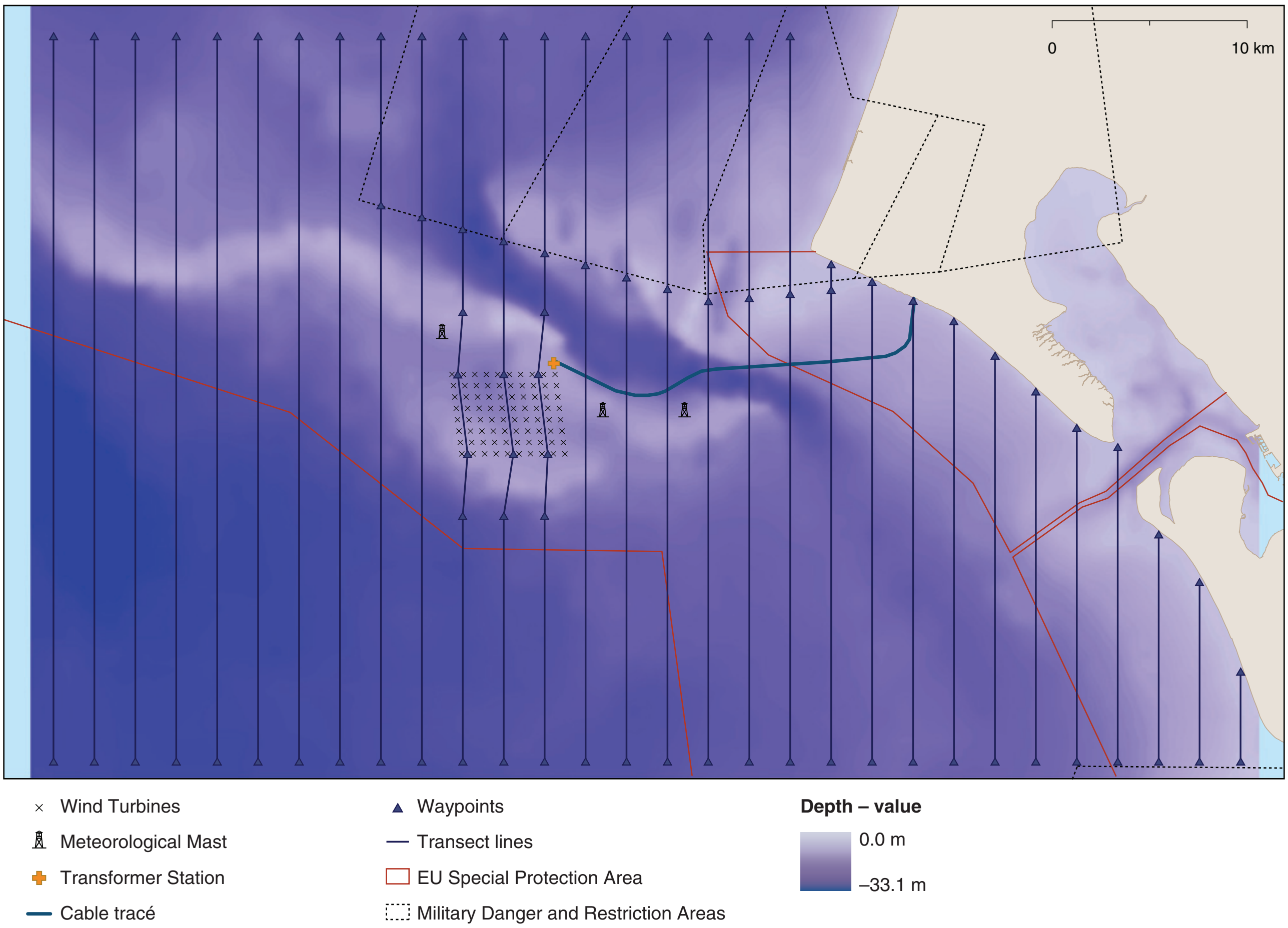


Figure 9. The Horns Rev study area, showing the total survey area and survey transect net. The wind farm turbines, transformer station and meteorological masts are shown. Also shown are EU Special Protection areas and military restriction and danger areas.

Horns Rev

The Horns Rev study area was surveyed by a total of 26 north-south oriented, parallel transects, flown at 2 km intervals from Skallingen in the east, westwards to approximately 37 km off Blåvands Huk (Fig. 9). These transects covered a total linear track of 821 km and covered an area of approximately 1,700 km². From August 2002 further four transect lines were added east of the study area, towards the west coast of Fanø (Fig. 9). This addition increased the study area by 146 km², to a total of 1846 km².

Data on number and spatial distribution of bird species in the Horns Rev area have been collected regularly by aerial surveys during the period August 1999-November 2005 (Noer et al. 2000, Christensen et al. 2001, 2002, Petersen et al. 2004). A total number of 34 aerial surveys have been performed during that period. Of these 16 surveys were performed during the pre-construction period from August 1999 until January 2002. Three surveys were performed during the construction phase from March 2002 until August 2002, while another 15 surveys were performed during the post-construction phase between January 2003 and November 2005 (see Christensen et al. 2006).

Nysted

The survey area was covered by 26 north-south orientated, parallel transects separated by a distance of 2 km and a total length of 579 km, covering an area of ca. 1,350 km^2 including the planned wind farm of ca. 23 km^2 (see Fig. 10).

Data on number and spatial distribution of bird species in the Nysted area have been collected regularly by aerial surveys during the period August 1999-December 2005 (references). Data from a total number of 32 aerial surveys are included in this report from that period. Of these 21 surveys were performed during the pre-construction period from August 1999 until August 2002. Three surveys were performed during the construction phase from January 2003 until August 2003, while another eight surveys were performed during the post-construction phase between January 2003 and November 2005 (see Kahlert et al. 2006). Data from two surveys in April 2005 have regrettably disappeared, and was not included in this report.

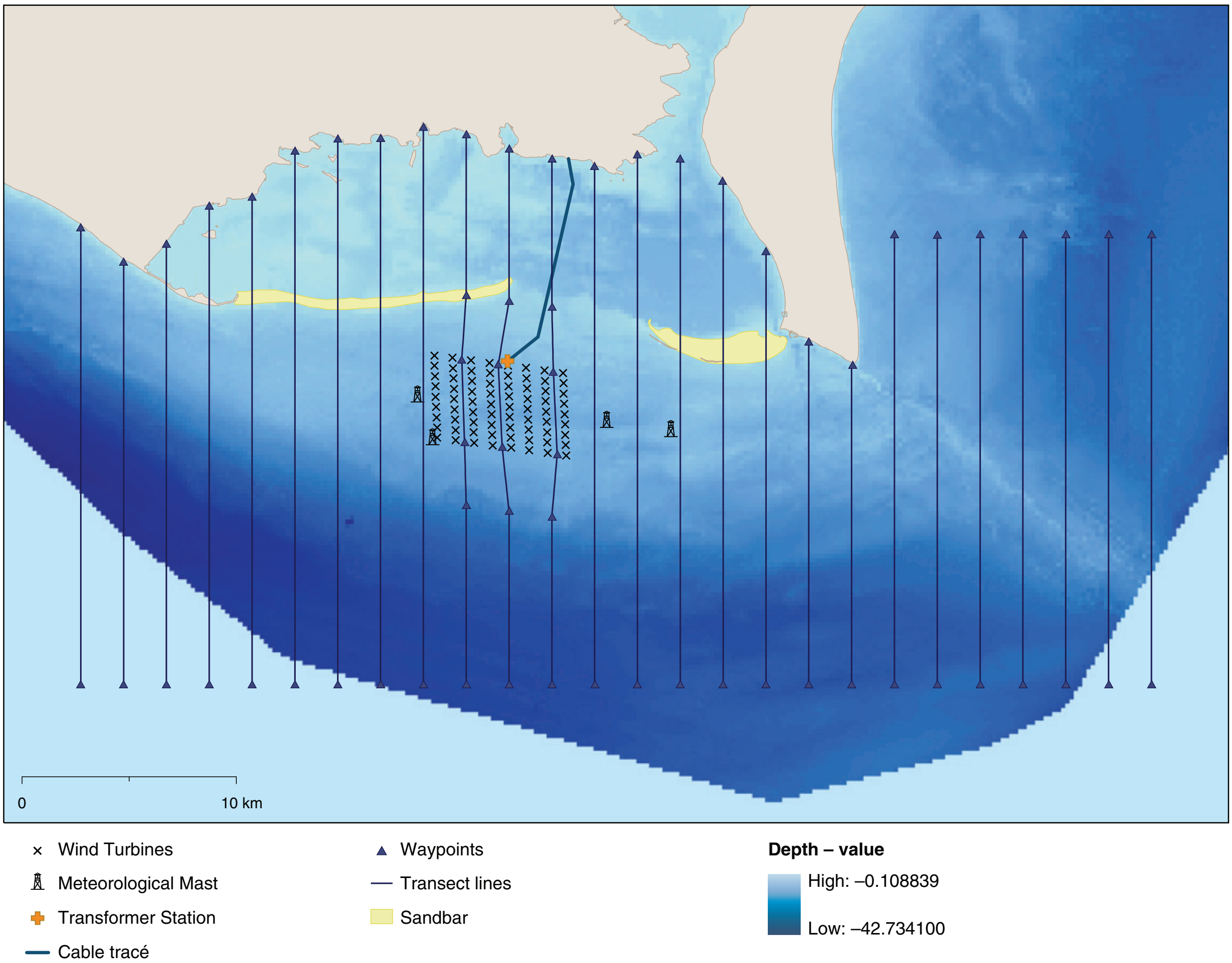


Figure 10. The Nysted study area, showing the total survey area and survey transect net. The wind farm turbines, transformer station and meteorological masts are shown.

2.4 Migratory studies at Nysted

From 1999 to 2005, observations of the bird migration have been performed day and night during 14 March - 19 April and 30 August – 12 November. These periods coincided with the main migration period of a substantial number of the species of waterbirds, birds of prey and passerines. Two days of effective observations were conducted each week from the observation tower. In total, 8 autumn weeks and 4-5 spring weeks were covered annually. Sunset and sunrise defined the grouping of bird data into day and night. Two observers were present in the tower to ensure maximum effectiveness, and for safety reasons. The most intensive studies were carried out on the western and eastern migrating waterbirds as the initial investigations prepared for the EIA showed that substantial numbers of these birds crossed the wind farm area. The migrating waterbirds were also represented by a number of large and long-lived species, which have a small annual reproductive output, predicted to be more susceptible at the population level to potential collisions (Noer *et al.* 1996, Morrison *et al.* 1998).

2.4.1 Visual studies of bird migration

The results obtained from the daytime telescope observations (30x or 32x) made it possible to describe abundance, phenology, diurnal pattern and flock size of species on the buoy-transect. The telescope observations thereby contributed to describe the local as well as the international importance of the study area for daytime-migrating birds. Furthermore, telescope observations supported in combination with the radar observations the explanation of effects at the species level. Data were recorded in a standard format of 15-minute periods.

2.4.2 Radar studies of bird migration

To compile spatial data on bird migration at long distance and during periods of poor visibility due to fog or darkness, a conventional azimuth ship navigation radar (Furuno FR2125) was used (Table 2, Fig. 11).

Table 2. Specifications of the radar equipment used to monitor the study area

Antennae	8 feet Horizontal beam width 0.95° Vertical beam width 20°
Tranceiver	X-band, 9,410 MHz, 25 kW Variable pulse length
Display	21" colour monitor (1,280 x 1,024 pixels)

Each echo on the radar monitor represented a flock of birds in the study area, and in this way the spatial migration pattern could be described both during day and night. Data were provided as the lateral position of objects, their migration speed and course. The performance of the radar was optimised continuously in order to obtain the best signal and simultaneously to minimise noise from sea and rain. Pre-defined settings specifically developed to detect birds were used. The radar was fixed at maximum signal gain. Suppression of sea and rain clutter was adjusted to 25-50% in most situations.

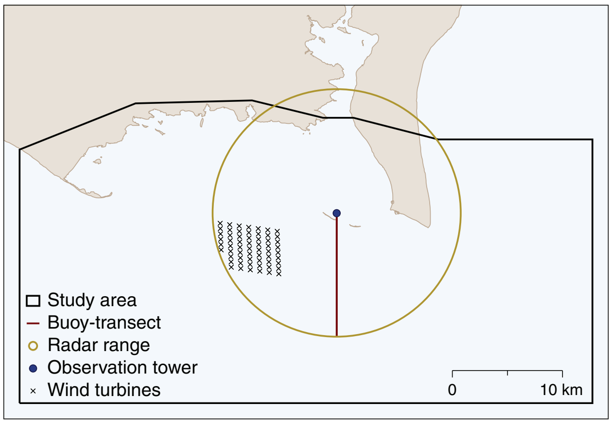


Figure 11. Location of the study area for migrating birds, the observation tower on which the radar was mounted, radar range, wind farm area and the Buoy-transect. Only turbines within the radar range are depicted.

Despite the attempts to optimize the performance of the radar, there are a number of factors, which may impair bird detection. This includes for example small size of birds/flocks, long distance, low migration altitude and an odd flight angle, which all could be influenced by weather conditions. It was therefore considered extremely difficult to take into account the almost indefinite number of combinations of these factors to calibrate the radar to give accurate estimates on the migration volume. For this reason, it was already at an early stage decided to put less emphasis on migration volume derived from the radar studies as a mean to conclude on wind farm effects. Nevertheless, radar is still considered as a powerful tool in order to detect such effects as shown in this report. This can for example be done by studying the change in flight patterns when birds approach a wind farm, and preferable in a pre- and post construction design of the same study area on a long time scale, so that the potential bias from a changing radar performance is held relatively constant.

Another aspect of reduced detectability is the socalled "shadow effect" behind static structures such as individual wind turbines, which causes the loss of a clear radar signature. However, this is considered not to be a major problem in the interpretation of data, as many of these tracks appear on the other side of the turbine shadow (Kahlert et al. 2004).

During autumn, the westerly-orientated migration of waterbirds was followed in the area between Gedser Odde and the wind farm area, and the southerly-orientated migration of birds coming from the direction of the mainland areas was followed between southeast Lolland and Gedser Odde (see Fig. 4). During spring, the easterly-orientated migration of waterbirds was monitored from the wind farm area to Gedser Odde. The migration routes were mapped by tracing the course of bird flocks from the radar monitor on to a transparency. Only tracks longer than 5 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 transparencies were digitised and entered into a GIS-database.

2.4.3 Weather data

Local weather conditions were included in the documentation of effects of the wind farm on migration routes to increase confidence of the conclusions. Energi E2 A/S (wind), The Danish Meteorological Institute (wind and visibility), Gedser Havudkik (visibility) and observations from bird tower (visibility) provided the data.

Wind data were either obtained from the Gedser Odde weather station or from meteorological masts at the wind farm area in accordance with availability of data. Only wind direction was used in this report, and due to the short distance between Gedser Odde and the wind farm, the use of data from two sites was unlikely to bias the wind data. Wind data were consistently compiled as means over 10-minute periods and assigned to the 15-minute bird count units in such a way that greatest overlap between bird data and wind data was obtained.

From 1999 to 2002, data on visibility were obtained from Gedser Odde obtained at 3 hour intervals, in 2003 at 6 hour intervals. In 2004 and 2005, observers in the tower continuously recorded the visibility, and thus this period represented the most accurate measure of this parameter.

However, it appeared that it was impossible to test the effect of visibility in the analysis in a meaningful way other than day- and nighttime. The overall problem of incorporating visibility was that very few bird data existed at poor visibility (less than 1 km) at which distances the most marked avoidance response was likely to occur (Kahlert et al. 2005). There were several reasons for the lack of data with poor visibility. First, it has proven extremely difficult to plan observation bouts, aiming at conditions with poor visibility. Second, waterbird migration is greatly reduced at poor visibility (Petterson 2005). Third, in a windy offshore place as the Nysted wind farm area, there is a very low probability of poor visibility, in particular during autumn (Kahlert et al. 2002).

2.5 Migratory studies at Horns Rev

2.5.1 Study area

Observations of birds were undertaken from the transformer station situated 560 metres north of the north-eastern corner of the wind farm. Mapping of bird movements was undertaken using surveillance radar both during day and night time. 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. 7). A combined use of radar and visual observations during the daytime provided 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 (c. 11 km) from the transformer station. Coverage of the area between ca. 355° and 95° was not possible due to the structure of the transformer station (see Fig. 7). However, during late autumn 2005, a fixed radar was in place at the transformer station, making it possible to obtain some data from this, otherwise, uncovered area.

2.5.2 Study period

During the period 2003 to 2005 combined visual and radar observations were performed in the months of March, April, May, August, September, October and November. A trial observation period for visual observations was performed in August 2002, but data from this period is not included in the analyses. Likewise, the radar was tested in May 2003, but usable data was first obtained during August 2003.

Observations of migratory birds at the Horns Rev wind farm were performed during a total of 19 visits to the area during 2003-2005. In total 243 hours and 45 minutes of visual observation (only daytime) and 403 hours and 18 minutes of radar observations (day and night time) were carried out (Table 3). In general the covered periods of spring and autumn, coincide 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 and autumn. Planned trips in the month of February, the period with the highest number of staging divers in the area, were not performed. Observations in the autumn of 2004 were temporarily stopped in September, as most of the turbines were not operational for technical reasons during this period. During all stays at the transformer station, two observers were present to ensure maximum effectiveness in counting, and for safety reasons.

2.5.3 Visual observations

Visual observation data were collected systematically along the four transects during daytime using a telescope (Leica televid 30x). All observations were recorded in 15-minute periods performed with 1-2 hours intervals between sunrise and sunset. At each visit to the transformer station, a full daylight period was covered and observations were performed by two observers operating in parallel.

Table 3. The period of effective observations (visual and radar) conducted from the transformer station at Horns Rev during 2002 (visual observations only), 2003, 2004 and 2005.

Period	Visual observations	Radar observations	
		FURUNO FR2125/FR2110	LITTON/DECCA (25kW)
28 April – 1 May 2003	26h 15min		
12-15 May 2003	29h 30min		
6-8 August 2003	9h 30min	7h 53min	
25-29 August 2003	14h 0min	32h 20min	
22-25 September 2003	27h 30min		
13-16 October 2003	5h 30min	39h 20min	
11-13 November 2003	7h 45min	32h 45min	
Total 2003	120h 0min	112h 18min	
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	
31 August – 1 September	12 h 15 min	23 h 0 min	
Total 2004	40 h 0 min	95 h 10 min	
8-11 March	7 h 0 min	22 h 45 min	
20-24 April	13 h 0 min	34 h 15 min	
10-13 May	16 h 0 min	24 h 15 min	
25-27 May	9 h 0 min	17 h 45 min	
16-19 August	10 h 45 min	37 h 0 min	
20-22 September	10 h 0 min	5 h 30 min*	
18-19 October	9 h 45 min	20 h 45 min	22-23 & 28 November:
22-24 November	8 h 15 min	28 h 0 min	5 h 35 min
Total 2005	83 h 45 min	190 h 15 min	5 h 35 min
Total 2003-2005	**243 h 45 min**	**397 h 43 min**	**5 h 35 min**

*radar observations were closed due to technical problems

2.5.4 Radar observations

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 (specifications given in Table 2) or FR2110 (similar specifications but only 12 kW)) was used. During late November 2005 it was possible to obtain data on bird migration by a second radar (Litton/Decca 25 kW, X-band) fixed at the transformer station. This radar was installed for ship traffic surveillance purposes, and was remotely operated from land. The location of this radar at the southeast corner of the transformer station, made it possible to record bird movements in the area northeast of the wind farm, an area that was not visible by the portable radar otherwise used during this study.

2.5.5 Flight altitude

Flight altitude is a key factor in the assessments of the collision risk between birds and wind turbines. The probability of collision is most likely highest for birds flying in the area swept by the rotors (at Horns Rev 30-110 m above sea level).

As a trial study, flight altitudes of visually identified birds or flocks of birds were calculated during 2003. The angle of the bird from the horizontal plane was estimated using a digital levelling device, measuring with an accuracy of 0.1°, attached to the telescope. Given the known height of the levelling device above sea level and the distance to the birds could be measured by the radar, the flight altitude was calculated using simple trigonometry (see Christensen et al. 2003 for more details).

Data on bird flight altitudes was not collected during 2004 and 2005, as an additional program focused on flight altitude of birds in relation to the offshore wind farms in Danish waters, including the Horns Rev wind farm, was proposed, and subsequently initiated in 2005 (see Blew et al. 2006).

2.5.6 Weather data

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. 7). Throughout the present study, data on wind direction and wind speed was compiled every 10th minute, and these records were subsequently assigned to bird observations, minimising the time span between weather and bird records. Thus the maximum deviance in timing between a weather and a bird record was 15 minutes.

2.6 Investigations of collision risk

Collision risk was calculated from data obtained by use of the Thermal Animal Detection System (TADS) at Nysted offshore wind farm (see Fig. 4) collected during four migration seasons: Spring 2004 (Desholm 2005a), autumn 2004 (Desholm 2005b), autumn 2005 (see Kahlert et al. 2006), and spring 2006 (see Kahlert et al. 2006).

The aims of this study were two-fold:

1. to collect data on the number of waterbird collisions and on the near rotor evasive behaviour using TADS, and
2. to compile information (data collected by TADS and radar) to build a stochastic predictive collision model (SPCM) for estimating the number of Common Eiders, the most common species in the area, colliding with the sweeping turbine blades at the Nysted offshore wind farm situated in the Baltic Sea, Denmark.

2.6.1 Thermal Animal Detection System (TADS)

The TADS is an infra-red based detection system that can monitor the behaviour of animals in total darkness and in an automated way so thermal video sequences are stored only if relatively hot animals enter the field of view. TADS has been developed for use in the severe and saline conditions of offshore areas (Desholm 2003, Desholm 2005b, Desholm et al. 2006). Collisions with the foundations and turbine towers are judged to be a solely low-visibility issue due to the lack of motion smear of the static structure. However, since visibility in the study area very rarely comes below 1 km and because Common Eiders tend to fly above turbine height at night, we have only modelled the rotor blade collisions.

Figure 12. Thermal camera mounted with a pan/tilt head on the A2 offshore turbine at Nysted wind farm.

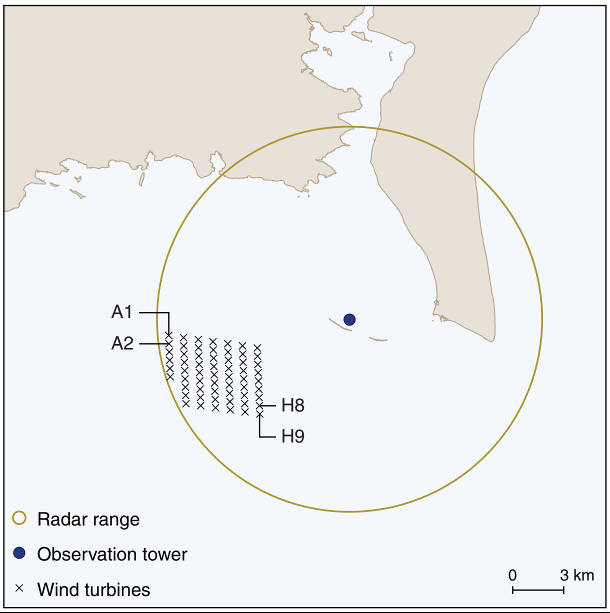
All objects with a temperature above absolute zero, i.e. -273°C, radiate heat. Thermal imaging is a method of obtaining images of objects by measuring their own, and the reflected heat radiation detectable within the infrared spectrum of wave lengths of 2-15 µm, and contrasts the ordinary photographic image which results from the reflection of visible light. For a more detailed description of the theory behind the thermal imaging technique see Desholm (2003).

Using a 24° lens, the maximum coverage (32.4%) of the disk area swept by the blades of a wind turbine rotor was achieved (hereafter referred to as the sweep area). For more details on the camera model Thermovision IRMV 320V from FLIR see specifications at the Internet site: http://www.flirthermography.com.

In order to identify birds appearing on the imagery to species level, a combination of body shape, the movements of the flying bird and the wing beat frequency has to be taken in to account. However, as the distance between the bird and camera increases the possibilities of identification will decrease.

The main features of the TADS (Fig. 12) are as follow:

1. A thermal video camera with a 24° lens that can detect birds in total darkness and, to a greater degree than the human eye (e.g. a chicken can be detected at a distance of 225 m when the visibility is only 30 m due to heavy snow storm; Desholm 2003), in dense fog also.
2. A thermal trigger software which start downloading video sequences to the hard disc of a computer when at least one pixel in the field of view exceeds an operator-defined threshold temperature level (i.e. it triggers 100% of the birds passing the field of view if camera settings is set correctly) ensuring an automated way of saving mainly sequences when birds are either passing or colliding with the turbines.
3. A sealed metal box for camera protection against precipitation and salty seawater spray.
4. A pan/tilt head enabling the operator to change the heading and vertical angle of the field of view.
5. A computer sited inside the turbine tower for the necessary software and video sequence storage.
6. A network connection from the turbine computer at sea to the NERI office on land.
7. A windscreen wiper and a sprinkler system.
8. A water valve for removal of condensing water inside the camera housing.



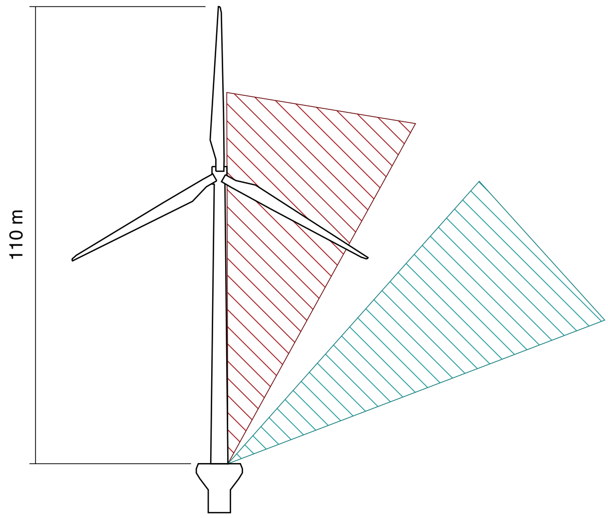


Figure 13. (Upper left): Placement of the observation tower (blue dot) and extent of radar range (yellow circle) for mapping the migration trajectories of waterbirds. The TADS was mounted on the H8 turbine. (Upper right): The two viewing modes used for collision monitoring with the 12 degrees lens. (Bottom): Thermal image showing the view when using the horizontal viewing mode for altitude estimation.

2.6.2 Measuring avian collisions

The TADS was mounted on the second most southern turbine (H8) in the eastern row during autumn periods and on the second most northern turbine (A2) during spring periods (Fig. 12). These positions represent the sector with highest migration volume of waterbirds during the respective migration seasons, and were chosen to potentially register as many passing birds as possible in the vicinity of a monitored turbine. The TADS was mounted on the side of the turbine tower from where the migrating Common Eiders were approaching the wind farm (west in spring and east in autumn) at c. 7.5 m a.s.l..

Data were collected during day and night during spring (mid March to mid April) and autumn (September and October). Only one operator adjusted the camera settings and collected the data, ensuring as high continuity and as low variance in the data collection process as possible. Two different views were used during data collection (see figure 13):

1. the preferred vertical view for monitoring the birds passing or colliding with the turbine tower and the turbine blades,
2. the 45° angle view for monitoring the near vicinity of the turbine towards the north.

The vertical view was the primary view usable only when the blades were rotating on the opposite side of the turbine tower in relation to the camera, and the aim using this viewing mode was to measure collisions directly. The 45º view was the secondary view usable during all possible wind directions. The aim using this viewing mode was to collect data on the migrants flying in the very close proximity of the turbine.

From the recorded thermal video sequences, the following data were derived:

- number of birds colliding with the turbine or passing in the near vicinity of it,
- number of sequences triggered,
- sequence length (seconds),
- view type,
- wind conditions during data collection (obtained from a meteorological mast within the wind farm area),
- numbers of and reasons for false (i.e. non-bird) triggered sequences (when other things than birds triggered the recording).

2.6.3 Collision model parameterisation

Not only can TADS be used to monitor the avian collisions with wind turbines, moreover it is capable of collecting input data for the collision prediction model. Since it will never be economical feasible to monitor all turbines within a large offshore wind farm a modelling approach will always be necessary. A framework for a predictive collision model will be presented in the following chapter and below is described those input that were collected by the TADS during the study. The remaining input data for the model originate from visual and radar data collected from 1999 to 2005 and will be presented in the paragraph on modelling.

2.6.3.1 Near rotor-blade avoidance response

The ability of birds to perform a near rotorblade avoidance in order to pass safely the area swept by the rotor-blades is an important factor to incorporate in any future predictive collision models. Such information will be obtained both from all three viewing modes. Ideally, this information should be plentiful and species specific, but it must be emphasised here that this study using one TADS only during one autumn migration season will not provide all the necessary data, and thus, more data collection will be needed in the future if this topic has to be understood. So far only one study has provided information on this topic (Winkelman 1992).

2.6.3.2 Flight altitude

Knowing the flight altitude of the migrants is essential for the process of predicting the number of future collisions through modelling. The height data will be derived from manually recorded thermal video sequences (Fig. 13) of birds passing between the turbine at which the TADS is mounted and the neighbouring turbine.

In order to estimate the flight altitudes of migrants using TADS, the distance and vertical angle to each individual/flock has to be estimated. The distance (A) to the recorded Common Eider flocks was estimated by trigonometry:

$$A = \frac{C}{\tan V_h} \qquad \text{Equation}$$

where C represents half the distance the flock flew when passing the field of view and V_h is half the horizontal angle of the applied camera lens which was a 24° lens. C was calculated for each flock by multiplying the time it took to pass half of the field of view with the ground speed (the mean air speed for Common Eiders corrected for the wind assistance experienced by the birds recorded by the TADS). The mean air speed for Common Eiders was estimated from five years of radar data where the species specific ground speed was corrected for the wind assistance.

From the visually obtained line of sight the vertical angle to each bird can be estimated by trigonometry:

$$V_v = \arctan\frac{a}{b} \qquad \text{Equation}$$

where a denotes the projected height of the bird at the neighbour turbine and b denotes the distance between the two turbines (Fig. 14).

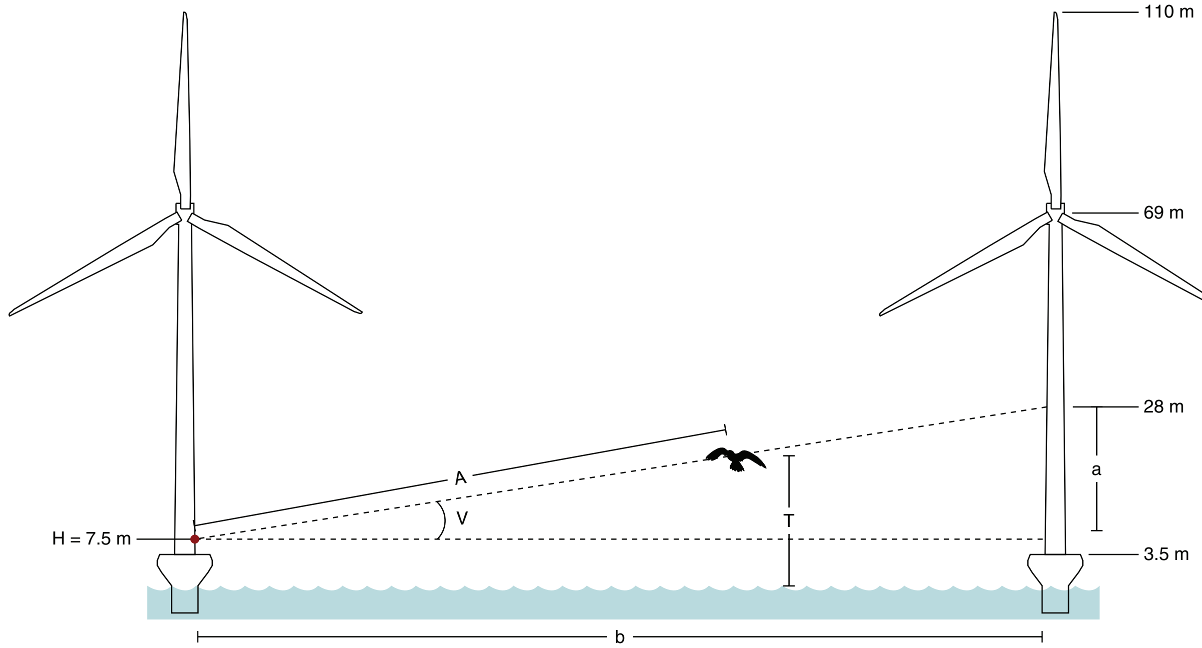


Figure 14. Schematic presentation of the trigonometry features used for estimating the flight altitude (T) of the migrating waterbirds. A denotes the distance (m) between the TADS and the bird flock (depicted as a single bird), V_v the vertical angle of flock, b the distance between the two turbines (480m), a the projected height on the neighbour turbine of the flock, and H the mounting height of the TADS.

Knowing the distance and angle to the bird, the flight altitude (T) of the recorded flocks of Common Eiders was estimated by trigonometry:

$$T = (\sin(V_v) \times A) + H \qquad \text{Equation}$$

where V_v is derived from equation 3 and A from equation 2 and H denotes the mounting height of the TADS (Fig. 14).

Measuring flight altitude by means of TADS is constrained by the relative small vertical opening angle of the camera lens (18°), which results in a limited field of view. This will exclude bird flocks flying high and close to the TADS from being detected. The view direction was set towards the south in autumn and towards north in spring in order to obtain data from both inside and outside the wind farm. Consequently, the number of flocks flying at the same height as the sweeping rotor-blades will be underestimated inside the wind farm but not outside. This must be kept in mind when analysing the frequency distributions of flying altitudes inside the wind farm, and thus, a correction factor will be applied for each 10 m altitude interval correcting the altitude frequency distribution for the decreasing TADS-coverage with increasing altitudes.

2.6.3.3 Flock size and species composition

From the horizontal recordings the number of individuals in each flock was estimated visually by a single experienced observer. From the same sequences species composition was determined by a combined assessment based on flight pattern, flock structure, migration speed, wing beat frequency and the general appearance of the individuals (known as the "jizz").

2.6.4 Avian collision model

Constructing collision prediction models necessitates discrimination between models for EIA studies (pre-construction) and models for effect studies (pre- and post-construction) since only the latter offers the opportunity of including the avian evasive actions towards wind turbines. This is because data on species specific evasive manoeuvring are very scarce. Consequently, data on evasive manoeuvre capabilities need to be collected at the study site of interest before proper estimates of the number of collisions (including avoidance behaviour) can be estimated through quantitative predictive modelling. Nevertheless, it is recommended to build non-evasive-type models as part of the EIA studies, as a first crude assessment of the potential risk of collision for any proposed wind farm.

2.6.4.1 Framework for a collision model

The present report focuses on the development of a stochastic predictive collision model for autumn migrating waterbirds (specifically Common Eiders). The model considers migrating birds colliding with the rotor-blades during one autumn season.

The model framework presented here have deliberately not embraced night-time periods and periods with very low visibility that are usually thought of as high-collision situations. This is because these situations are judged to be of minimal importance in the present study, because: 1) the focal species tend to fly above turbine height at night and 2) situations when visibility is below 1km hardly ever occur at the study area during migration periods, and 3) we have anecdotal evidence that Common Eiders land on the water and cease migration when unfavourable weather conditions suddenly appear. This also explains why we have chosen to deal with rotor-blades collisions only, since collisions with the foundations and turbine towers are, due to lack of the motion-flare effect, judged to be a solely low-visibility issue and therefore not relevant in the present study. The model was designed and runs in the software Stella (Isee Systems) and the model code is available as text in Kahlert et al. (2006) or as Stella file at www.dmu.dk.

Risk of collision is defined as the proportion of birds/flocks exposing themselves to a collision by crossing a scale-specific collision conflict window (e.g. a wind farm or the area swept by the rotor-blades). The risk of collision (r_i) is assessed at four levels of conflict windows: Level 1 relates to the study area, level 2 the wind farm, level 3 the horizontal reach of rotor-blades, and level 4 the vertical reach of rotor-blade (Fig. 15). The value of r_i can be measured directly for each level post-construction as an average transition probability with its related variability (e.g. the standard deviation), or be estimated pre-construction by multiplying the pre-construction proportion of birds/flocks (p_i) passing the level specific conflict window with the assumed (published estimates) proportion of birds (a_i) not showing any evasive manoeuvres at the given level.

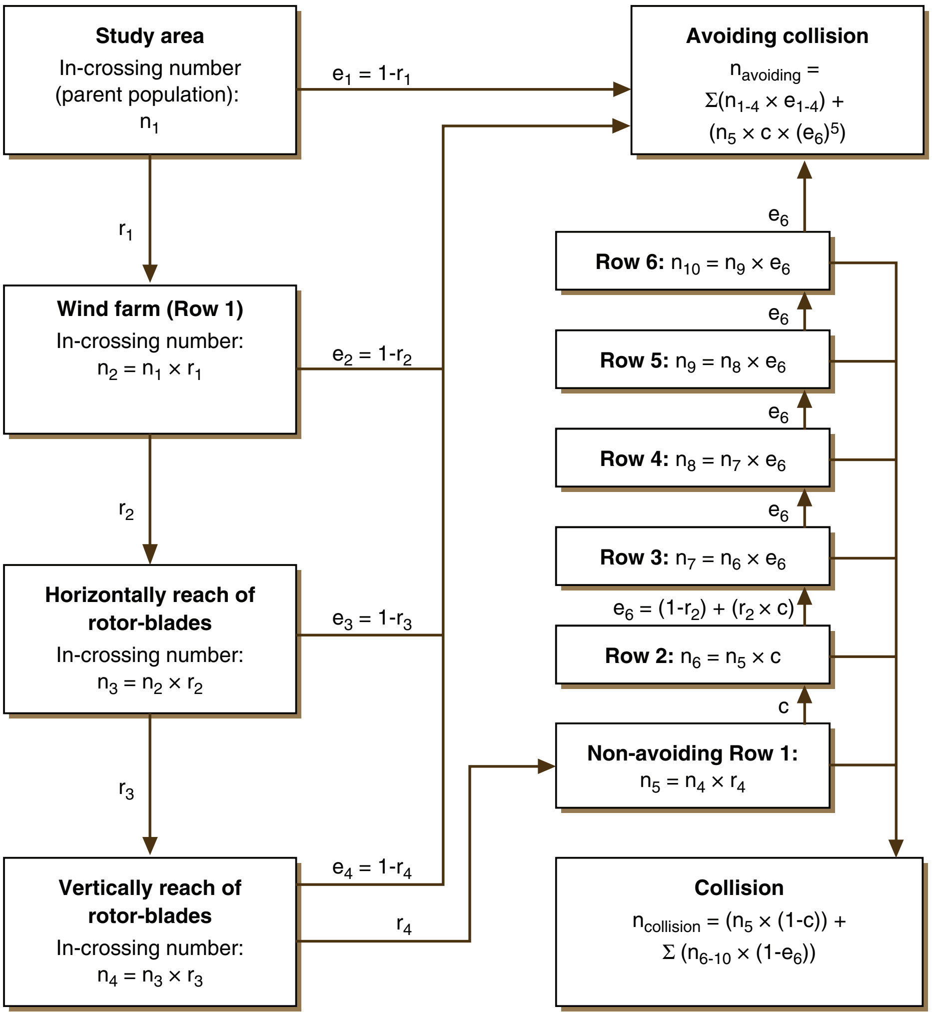


Figure 15. Schematic presentation of the collision prediction model where the boxes to the left represent the four scale-specific conflict windows and the two large boxes to the right the non-colliding and colliding segments of the migrants. The six values of n_i denotes the number of birds/flocks which enter each box and can be calculated in accordance to the equations presented in the boxes. The migration volume in study area is represented by n_1. Risk of collision is denoted r_i and is defined as the proportion of birds/flocks exposing themself to a collision by crossing a collision conflict window (e.g. wind farm or area swept by the rotor-blades). The evasive transition rates are denoted as e_i and c is a factor describing the by-chance-probability (c) of not colliding with the rotor-blades when crossing the area swept by the rotor-blades.

After level 4, a factor describing the by-chance-probability (c) of not colliding with the rotor-blades must be incorporated to account for those birds passing safely the area swept by the rotor-blades by chance (Fig. 15; Tucker 1996, Band et al. in press). An overall risk of collision (R) for the first row of turbines can be obtained by multiplying the four probability risk values:

$$R = r_1 \times r_2 \times r_3 \times (r_4 \times (1-c)) \qquad \text{Equation}$$

In the present report, the stochastic way of estimating the overall number of collisions at the wind farm ($n_{collision}$) will be applied incorporating the variability of the input parameters and variance (standard deviation) estimates of the output values (e.g. $n_{collision}$ and $n_{avoiding}$) will be produced. We will simulate the migration event from n_1 through $n_{collision}$ in accordance to the collision prediction model (Fig. 15) by re-sampling transition probabilities, wind directions, c-values and n_1-values from probability distributions collected in the field post-construction and from published estimates.

The first part of the model covers the front row of turbines only, and hence, the second and last part of the model deals with the secondary row-passing's (equal to n_m) starting with $n_4 \times r_4 \times c$ individuals (Fig. 15). This approach implies that only birds passing the area swept by the rotor-blades at the first row of turbines, and which showed no evasive response towards the rotating turbine-blades, will have the possibility of passing the area swept by the rotor-blades of the consecutive rows of turbines. This is because birds avoiding the turbines in the first row will, in all probability, exhibit the same perception of risk when passing the turbines at the next row of turbines, and hence, most probably perform a similar evasive response again.

The average number of rows of turbines the flocks of waterbirds passed when crossing the wind farm area was estimated from the autumn radar base-line data collected at the study site from 2000-2002. Only tracks entering the wind farm through the eastern gate was used. Each track was followed through the wind farm area and the number of north-south orientated turbine rows passed was counted. If a track terminated inside the wind farm area its last node was prolonged until it left the wind farm area by the projected route.

The mean number of rows passed by the migration Common Eiders was adapted in the collision prediction model (Fig. 15). The number of collisions from row number two and onwards were estimated as the proportion of the birds that flew close enough to the turbines to be within the wind dependent horizontal risk window and which did not pass the rotating rotor-blades by chance. Remember that birds susceptible to collisions at row 2 and onwards are those that, at row number one, were within the vertical and horizontal risk window and which did not show any evasive response towards the turbines and passed the sweeping rotor-blades by chance.

Parameterisation of the collision prediction model was done by applying both radar, TADS and visual observations in the data baseline collection protocol as follows for each of the four spatial levels:

Level 1. This level relates to the study area and specify its in-crossing number n_1 representing the overall number of birds/flocks passing the study area during a migration event (i.e. spring or autumn migration season). The present model only deals with autumn migrating Common Eiders and the overall numbers were adopted from Table 34.

Level 2. This part of the analysis requires radar data defining the mean probability of migrants passing the wind farm (r_1). Here, radar data were grouped by date and if less than 10 radar tracks were observed on a day they were grouped with the following days until at least 10 tracks were present in the group. This resulted in 47 days/periods for which r_1 and its related variation could be calculated. A frequency distribution was produced and, if normally distributed, the mean and the standard deviation were used to parameterize a normal distribution in the software Stella from which r_1 is re-sampled at each modelling event.

Level 3. For this part of the analysis, radar data of the distance to nearest turbine for flocks passing through the wind farm was obtained from all post-construction waterfowl tracks (mainly Common Eider) passing the eastern (Row 1) row.

The proportion (r_2) of the migrating flocks that pass within the horizontal risk distance (equal to the projected length of the rotor-blades) of the turbines can be calculated for all possible wind directions. At each autumn season model event, a wind direction was re-sampled from a normal distribution describing the wind directions associated with all the 10,672 post-construction waterfowl radar tracks where wind data were available. This wind direction was then used to estimate the horizontal risk distance (HRD) from the turbine:

$$HRD = L - (L \times \cos D_{wind}) \qquad \text{Equation}$$

where L is the length of the rotor-blade (42 m) and D_{wind} is the direction from were the wind is blowing. For each re-sampled wind situation a HRD can be calculated and an estimation of the proportion (r_2) of waterfowl flocks flying within each rotor-blades performed. Hence, for each model run a wind dependent r_2 is re-sampled which includes the horizontal avoidance response by Common Eiders towards the wind turbines.

Level 4. In order to estimate the proportion (r_3) of birds flying within the vertical reach of rotor-blades, an altitude distribution from the TADS-data is used. Altitude data on waterfowl flying within the wind farm were applied and thereby the potential vertical avoidance response by the birds are included in the model. However, the relatively low volume of data meant that no reliable variance estimate for the mean could be estimated, so a deterministic mean value was used for all model run events.

At this stage, n_4 (number of birds passing the area swept by the rotor-blades of row 1) was estimated and the final transitions to birds colliding ($r_4 \times (1-c)$) and avoiding the rotor-blades ($e_4 + (r_4 \times c)$) must hereafter be executed. For inclusion of the near rotor-blade avoidance (e_4) which must be collected during both day and night, infrared detection systems (e.g. TADS) must be applied to collect data on ability of the different species of birds to perform evasive actions when crossing the sweeping rotor-blades. So far, such evasive factors have only been reported in the study by Winkelman (1992) using a thermal camera. In total, 92% of the birds (all species combined) approached the rotor-blades without any hesitation during the day time whereas this figure was 43% at night (Winkelman 1992). It is assumed that birds showing evasive action when crossing the area swept by the rotor-blades are passing safely.

Finally, an avoiding-by-chance factor (c) must be incorporated after level 4 for those birds crossing the area swept by the rotor-blades safely without performing any evasive actions. Procedures for calculation of "c" can be found in Tucker (1996) and Band et al. (in press) and will be directly incorporated in the collision prediction model.

Those birds passing safely (by chance) the sweeping rotor-blades of the first turbine row are now the subject of estimating the number of collisions at the remaining rows of turbines (Fig. 15).

The end product of the collision prediction model will be the predicted number of birds colliding with the turbines:

$$n_{collision} = (n_5 \times (1-c)) + \Sigma(n_{6-10} \times (1- e_6)) \quad \text{Equation}$$

and the predicted number of birds that avoid (either by chance or by evasive actions) colliding with the turbines:

$$n_{avoiding} = \Sigma(n_{1-4} \times e_{1-4}) + (n_5 \times c \times (e_6)^5) \quad \text{Equation}$$

where n_1 (overall number of birds passing the study area) equals the sum of $n_{collision}$ and $n_{avoiding}$.

2.7 Quality control

At Horns Rev, comparability in visual transect observations between different days and periods, was obtained by performing visual observations on days with good weather. In this way, only few observation periods (the 15 minute intervals) were affected by rain, which may reduce detectability of smaller species at the longest distances. In few situations of severe sun reflections during transect observations, the full 15 minute observation period was cancelled. If possible, such cancellations were compensated by making alternative observations during concurrent days.

All observations of birds during the aerial surveys were recorded on a Dictaphone. During subsequent transcription unusual data were underlined or commented to make a later exclusion of erroneous data possible. After being computerised into databases, all records were checked once again to identify errors during this procedure.

The present report is subject to the following quality control:

- Internal scientific review by a senior researcher
- Internal editorial and linguistic revision
- Internal proof-reading and spell check
- Layout followed by proof-reading
- Approval by project managers.

3 Data analyses

Thomas Kjær Christensen, Ib Krag Petersen, Johnny Kahlert, Mark Desholm

3.1 Habitat loss

All observations dictated on the Dictaphone tapes during aerial surveys were first transcribed to paper sheets, and then entered into an Excel spreadsheet. Survey track data was transferred to a GIS platform. A combination of ArcGIS/ArcView and TurboPascal software was used to geo-reference each observation and to assign observations to transect band and side of flight track. From these data GIS layers containing observations for each survey was established.

Databases containing observation and track data from all surveys were created, with observation databases containing 38,416 records from Horns Rev and 28,908 records from the Nysted study area.

Survey track data were created as GIS point themes and line themes. Survey track lines have been used, containing information on survey effort along the line.

For all relevant species, distribution maps based on pooled data from all surveys carried out during the pre-construction phases and the post-construction phases, were summarised at a grid resolution of 2x2 km. Thus bird distributions are described as relative densities, corrected for variation in survey coverage. A description of the overall survey coverage by 2x2 km grid cells is given in figures 16a-b.

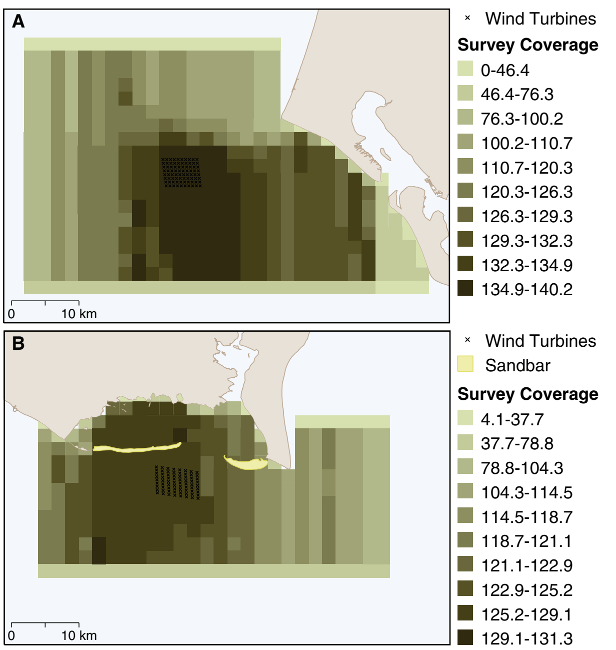


Figure 16. (A) Transect length survey effort (in km) per 2 x 2 km grid squares in the study area, summed for all 34 surveys performed in the Horns Rev study area. See text for details. (B) Transect length survey effort (in km) per 2 x 2 km grid squares in the study area, summed for all 32 surveys performed in the Nysted study area. See text for details.

To assess the number of birds of the different species that would be susceptible to potential disturbance effects from the wind turbines, and to assess the importance of wind farm areas and the adjacent waters, we described bird preference for the wind farm area and different adjacent zones of potential impact relative to their preference for the entire study area. For this analysis the actual bird encounters were used rather than estimates of relative densities. For the Horns Rev study area this was done on the basis of 16 pre-construction surveys and 15 post-construction surveys. In the Nysted survey area aerial surveys were ceased in autumn during the post-construction phase. Therefore winter and spring surveys were chosen for this purpose in order to ensure adequate comparability between the pre- and post-construction data sets.

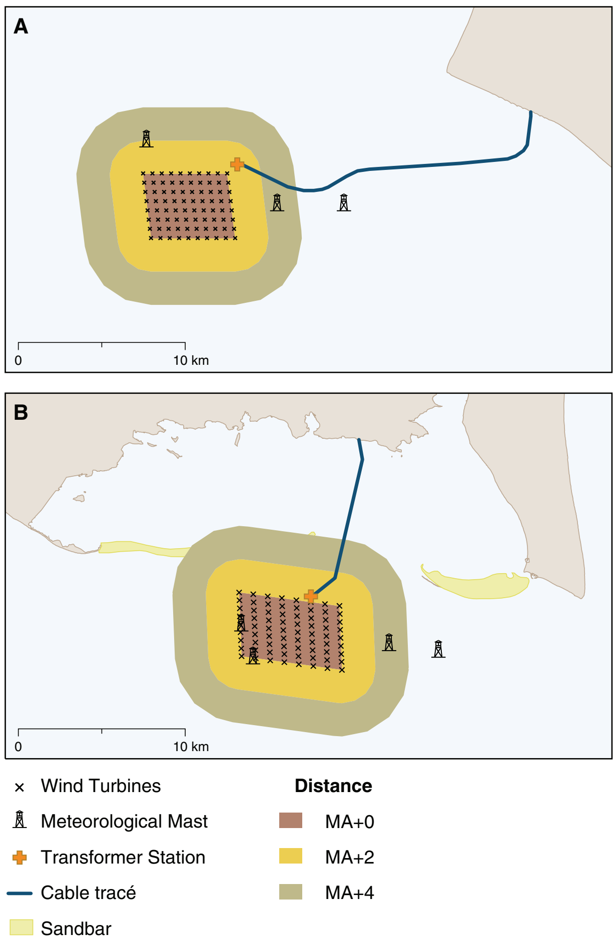


Figure 17. (A) The Horns Rev wind farm with indication of the extend of a 2 km and a 4 km zone around the wind farm. (B) The Nysted wind farm with indication of the extend of a 2km and a 4 km zone around the wind farm.

Jacobs selectivity index (D) was used to describe the selection for the wind farm area and its vicinity of 2 and 4 km zones (Figure 17a-b) as compared to the distribution over the entire survey area (Jacobs 1974). This was done for selected bird species. D-values vary between –1 (all birds present outside the area of interest) and +1 (all birds inside the area of interest), and is calculated as:

$$D = \frac{(r - p)}{(r + p - 2rp)}$$

where r = the proportion of birds in the area of interest compared to the birds in the whole study area, and p = the proportion of the transect length in the area of interest compared to the total transect length in the whole study area.

The difference between the two proportions is tested as the difference between the observed number of birds in the area of interest and the number expected in this area, estimated from the proportion of the length of transect in relation to transect length in the total area (one-sample χ^2-test). In this report, the tests were made on the basis of numbers of observed clusters. For some species a cluster can hold a wide range of number of individual birds, from 1 to 26,000 in the case of Common Scoter. Results based on tests on number of individuals are therefore also presented, regardless of the fact that birds observed as groups (clusters) does not meet the criteria of being independent. Results from these latter tests are only used when explicitly stating that they are based on number of observed birds.

A comparison of pre- and post-construction D-values and preference for these zones was used to describe changes in the bird utilisation of the zones.

Although useful to distinguish between general patterns of avoidance/attraction shown by birds post construction relative to their observed distribution during the base-line, these methods of analysis were insufficient to provide a statistical comparison of bird densities before and after turbine construction. For this reason, a further layer of data analysis was undertaken for most abundant species present at both sites. We used bird encounter rate as an approximation to density, corrected for effort invested on transects, to calculate mean densities in the area of each of the two wind farms, an area 2 km from the periphery of both wind farms and an area between 2 and 4 km from the periphery of both wind farms to compare any potential displacement/attraction with the overall patterns in the control area (greater that 4 km from the outermost turbines where no effects were anticipated as a result of construction) and in the entire area subject to survey. Encounter rate was calculated as the number of birds reported per kilometre of aerial survey route per observer (normally two, but where sun dazzle or some other factor inhibited data collection this was also accounted for in the measure of effort). Encounter rates were then calculated for the five geographical areas defined above for both wind farm aerial survey study areas, and the data compared for the month or months when each species or species groups were most abundant. This is because species abundance varied greatly with year and month as well as the effects of turbine construction, and this variance needs to be accounted for in any analysis. Because of logistic constraints (especially weather), it was not possible to fly all areas in all of the same months in all years, hence the need to restrict the analysis to one or two months in the year when each species was abundant. The species for which sufficient data existed were selected as follows, using the month indicated for the statistical comparisons of mean encounter rates: divers (Horns Rev, March), Common Scoter (Horns Rev, March), Long-tailed Duck (Nysted, January), Herring Gull (Horns Rev, March; Nysted, January), Little Gull (Horns Rev, March), Kittiwake (Horns Rev, March), Terns (Horns Rev, April and May) and Auks (Horns Rev, February, March, April). Mean values were generated from the individual surveys in each year with 95% confidence intervals, comprising 2000, 2001 and 2002 as pre-construction samples and 2003, 2004 and 2005 as those post-construction for the Nysted study site, while 2000 and 2001 comprised the pre-construction data and 2003 to 2005 the post-construction data for the Horns Rev site. The mean values were tested using standard Students' t-tests with corrections for unequal variances. Although statistically significant differences were defined at the 0.05 probability level, those P values falling between 0.05 and 0.10 are identified on the graphs for clarity.

The distance from each observation to the nearest wind turbine was calculated. Using these data a cumulated distance frequency distribution was created, using distance intervals of 500 m. and based on number of encountered individuals. Data from the pre-construction phase as compared to the post-construction phase was analysed in this manner with the aim to describe potential impact on bird species from the turbines. Data was selected within a specific distance from the turbines. For Nysted a truncation distance of 5 km was chosen as this distance ensured that the potential maximal impact distance was included, but at the same time that the geographical area had as homogenous survey and habitat coverage as possible. In a similar way the truncation distance for Horns Rev was chosen at 8 km distance from the turbines. A Kolmogorov-Smirnov Two-sample test was used to determine whether pre- and post-construction data were significantly different.

3.2 Migratory studies at Nysted

3.2.1 Migration pattern

Abundance

In order to describe the occurrence of various species or species groups, which migrated in the study area during spring and autumn, simple calculations of the seasonal (spring/autumn) species specific migration volume were undertaken based on the visual recordings from the observation tower. It was not intended to model the migration of birds at any time during the migration seasons, as these models tend to have little predictive power (Kahlert et al. 2000). Moreover, data provided on an annual basis were considered insufficient, as for example the number of daytime observation hours (ca 80) during one autumn was much less than the entire autumn migration period (795 hours). However, during seven autumn and six spring periods (1999-2005), 579 and 259 hours of observations, respectively, were gathered and were distributed relatively evenly in time, except during peripheral periods (see Kahlert et al. 2006).

For Common Eiders, which were observed during most 15-minute periods, a calculation of the total seasonal migration volume was carried out based on data from the entire study period 1999-2005. Variation in the phenology (occurrence during the migration season broken into 10 day-periods) and the diurnal pattern (variation in migration between one-hour intervals during daytime) were also considered. Hence, for each hour (6-7, 7-8 etc. in each 10-day-period, a daily mean migration intensity was calculated (no birds/hour) and multiplied by the number of daylight hours in order to obtain the mean total number of migrating Common Eiders in a 10-day period, where the change in diurnal migration pattern represented the variation. Mean migration volume estimates for each 10-day period were summed over the season (autumn or spring) to calculate total seasonal migration volumes.

On autumn migration many of the Common Eiders, which were counted on the buoy-transect, were known to have passed Gedser Odde. Comparable numbers should therefore be observed at the two sites. This information was used in order to validate the calculation approach. In October 2004, almost daily daytime counts were carried out at Gedser Odde. Therefore, an October calculation was derived from the bird tower data. This calculation estimated 163,174 migrating Common Eiders. At Gedser Odde 142,798 were observed (www.dof-storstroem.dk). Hence, the estimated and observed numbers appeared to be comparable.

The autumn abundance of Cormorants was estimated in a different manner due to their unique behaviour. As a staging migrant, Cormorants were in contrast to the true migrants such as Common Eiders difficult to count because they would fly in many directions and forage over the entire study area during daytime. Possibly for this reason the number of Cormorants was markedly underestimated by the aerial surveys (e.g. Kahlert *et al.* 2000). However, Cormorants aggregated occasionally in very large flocks near the observation tower. For example, this occurred as they undertook social foraging bouts in the offshore area south of the observation tower typically in the morning or late afternoon, or while they were disturbed when roosting on the Rødsand Sandbar and all fled in the same direction thereby passing the observation tower. These good observation conditions for Cormorants occurred 1-3 times each autumn. The maximum number represented the autumn estimate of staging Cormorants in the study area. The maximum number was preferred to the average, as the maximum obtained by the counts was still likely to underestimate the true number of Cormorants using the study area. Individual or small flocks of foraging (diving) Cormorants were probably overlooked during the counts due to the restricted range from the observation tower. Also, Cormorants show large foraging range (up to 50 km) and it was known that they may leave the study area to forage or roost elsewhere, e.g. at Hyllekrog (Kahlert *et al.* 2004).

Other species than Common Eiders and Cormorants tended to occur in discrete periods followed by long periods with no observations. The data for other species was therefore inflated by a substantial number of zeros when broken down to hours within each 10-day period. Even if this was taken into account by using a logistic modelling approach (probability of the presence of a speices combined with migration intensity when present), seasonal migration intensity of these other species became unrealistically low. Accordingly, a simplified calculation approach was used, in which the mean migration intensity (no. birds/hour) was calculated for each 10-day period and multiplied by the number of daylight hours in order to obtain the mean total number of migrating birds in a 10-day period. Hence, no diurnal migration component was incorporated into the estimation. Mean migration estimates for each 10-day period was summed over the season (autumn or spring) to calculate to the migration volume for the selected species.

For all selected species except Cormorants, only birds that were orientated in the main direction of the migration were included in the estimation of migration volumes in order to minimise double counts, i.e. westerly orientations during autumn and easterly during spring. The estimated numbers at Nysted were compared with the numbers in the biogeographic populations in order to determine whether a species occurred in internationally important numbers. An area is recognised as being of international importance to a species if 1% of its flyway population is present regularly at a site at some time during the annual cycle (Prater 1981, and see also http://www.ramsar.org/-key_criteria.htm).

Species composition and flock size

The relative importance of individual species or species groups was calculated for the most abundant ones based on the numbers observed on buoy-transect during daytime. Data were separated into autumn and spring.

Mean flock size of daytime migrating birds (± 95% confidence limits) was calculated from the visual recordings. As the species-specific distributions of flock sizes (typically left-skewed) differed markedly from normal distributions, log-transformation of data was undertaken when calculating the mean flock size. This approach was generally less sensitive to extreme observations of very large flocks, which may occur at a very low frequency, compared to calculation of untransformed means.

3.2.2 Lateral displacement

The rationale behind the study, in which effects from the Nysted Offshore Wind Farm were to be measured, was first to provide a base-line description of species and their spatial and temporal occurrence before the turbines were erected. Data from the base-line investigations were collated over a number of years to provide a reference incorporating natural inter-annual variation. During and post construction, a monitoring programme was carried out in order to compare with the base-line data and to determine possible avoidance or attraction effects on migrating birds caused by the construction and operation of the wind farm.

Based on the progress and extent of construction and operational activities (see section 1.3), bird studies have been divided into three phases as follows:

1. Base-line study before erection of the wind farm, 1999-2002;
2. Monitoring study during the main construction phase, October 2002 - July 2003 (referred to as 2003, as no data were compiled late autumn 2002);
3. Monitoring during the operational phase of the wind farm[*)], August 2003 – April 2005

[*)] Note that the first provisional operation phase during autumn 2003 was amalgamated with the commercial operation period in 2004 and 2005, as from a bird perspective there was no difference between the provisional and commercial phase (see also the comparable results in autumn 2003 and 2004 in Kahlert *et al.* 2005).

In order to test the predictions of the main hypothesis that birds would show a lateral response to the wind farm, statistical differences in the comparisons base-line *vs.* construction and base-line *vs.* operation were measured. In most comparisons, data were pooled within the phases, as the results generally appeared at distinct levels (see also Kahlert *et al.* 2005). The amalgamation of data increased the power of the tests, reduced the number of inter-annual comparisons (which lowered the risk of type 1 errors). In addition, it reduced the complexity when explaining results. However, the inter-annual variation in variables was presented in Kahlert et al. (2006) and referred to in the text, when specific years showed unusual patterns.

Comparisons between project phases were extended by incorporating weather variables, visibility and time of the day as additional predictors in multi-factorial statistical models. These important predictors of bird migration were partly related to the main hypothesis and could strengthen the explanatory power of the models. Hence, the multi-factorial approach was applied in order to increase confidence of the conclusions.

3.2.3 Response distance to wind farm

During autumn, westward-directed waterbird migration tracks were traced by use of radar from just south of the observation tower and until they had passed the wind farm area to determine the response distance of waterbirds towards the wind farm. Of all the tracks those were selected that crossed two transects 5,000 and 6,000 m east of the wind farm at which distance effects on migration routes were not expected. Additional transects were positioned at 100, 200, 300, 400, 500 1,000, 1,500, 2,000, 2,500, 3,000, 3,500 and 4,000 from the most easterly row of turbines, respectively, and had the same orientation and length as this row (Fig. 18). For each of these transects and the transect at 5,000 m, corresponding transects 100 m closer to the wind farm were positioned. In this way 13 100 m transect intervals (0-100, 100-200, 200-300, 300-400, 400-500, 900-1,000 m etc.) were defined. For each track 13 migration courses were calculated, one for each interval between two corresponding transects, as the course between the intersections of the migration track and the two adjacent transects. For each transect interval the mean migration course of the tracks was calculated with standard deviation.

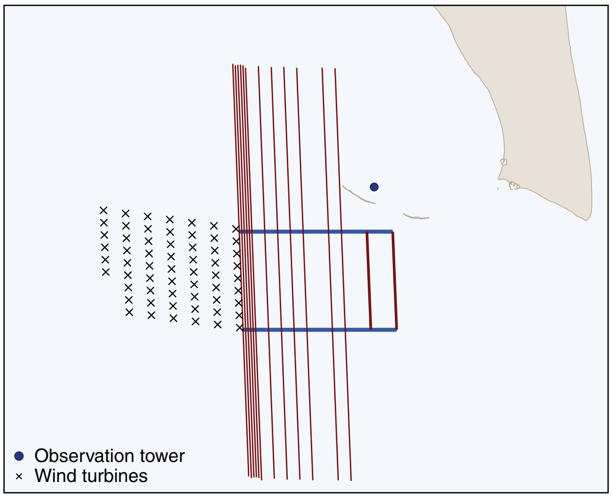


Figure 18. Transect lines, which were used in the analyses of the orientation of migration routes at the Nysted Offshore Wind Farm.

The mapping of migration routes gives the opportunity to test potential changes in the mean orientation at different distances from the wind farm area, and to test whether a systematic change in migration route has occurred. For example, if most birds avoid the wind farm by making lateral adjustments to the north, the mean track orientation will differ as a result of this lateral reorientation. However, if birds show lateral response differences in the distributions of migration courses with respect to distance to the wind turbines, *e.g.* a deflection of individuals both to the north and to the south of the wind farm, this could result in a bimodal distribution of migration courses close to the wind farm, but a unimodal distribution further away where the deflection has not yet begun. In this case, one could expect no significant difference in mean orientation, but a significant increase in the standard deviation of the mean.

The data set was divided into two groups – one group for those tracks that crossed the eastern gate, and another group of tracks that passed either north or south of the wind farm. During the operational phase, the positions of turbines as they appeared on the radar monitor were used as a reference to the tracks of migratory birds. Northerly and southerly winds can displace westward-migrating flocks to the south and north, respectively. Time of day (day and night) may affect the spatial placement of migration routes, especially after the wind turbines have been erected (*cf.* predictions from the hypothesis).

'Response distance' was only relevant for bird flocks approaching the wind farm during autumn. The approach of bird flocks during spring migration could not be described, as the area to be covered was beyond the maximum range (e.g. Fig. 11), which was appropriate to use for detection of bird flocks with the present radar equipment.

3.2.4 Probability of crossing the eastern gate of the wind farm area

Methods used for autumn analysis: Those tracks were selected that passed the line due south of the observation tower and migrating in a westerly direction (the Buoy-transect; see Fig. 11). Thus, the extracted radar tracks represented the bird flocks, which approached the wind farm and may show a lateral avoidance response to the wind farm. Flocks (radar echoes) were followed to see whether they crossed the eastern edge of the wind farm area or not, and the proportion of flocks that actually did so was calculated. Those tracks, that took a southwesterly or northwesterly course and crossed one of the two transects northeast and southeast of the wind farm (Fig. 19), were included in the group of tracks that passed the wind farm to the north or south as these flocks were unlikely to cross the eastern edge of the wind farm.

In order to describe the migration pattern in detail, a logistic regression model was used to describe the probability of passing the wind farm area incorporating the following four factors and their first order interaction:

1. Phase (base-line *vs.* operation),
2. north-south placement of the track (latitudinal), measured as the distance from the observation tower to the intersection between the migration track and the Buoy-transect,
3. time of day (day and night),
4. crosswinds (northerly and southerly winds).

Methods used for spring analysis: During spring, the flight behaviour of birds was studied after they have passed the wind farm. Those tracks were selected that passed the transect due south of Lolland (Fig. 19). The proportion of migration tracks that crossed the eastern edge of the wind farm area was calculated

In order to describe the migration pattern in detail, a logistic regression model was used to describe the probability of flocks crossing the eastern gate of the wind farm, incorporating the following three factors and their first order interaction:

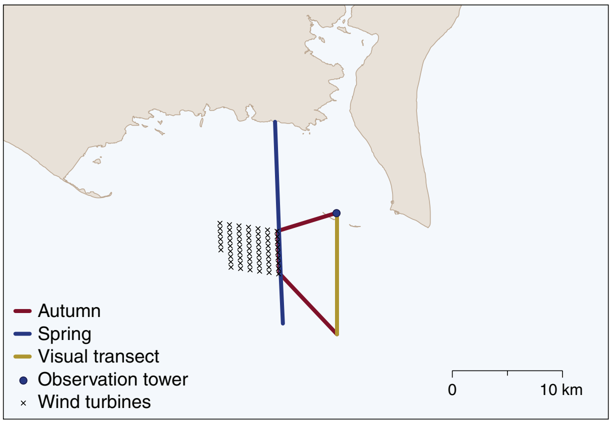


Figure 19. Transects, which were used in the analyses of the probability of crossing the eastern gate of the Nysted Offshore Wind Farm.

1. Phase (base-line *vs.* operation and base-line *vs.* construction)
2. time of day (day and night),
3. crosswinds (northerly and southerly winds).

3.2.5 Migration intensity in the wind farm area

The data relating to migration intensity were presented as before, during and post construction comparisons for spring and autumn separately: 1) Visual migration intensity at the buoy-transect; 2) Migration intensity at the eastern and northern gate of the wind farm and 3) Track densities from the eastern part of the wind farm area and a corresponding reference area.

Visual migration intensity
Count data based on the visual telescope counts compiled at the buoy-transect east of the wind farm area were converted into standardised migration intensities (number of birds per 15-minute period). Only westerly-orientated flocks were used during autumn as these reflected the movements of true migrants approaching the wind farm. Similarly, eastbound migrating birds were analysed during spring, where the area east of the wind farm represented the "backside" of the wind farm after the birds have passed it. As migration intensities were difficult to attribute to conventional statistical distributions, differences in migration intensities between project phases (base-line, construction and operation) were tested, using non-parametric tests (Kolmogorov-Smirnov Test).

Migration intensity at eastern and northern gate
Furthermore, the number of flocks crossing the eastern and northern gate of the wind farm was counted, using radar data (Fig. 20). It has previously been concluded that migration tracks passing the northern gate from the north were mainly terrestrial birds, but included to some extent geese migrating from the mainland areas and potentially staging waterbirds undertaking local movements. Tracks crossing the eastern gate from the east could mainly be ascribed to migratory waterbirds, mainly Common Eiders (Kahlert *et al.* 2000). Only flocks flying into the wind farm area following the main heading of autumn migration (towards the west

and south) were included in the analysis. During spring, the same transects were used as during autumn. Because the main heading of migration during spring was towards the east and north, only bird flocks that flew out of the wind farm area at the eastern and northern gates were incorporated in the analysis.

The counts at the transect were standardised to number of flocks per 15-minute period. Data from previous years have shown that migration intensity tended to be more sensitive to tail- and headwinds rather than to different crosswind regimes (see *e.g.* Fig. 30 in Kahlert *et al.* 2004). In previous analyses, tailwind for birds crossing the eastern gate during the autumn was defined as 0-180° and headwind as 180-360°. At the northern gate, tailwind was assigned to 270-360° and 0-90°, whereas headwind was defined as 90-270°. Tail- and headwind definitions were turned 180° during spring due to a reversed orientation. These definitions came from the local orientation of birds in the study area. More generally birds in Fehmarnbelt tended to be orientated along a NE-SW-axis both during spring (towards NE) and autumn (towards SW) (Hüppop *et al.* 2004). When tail- and headwinds were adjusted according to this axis, the sensitivity of birds towards tail- and headwinds became even more pronounced insofar that they preferred tailwind.

Migration intensity was presented as the average number of flocks crossing at either gates per 15-minute period separated by the prevailing wind conditions (headwind/tailwind in the adjusted version) and time (day/night). Differences in migration intensity between project phases were tested with Kolmogorov-Smirnov Tests.

Track densities
Two areas of comparison were arbitrarily chosen to describe the overall migration intensity outside and inside of the wind farm area. It was set as criteria that the area should be of limited extent (to reduce effects of the distance-related variation in detection rate) and that an appropriate reference area of the same size just outside the wind farm area could be defined. This resulted in an area of 10.8 km^2 positioned in the eastern part of the wind farm and a similar-sized corresponding reference area east of the wind farm (Fig. 21).

Based on radar observations, the lengths of radar tracks (equiv. to bird flocks) were calculated in squares of 0.1 km^2 in the two chosen areas (expressed as the total sum of track metres within each cell). By dividing the length of tracks by the total number of tracks in each year (onwards referred to as track density), the between year variance in observation effort was taken into account. Furthermore, the effect of the distance-related variation in the detection rate of the radar was incorporated by calculating the proportional decline in track densities during the base-line study when there were no effects of the wind farm. This "natural" proportional decline in track densities was compared with data from the construction and operational phase. The rationale behind these comparisons was that reduced migration intensity in the wind farm area caused by its construction or operation would be associated with a further proportional decline in track densities in the eastern wind farm area.

3.3 Migratory studies at Horns Rev

3.3.1 Visual observations

General data collection
During all 15 minute observation periods along the four transects used for visual observation, the total number of identified and unidentified birds, flock size and direction of movements were noted when crossing the transect lines. A total of 54 species were identified, whereas others were identified into 10 species groups, e.g., gulls or terns. Species that are difficult to identify like, Red-throated and Black-throated Divers, and Arctic and Common Tern were consistently pooled as divers and terns, respectively, and hence treated as one species

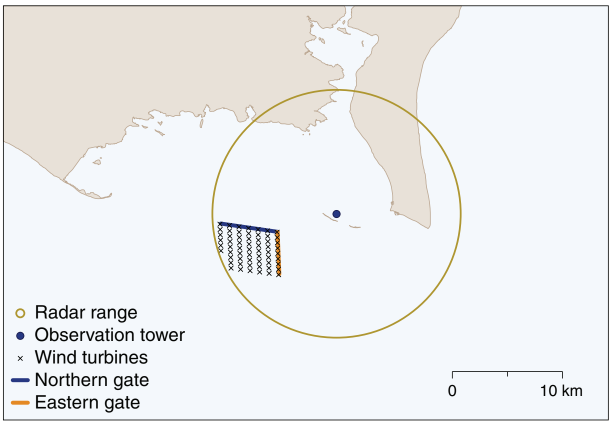


Figure 20. Location of the northern and eastern gates at the Nysted Offshore Wind Farm used for estimating the migration intensity in the wind farm area.

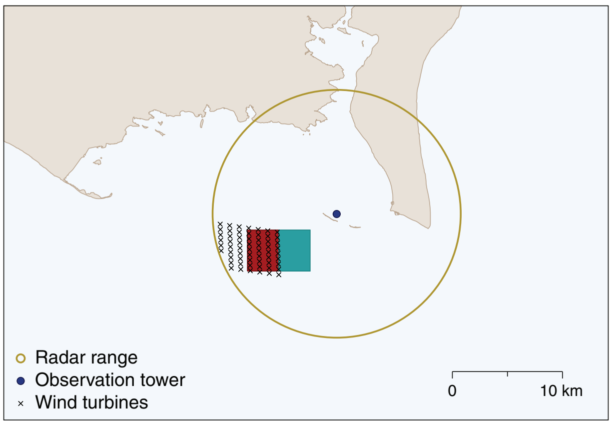


Figure 21. Location of the the eastern wind farm area (red) and the reference area east of wind farm (blue) used for comparisons of track densities.

On the two transects following a row of turbines (see Fig. 7), the number of birds resting or perching on the circular platform at the base of individual turbines was recorded at the start of each 15-minute observation period. Likewise, the activity of all turbines (active or not active) was noted. In addition, all recordings of birds crossing these two transects were assigned to turbine intervals, e.g., it was noted in between which two turbines the birds were flying.

To obtain a measure of species specific migration intensity, the mean number of birds passing each transect was calculated in 15-minute intervals. However, 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.

As highlighted in the EIA report (Noer et al. 2000), the risk of collision between birds and wind turbines will mainly concern bird species that will occur at critical altitudes (i.e. at rotor heights) either when foraging or when migrating. Likewise, species occurring in substantial numbers through specific periods of the annual cycle may be at risk. At Horns Rev divers, Gannet, skuas, gulls and terns have been listed as species that may fly regularly at critical altitudes, and Common Scoter as a species that occur in substantial numbers (Noer et al. 2000, Christensen et al 2001, 2002, and 2003). Consequently, in the description of phenology and behaviour, focus is placed on these species, excluding species that only have occurred by accident and in low abundance or species that generally are associated with terrestrial habitats. Full species lists showing total numbers observed during visual observations, and of miscellaneous observations, are given in Christensen et al. (2006).

Turbine activity and birds

To investigate whether birds that flew into the wind farm did so in relation to the activity of turbines, e.g., more often flew in between two turbines when these were not in operation, we analysed the frequency of bird entrances into the wind farm in relation to turbine activity.

Data was obtained from the 15 minute visual observation periods conducted at the transect following the eastern row of turbines in the wind farm. As the activity of individual turbines was noted at each observation period and since birds were recorded in the separate intervals/openings between two turbines, all observations could be categorised in three classes: both turbines were active, one turbine were active and both turbines were not active. A total of 51.5 hours of observation from 206 15 minute periods revealed 1,442 observation units when separated on the 7 openings between the 8 turbines. Of these, 1,026 units represented both turbines in action, 264 units represented one active turbine, and 152 units represented two inactive turbines.

The analyses of bird reactions to active or inactive turbines were performed as chi-square tests (2 x 3 tables), comparing the number of observation units with recorded birds in relation to the total number of units in each activity class. The results are presented as the proportion of units with observed birds for each class of turbine activity.

Turbines as resting or perching platforms

To asses whether the turbines provided attractive platforms for birds to rest on or to perch from, the number of birds present on the turbine platforms (c. 8 m above sea level) was noted at the start of 158 and 148 15-minute periods visual transect observation periods at the eastern row of turbines and at the row within the wind farm, respectively.

The effect of the position of the turbines, i.e., positioned at the edge or within the wind farm, on the attractiveness to birds was assessed by comparing the number of records made of resting birds on the ten turbines at the edge of the wind farm and the number of records made on the 6 turbines located within the wind farm.

As the present data was collected with the intension of making a basic assessment of the potential importance of the turbines as resting and perching platforms for birds, the data was not subject to detailed optimising corrections. This means that no corrections were made for differences in observation probability, e.g., given that most sitting or perching birds generally are orientated into the wind, in order to get the proper aerodynamic drag on the wings when landing and taking off. Thus, the majority of birds would be sitting on the windy side of the turbines. As no differentiation between the records were made with respect to wind directions, the results should, for this reason, be taken only as indications of the pattern of bird occurrence on the turbines.

3.3.2 Radar observations

On the radar monitor, echoes of birds could be easily identified, as these showed a very different pattern of movements and appearance than, e.g., ship echoes. However, during periods of substantial wave activity due to windy conditions, identification of bird echoes were markedly impeded, as bird echoes could not be separated from echoes obtained from waves. Given this restriction, each echo on the radar monitor corresponded to a single bird or flock of birds in the study area, and the migration routes were mapped by tracing the course of bird flocks from the radar monitor on to transparencies, from which the tracks were subsequently digitised into a GIS-database. The shortest tracks, e.g. shorter than 1 km (arbitrary value) were excluded from the analysis. When possible, species and flock size were recorded. At each visit to the transformer station, radar observations were aimed to cover a full 24 hour cycle, or at least to cover night and day time periods in equal proportions. For all recordings, sunset and sunrise defined the grouping of bird data into day and night.

A total of 7.770 bird tracks were recorded by radar during August 2003 to November 2005. Of these, 172 were obtained by the remotely operated Litton/Decca radar during November 2005. Species identification was made on 1,190 tracks, involving 29 species and 7 species groups. The direction of the tracks of bird echoes were noted as southwards or northwards, and the speed of bird movements was noted when possible by using standard in-built software tool of the radar.

Even though an almost equal number of northbound (3,684) and southbound (4,086) bird tracks has been recorded during 2003-2005, the main focus of the present report is based on southbound migration approaching the wind farm. The emphasis on the southbound migration was due to two 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, and 2) the general behaviour of birds approaching the wind farm is not assumed to deviate in relation to the direction of approach.

Following the methods employed at the start of this study (Christensen et al. 2004, Christensen & Hounisen 2005), data analyses were aimed to test the main hypothesis that migratory birds show a lateral avoidance response to the wind farm. To evaluate this hypothesis, data were processed and included in the following analyses 1) a general analysis of the average orientation of both southward and northward bird migration towards and around the wind farm, 2) an analysis of lateral changes in migration orientation, and 3) an analysis of the probability of birds passing the wind farm.

Analyses of overall migration intensity in the area were not performed, as this generally reflected a decreasing detectability of bird echoes by the radar with increasing distance (cf. data from 2003 and 2004), rather than reflecting an actual pattern of bird migration intensity in the area.

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.

Overall migration patterns around the wind farm

With the radar located north of the wind farm, analyses of the bird movements at the southern and eastern edges of the wind farm are 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.

For these reasons, the present report only makes a general approach in assessing the possible effect of the wind farm on the overall pattern of both southward and 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. 167). In each grid cell the mean orientation of migration was calculated based on the orientation between start and end point from all individual track segments present within separate grid cells, after transformation of track orientation into values of between -90° (westerly orientation) and +90° (easterly orientation) of northbound tracks. The analyses included all 3,684 tracks of northward migrating birds, and all 4,086 tracks of southward migrating bird recorded by radar. The number of track segments ranged between 2 and 852 per grid cell, totalling 8,553 segments of northbound tracks, and between 3 and 1,089 per grid cell, totalling 9,372 segments of southbound tracks.

Lateral changes in migration routes

Analyses of lateral changes in the orientation of bird migration were carried out for birds approaching the wind farm from the north and from the east. Analyses were performed for each of the three study years separately, comprising a total of 2,108 tracks north of the wind farm and 1,168 track east of the wind farm. The tracks included in these analyses complied to the criteria of crossing 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, see Fig. 22). 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).

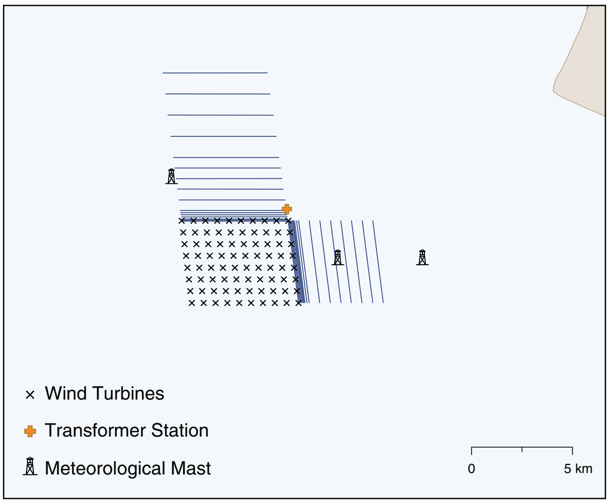


Figure 22. Location of transects north and east of the Horns Rev wind farm used in the analyses of lateral changes in migration orientation of birds.

For each bird track that intersected two adjacent transects the migration course were calculated between intersection points. Subsequently, the mean orientation of migration was calculated for all distance intervals. 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 (given that the overall orientation of bird migration approaching the Horns Rev wind farm showed a south-westerly orientation, cross winds were classified as easterly and westerly wind directions in analyses of tracks both north and east of the wind farm) and time of day (day and night).

Probability of birds passing into the wind farm area
Analyses of the probability of birds entering the wind farm were performed on a subset of tracks recorded north and east of the wind farm, respectively. These tracks were selected using the criteria set up by Christensen et al. (2004), including only tracks that passed two transects located 1,500 and 2,000 meters from the wind farm and that were longer than 2 km.

The proportion of tracks that entered into the wind farm area from the north and east was calculated separately. The effect of cross winds and time of the day (day and night) was analysed separately by chi-square tests (2x2 tables, continuity adjusted) on the frequencies of occurrence.

Given the selection criteria's set for tracks included in this analysis, sample sizes in 2004 were too small to allow analyses (data was analysed on a relaxed criterion, including track of very short length (Christensen & Hounisen 2005: N = 49 tracks north of the wind farm; N = 31 tracks east of the wind farm)). However, in this final analysis, data from all years were pooled including 458 tracks north of the wind farm and 342 tracks south of the wind farm.

Bird movements within the wind farm
In order to describe the behaviour of birds flying inside the wind farm, tracks that crossed the northern and eastern row of turbines while approaching the wind farm, and hence represented birds that flew in between the turbines, were selected for further analyses. All tracks were related to a grid-net, confined by the turbines in the first 4 rows from either the north and east side of the wind farm, and hence describe bird movements within the first 3 row intervals. The number of grid-cells was 27 in the analyses of bird tracks entering from the north, and 21 grid-cells in analyses of birds entering from the east (Fig. 23).

For all grid-cells, the mean orientation of the segments of tracks was calculated. However, in the analyses of bird movements within the wind farm, the outermost two grid-cells in all 3 row intervals were omitted, to avoid an effect of the adjacent edges of the wind farm (birds just crossing the corners of the wind farm). Within the remaining central grid-cells (15 at the north and 9 at the east), analyses were performed in the different row-intervals and based on standard deviation in flight orientation, as mean orientation may not differ as birds may change orientation side-ways in both directions.

Disappearance of echoes
During both the collection of radar data and in the subsequent analyses of bird movements, it was acknowledged that many echoes of migrating birds often stopped abruptly and disappeared from the radar screen for no obvious reason. Even though bird echoes disappeared all over the study area, this pattern was obvious also in echoes of birds approaching the wind farm.

Disappearance of birds on the radar monitor may have several explanations. 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 too 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.

Given the 20° vertical beam width of the radar, some bird echoes may have passed above the radar without being detected. This was only observed on a few occasions when birds were flying very close to the transformer station, and offered no general problem, as most of these echoes could be seen again when moving just a short distance away.

As both explanations may reflect that birds react to the presence of the wind farm, visual data was collected in the spring of 2004 to describe the flying behaviour of birds approaching the wind farm. In total, observations were made on 96 flocks of Common Scoters approaching the wind farm from the north, of which the flying behaviour in relation to the wind farm was noted.

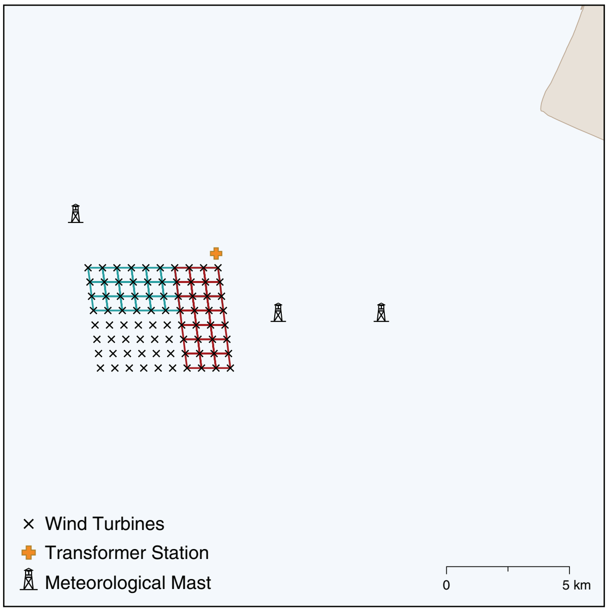


Figure 23. The grid cells used in analysing bird movements within the Horns Rev wind farm. For birds flying into the wind farm from the north 27 cells covering the first 3 row intervals were used. For birds flying in from the east, 21 cells were used. Note the overlap in the grid cells in the upper 9 upper-right corner of the wind farm.

4 Results

Ib Krag Petersen, Jens Peder Hounisen, Johnny Kahlert, Thomas Kjær Christensen, Mark Desholm

4.1 Changes in waterbird distribution at Horns Rev and Nysted

In this section results from aerial surveys of bird distributions are presented. Only selected species are treated here, this being the most numerously occurring species, species of particular conservation interest or species from which data is available for both wind farms.

Distribution data are presented as relative densities as numbers of individuals per covered survey track km, cumulated for the pre- and the post-construction phase of the individual wind farm.

4.1.1 Species account for the Horns Rev study area

Red- and Black-throated Diver *Gavia stellata/arctica*

A total of 3,919 divers were observed during the 34 aerial surveys (Table 4, see Christensen et al. 2006). Of these 76% was unidentified divers sp., while 23% were Red-throated Divers and less than 0.5% was Black-throated Diver.

Maximum numbers encountered during any one survey were 483 birds on 23 April 2003 and 420 birds on 17 February 2000 (see Christensen et al. 2006). Divers were most abundant in the study area during the period from February till late April, with decreasing numbers found in May of 2004 and 2005. In the period from August through January divers were recorded in lower numbers (Fig. 24).

Divers showed no clear depth selection, between 5% and 11% of birds were present in all 2 m depth intervals from 4 to 26 m (Fig. 25).

Concentrations of divers were observed in the northwestern and southwestern parts of the study area, with more temporary concentrations around Blåvands Huk (Fig. 26). No prominent distributional difference between years was found.

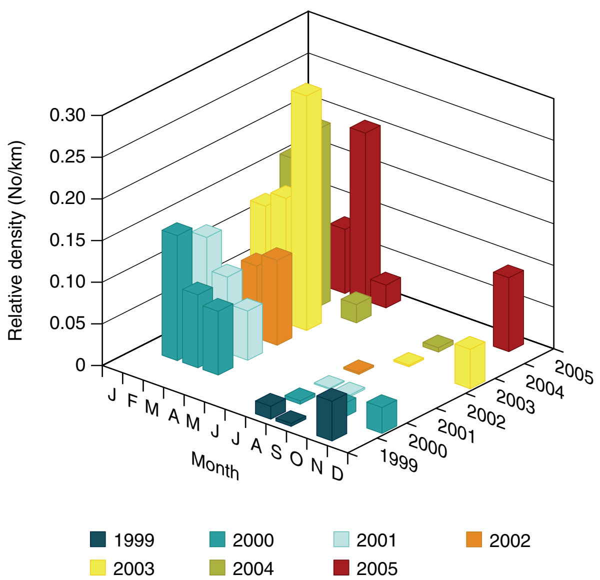


Figure 24. Phenology chart of occurrence for Red-throated/Black-throated Divers in the Horns Rev study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

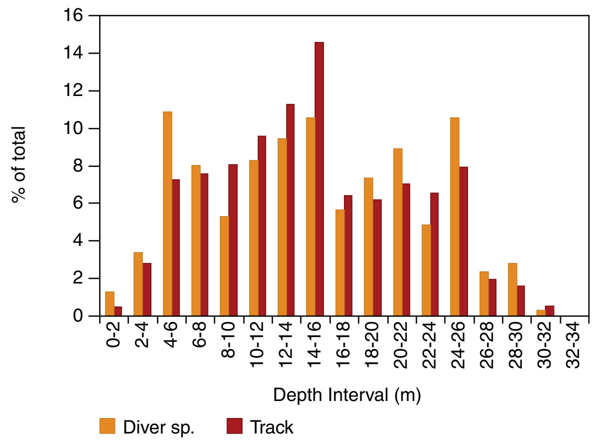


Figure 25. Water depth frequency distribution, in 2 m depth intervals, of diver sp. in the Horns Rev study area, compared to the corresponding frequency distribution of the survey track line. N = 3,652.

Table 4. The number of encountered diver sp. at Horns Rev by year and month. The number of surveys per month is indicated in the bottom row. In February 2000 and in December 2003 two surveys were carried out within the same month.

Year	Total	JAN	FEB	MAR	APR	MAY	AUG	SEP	OCT	NOV	DEC
1999	99						23	5		71	
2000	741		420	141	113		6		23		38
2001	437		196	149	87		2	3			
2002	321	54		126	138		3				
2003	1036		170	254	483			3			126
2004	712		296	370		38		8			
2005	573			133	233	48	0			159	
Total	3919	54	1082	1173	1054	86	34	19	23	230	164
No. of Surveys	34	1	5	6	5	2	5	4	1	2	3

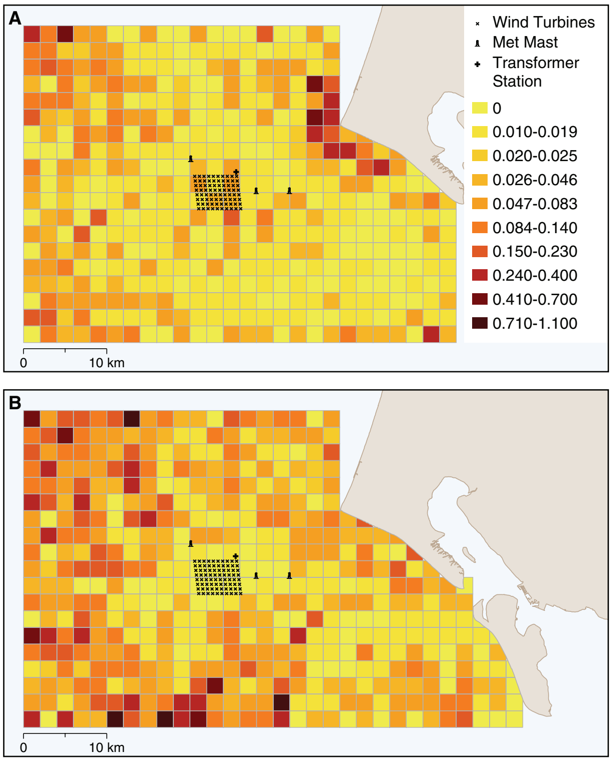


Figure 26. Relative density of Red-throated/Black-throated Diver in the Horns Rev study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

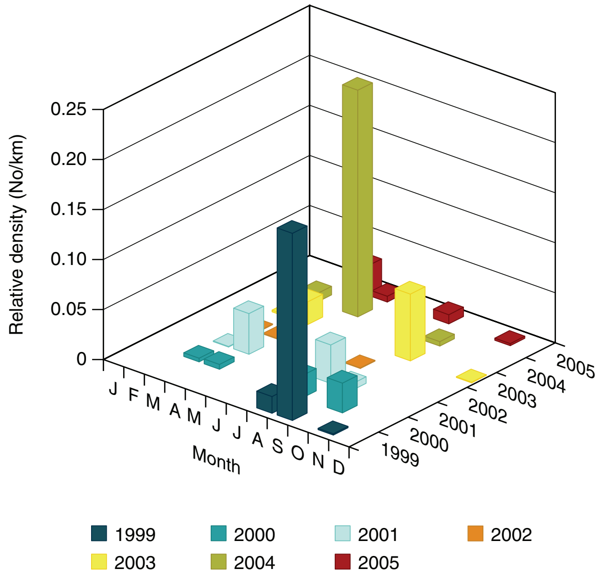


Figure 27. Phenology chart of occurrence for Gannets in the Horns Rev study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

Gannet *Sula bassana*

A total of 1,144 Gannets were recorded during the 34 surveys (Table 5 and see Christensen et al. 2006). The variation in total numbers between years was high, ranging from three encounters in 2002 to 415 encounters in 2004. Gannets were found in the study area in highest numbers during spring and early autumn (Fig. 27). Highest numbers encountered during a single survey were 392 birds on 10 May 2004 and 265 birds on 3 September 1999.

The Gannet is an offshore species, feeding on pelagic fish. Pelagic fish are highly mobile, and can assort themselves according to biotic and abiotic conditions, and thus vary considerably between surveys. The variable nature of Gannet distribution within the study area is likely to be governed by such changes in fish distribution. The overall abundance was highest in the western parts of the study area, but concentrations were also found around Blåvands Huk, close to land (Fig. 28). The Blåvands Huk concentrations primarily derive from those of a single survey on 10 May 2004, when the species displayed a distribution pattern very unlike that of other surveys.

Table 5. The number of encountered Gannets at Horns Rev by year and month. The number of surveys per month is indicated in the bottom row. In February 2000 and in December 2003 two surveys were carried out within the same month.

Year	Total	JAN	FEB	MAR	APR	MAY	AUG	SEP	OCT	NOV	DEC
1999	**292**						25	265		2	
2000	**88**		0	6	7		33		42		0
2001	**134**		0	1	60		63	10			
2002	**3**	0		1	1		1				
2003	**149**		0	3	39			105			2
2004	**415**		1	15		392		7			
2005	**63**			0	33	10	16			4	
Total	**1144**	**0**	**1**	**26**	**140**	**402**	**138**	**387**	**42**	**6**	**2**
No. of Surveys	34	1	5	6	5	2	5	4	1	2	3

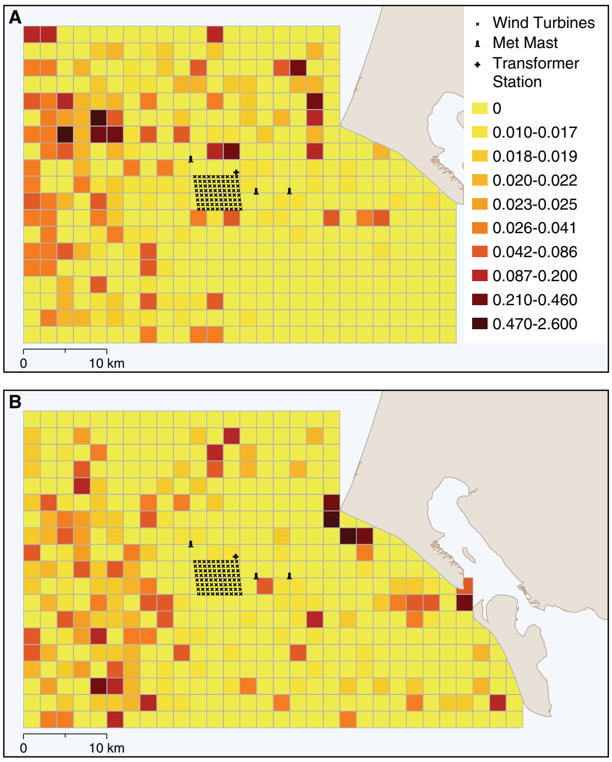


Figure 28. Relative density of Gannet in the Horns Rev study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

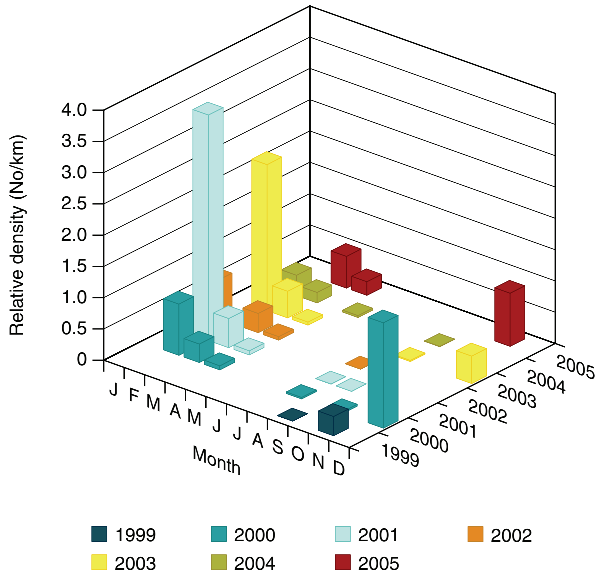


Figure 29. Phenology chart of occurrence for Common Eider in the Horns Rev study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

Common Eider *Somateria mollissima*

A total of 21,718 Common Eiders were recorded during the 34 surveys at Horns Rev. Highest numbers within a single survey were 5,438 on 9 February 2001 and 3,013 on 13 February 2003. Numbers fluctuated greatly between years. The low figure for 1999 (463 encountered birds) was caused by the fact that no spring surveys were undertaken in that year (Table 6 and see Christensen et al. 2006).

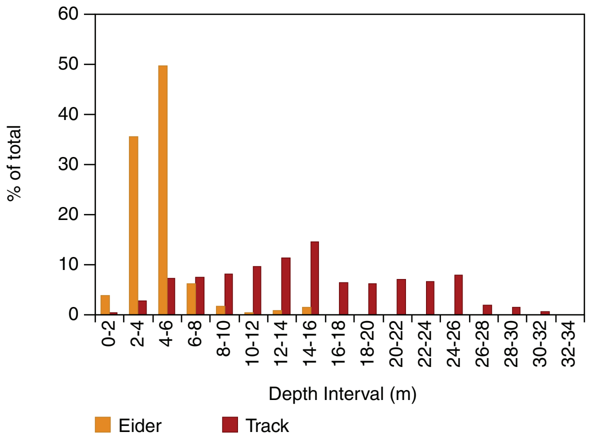
Most Common Eiders were recorded from November through to late March (Fig. 29), with a maximum of 3.6 birds per surveyed transect kilometre in February 2001.

Common Eider is an inshore diving duck, mainly feeding on epifauna molluscs. An analysis of the depth frequency distribution of 20,097 non-flying Eiders encountered at Horns Rev showed that depths from 0 to 6 m were selected for, with 50% of the encountered birds recorded in the depth interval of 4 to 6 m, and similarly 36% of the birds in the 2 to 4 m depth interval. 95% of the birds were recorded at depth intervals between 0 and 8 m (Fig. 30).

The overall distribution of Common Eiders at Horns Rev showed that the concentrations were on shallow water along the coast of Skallingen, Blåvands Huk and Fanø, with a maximum of 20 birds per surveyed transect kilometre (Fig. 31). Favourable water depths are also found at Horns Reef, but at this depth this sandy-bottom habitat was not suitable for, nor selected by, Common Eiders.

Table 6. The number of encountered Common Eiders at Horns Rev by year and month. The number of surveys per month is indicated in the bottom row. In February 2000 and in December 2003 two surveys were carried out within the same month.

Year	Total	JAN	FEB	MAR	APR	MAY	AUG	SEP	OCT	NOV	DEC
1999	**463**						0	5		458	
2000	**5009**		2295	476	97		37		42		2062
2001	**6305**		5438	763	99		2	3			
2002	**1349**	823		448	75		3				
2003	**5018**		3013	720	84			32			1169
2004	**920**		566	292		55		7			
2005	**2654**			879	252	0	0			1523	
Total	**21718**	**823**	**11312**	**3578**	**607**	**55**	**42**	**47**	**42**	**1981**	**3231**
No. of Surveys	34	1	5	6	5	2	5	4	1	2	3



Fiigure 30. Water depth frequency distribution, in 2 m depth intervals, of eider in the Horns Rev study area, compared to the corresponding frequency distribution of the survey track line.

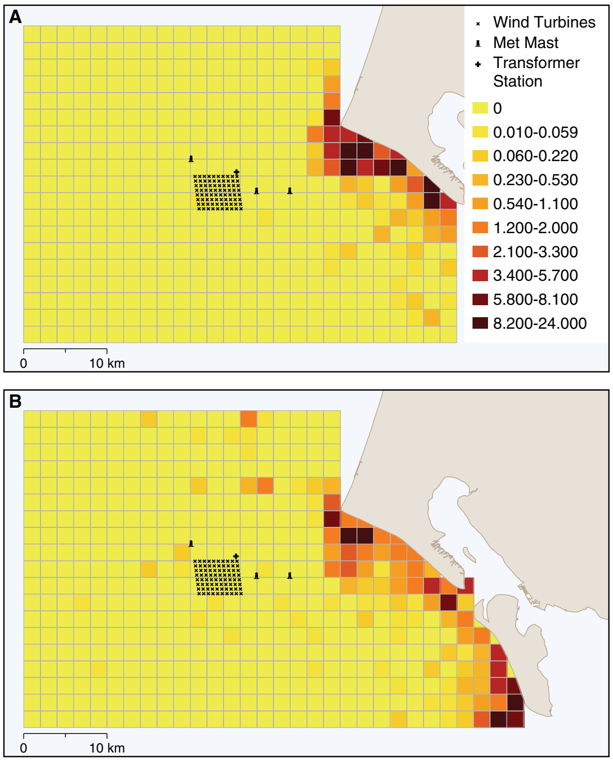


Figure 31. Relative density of Common Eider in the Horns Rev study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

Common Scoter *Melanitta nigra*

A total of 917,700 Common Scoters were recorded during the 34 surveys, making this species far the most numerous in the study area. The highest numbers recorded within a single survey was 381,042 birds on 16 March 2003, 75,992 birds on 13 February 2003 and 51,965 birds on 4 December 2003 (Table 7 and see Christensen et al. 2006). The very high numbers encountered in March 2003 probably coincided with the peak migration of Common Scoters from the North Sea into the Baltic, and the high number is regarded exceptional. The overall number of Common Scoter in the study area increased during the years of investigations, with generally higher numbers in 2003 to 2005 than in the previous years. The low numbers recorded in 1999 is mainly due to the fact that no spring surveys were performed that year.

Common Scoters were recorded throughout the year at Horns Rev, although no surveys were undertaken in June and July. The species is most numerous in the study area from November to April (Fig. 32), with a maximum of 225 birds per surveyed transect kilometre in March 2003 and 33 and 59 birds per kilometre respectively in February and December 2003.

Table 7. The number of encountered Common Scoter at Horns Rev by year and month. The number of surveys per month is indicated in the bottom row. In February 2000 and in December 2003 two surveys were carried out within the same month.

Year	Total	JAN	FEB	MAR	APR	MAY	AUG	SEP	OCT	NOV	DEC
1999	**10401**						68	102		10231	
2000	**41667**		11051	10459	9230		283		2208		8436
2001	**46218**		11041	13295	16902		319	4661			
2002	**46154**	30483		10877	3802		992				
2003	**574988**		75992	381042	25929			3397			88628
2004	**97985**		42260	42312		10698		2715			
2005	**100287**			42006	5769	15656	4559			32297	
Total	**917700**	**30483**	**140344**	**499991**	**61632**	**26354**	**6221**	**10875**	**2208**	**42528**	**97064**
No. of Surveys	34	1	5	6	5	2	5	4	1	2	3

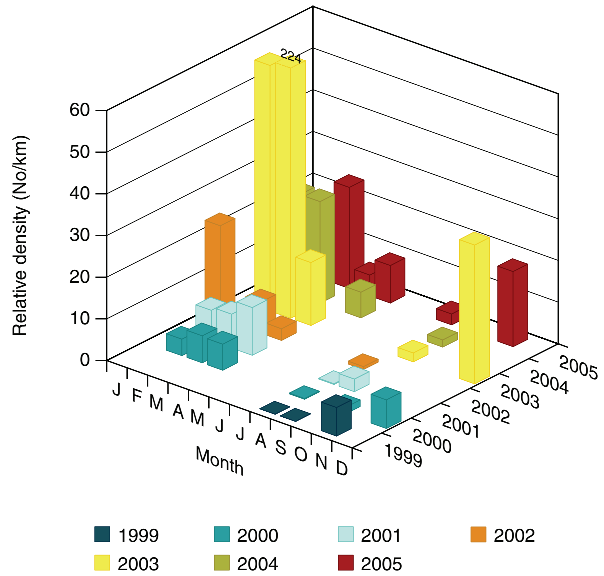


Figure 32. Phenology chart of occurrence for Common Scoter in the Horns Rev study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

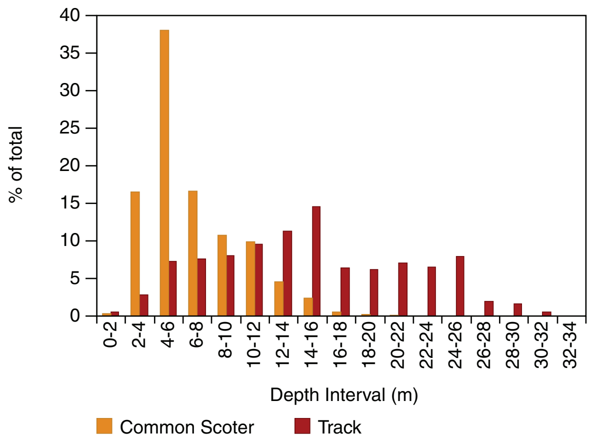


Figure 33. Water depth frequency distribution, in 2 m depth intervals, of Common Scoter in the Horns Rev study area, compared to the corresponding frequency distribution of the survey track line. N = 629,608.

Common scoter is a diving duck, mainly feeding on infauna molluscs in soft sandy substrates. An analysis of the depth frequency distribution of 629,608 non-flying Common Scoter encountered at Horns Rev showed that depths from 2 to 10 m was positively selected by the species, holding 82% of the birds, while 38% were recorded in the depth interval between 4 and 6 m, and very few birds were recorded beyond 16 m (Fig. 33).

The overall distribution of Common Scoter in the study area showed marked changes through the study period. The coastal areas off Fanø, Skallingen and Blåvands Huk were important to the species throughout the study period, with peak abundances of up to 630 birds per surveyed transect kilometre. A concentration of Common Scoters appeared in the south-western tip of Horns Rev, and later areas westwards along Horns Rev and the shallow water north of this increasingly became important to the species (Fig. 34).

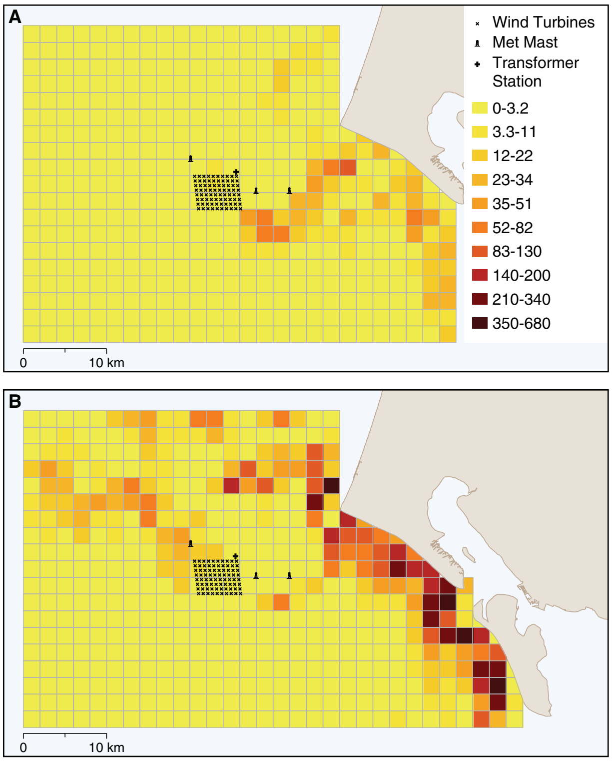


Figure 34. Relative density of Common Scoter in the Horns Rev study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

Herring Gull *Larus argentatus*

A total of 45,974 Herring Gulls were recorded during the 34 surveys. The highest numbers of Herring Gulls recorded during a single survey were 4,025 on 17 February 2000. The maximum numbers in a survey year were 11,064 in 2003, with lowest numbers being 1,080 in 1999, where only three surveys in autumn and early winter were performed (Table 8 and see Christensen et al. 2006).

Herring Gulls were recorded throughout the year at Horns Rev. The species is most numerous in the study area during autumn, late winter and early spring, with a maximum of 3.2 birds per surveyed transect kilometre in February 2003 (Fig. 35).

An analysis of the depth frequency distribution of 45,974 Herring Gulls encountered at Horns Rev showed a selection of water depths from 0 to 6 m of depth, holding 32% of the recorded birds, and a second top in the depth interval from 12 to 16 m, holding 31% of the birds. Offshore gatherings of Herring Gulls were mainly caused by active fishing vessels. This phenomenon is expected to have caused the increased presence of Herring Gulls at the 12 to 16 m depth interval.

The overall spatial distribution of Herring Gulls showed concentrations in the eastern parts of the study area, with a maximum of 37 birds per surveyed transect kilometre (Fig. 36). Another concentration was found approximately 10 km northwest of Blåvands Huk, an area associated with intensive fishery activity.

Table 8. The number of encountered Herring Gulls at Horns Rev by year and month. The number of surveys per month is indicated in the bottom row. In February 2000 and in December 2003 two surveys were carried out within the same month.

Year	Total	JAN	FEB	MAR	APR	MAY	AUG	SEP	OCT	NOV	DEC
1999	**1080**						254	590		236	
2000	**10517**		7352	1857	112		775		191		230
2001	**5382**		672	1169	1865		820	856			
2002	**5263**	917		1553	804		1989				
2003	**11064**		4151	2695	2029			1611			578
2004	**6861**		3644	566		213		2438			
2005	**5807**			250	1939	185	697			2736	
Total	45974	**917**	**15819**	**8090**	**6749**	**398**	**4535**	**5495**	**191**	**2972**	**808**
No. of Surveys	34	1	5	6	5	2	5	4	1	2	3

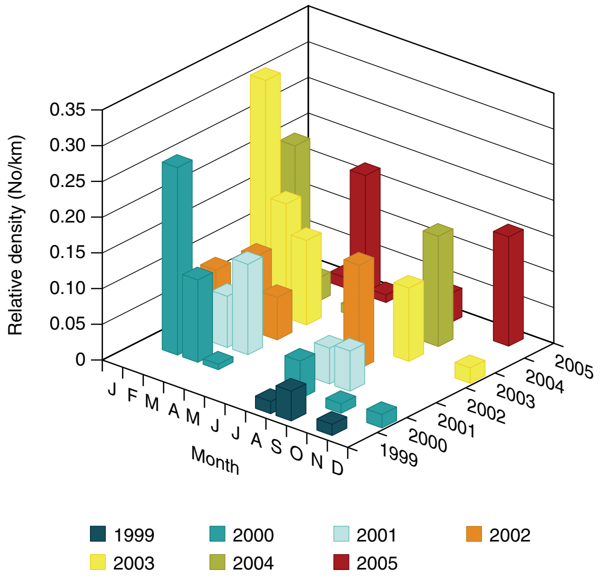


Figure 35. Phenology chart of occurrence for Herring Gull in the Horns Rev study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

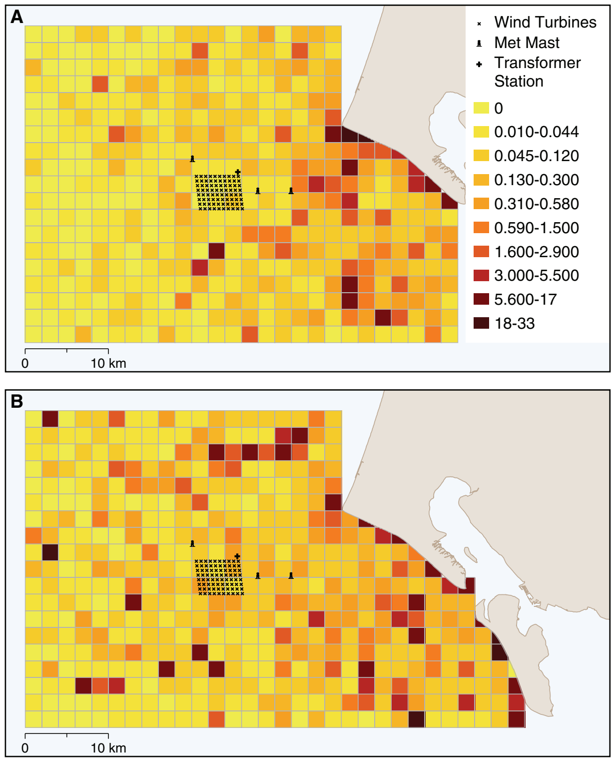


Figure 36. Relative density of Herring Gull in the Horns Rev study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

Little Gull *Larus minutus*

A total of 1,451 Little Gulls were recorded during the 34 surveys. The highest numbers recorded were 372 and 317 respectively on 16 March and 23 April 2003. The species was much more numerous in the study area between 2003 and 2005 than during the early period of the study, from 1999 to 2002 (Table 9 and see Christensen et al. 2006).

Little Gulls were primarily recorded in March and April at Horns Rev, with a maximum of 0.2 birds per surveyed transect kilometre in March 2003 (Fig. 37).

An analysis of the depth frequency distribution of Little Gull encountered at Horns Rev showed a peak of 19% of the birds in the depth interval from 12 to 14 m and 52% of them in the interval between 8 and 16 m (Fig. 38).

In this part of the world Little Gull winter in offshore areas, where they feed on zooplankton. The birds therefore show a very variable distribution pattern, governed by local fronts that bring prey to the sea surface. Most Little Gulls were recorded along a south-east-northwest axis through the central part of the study area (Fig. 39). Few Little Gulls were recorded in the south-eastern and north-eastern parts of the study area.

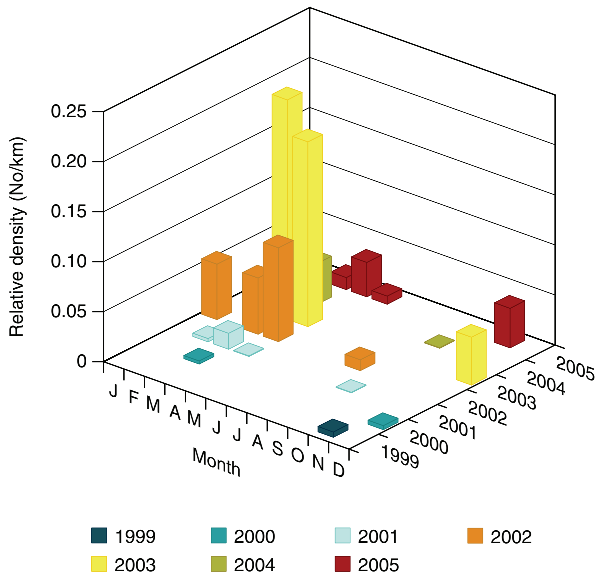


Figure 37. Phenology chart of occurrence for Little Gull in the Horns Rev study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

Table 9. The number of encountered Little Gulls at Horns Rev by year and month. The number of surveys per month is indicated in the bottom row. In February 2000 and in December 2003 two surveys were carried out within the same month.

Year	Total	JAN	FEB	MAR	APR	MAY	AUG	SEP	OCT	NOV	DEC
1999	**8**						0	0		8	
2000	**10**		0	5	0		0		0		5
2001	**33**		5	26	1		0	1			
2002	**300**	76		82	127		15				
2003	**822**		6	372	317			0			127
2004	**132**		60	71		0		1			
2005	**146**			21	40	14	0			71	
Total	**1451**	**76**	**71**	**577**	**485**	**14**	**15**	**2**	**0**	**79**	**132**
No. of Surveys	34	1	5	6	5	2	5	4	1	2	3

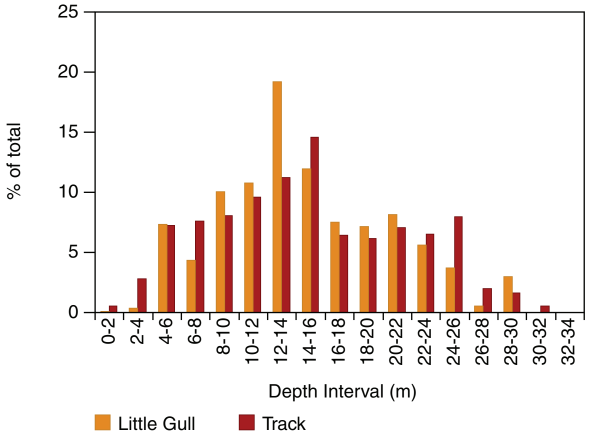


Figure 38. Water depth frequency distribution, in 2 m depth intervals, of Little Gull in the Horns Rev study area, compared to the corresponding frequency distribution of the survey track line. N = 1,451.

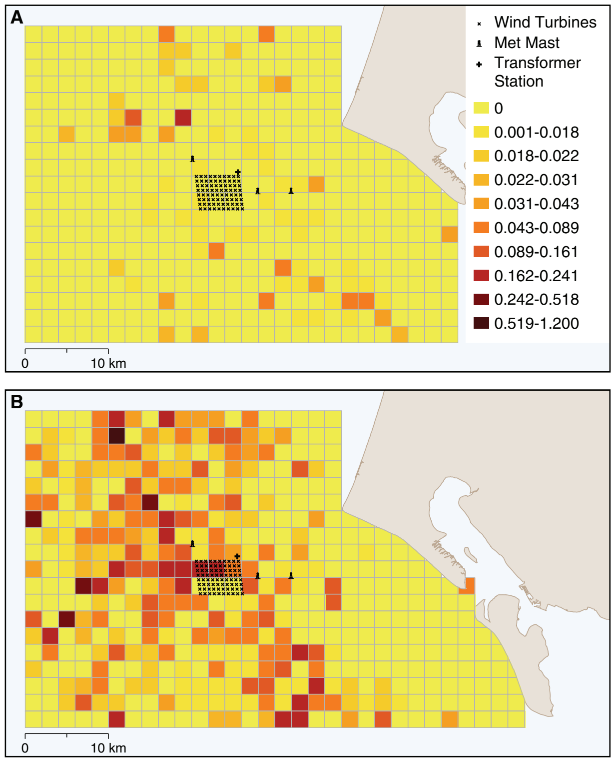


Figure 39. Relative density of Little Gull in the Horns Rev study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

Arctic/Common Tern *Sterna paradisaea/hirundo*

A total of 3,279 Arctic/Common Terns were recorded during the 34 surveys. The maximum numbers recorded during single surveys were 843 birds on 22 August 2001, 692 birds on 3 August 1999 and 545 birds on 27 April 2000 (Table 10 and see Christensen et al. 2006).

Arctic/Common Tern was primarily recorded in April/May and in August at Horns Rev, with a maximum of 0.51 birds per surveyed transects kilometre in August 2001, 0.46 in August 1999 and 0.37 in April 2000 (Fig. 40).

The overall distribution of Arctic/Common Tern at Horns Rev is complex, showing a concentration around the central parts of Horns Rev and off Blåvands Huk (Fig. 41). The abundance of these species was low in the south-eastern and south-western parts of the study area.

Table 10. The number of encountered Arctic/Common Terns at Horns Rev by year and month. The number of surveys per month is indicated in the bottom row. In February 2000 and in December 2003 two surveys were carried out within the same month.

Year	Total	JAN	FEB	MAR	APR	MAY	AUG	SEP	OCT	NOV	DEC
1999	**785**						692	88		5	
2000	**723**		0	1	545		177		0		0
2001	**887**		0	0	40		843	4			
2002	**86**	0		0	1		85				
2003	**378**		0	0	229			143			6
2004	**351**		0	0		346		5			
2005	**69**			0	0	53	16			0	
Total	3279	**0**	**0**	**1**	**815**	**399**	**1813**	**240**	**0**	**5**	**6**
No. of Surveys	34	1	5	6	5	2	5	4	1	2	3

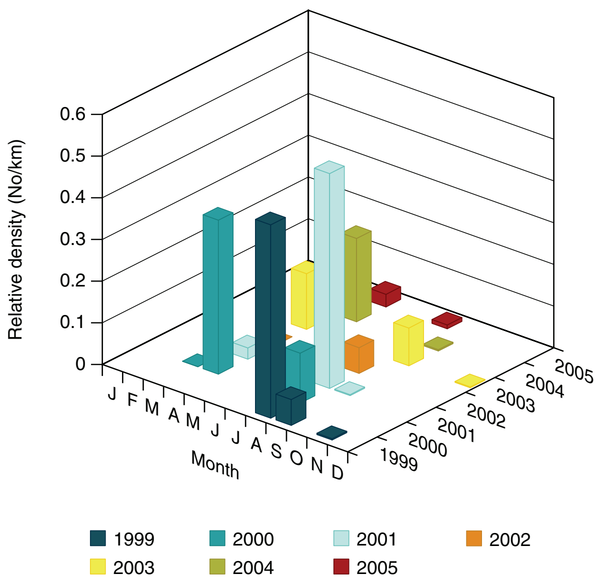


Figure 40. Phenology chart of occurrence for Arctic/Common Tern in the Horns Rev study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

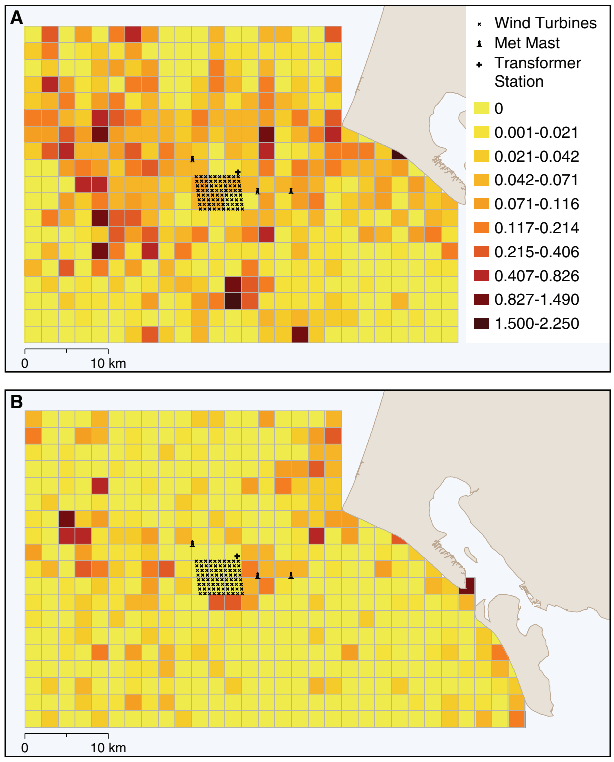


Figure 41. Relative density of Arctic/Common Tern in the Horns Rev study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

Guillemot *Uria aalge*/ Razorbill *Alca torda*

A total of 2,430 Guillemots/Razorbills were recorded during the 34 surveys. The maximum numbers recorded during a single survey was 384 birds on 12 November 1999 and 358 birds on 18 November 2005 (Table 11 and see Christensen et al. 2006).

Thus, the two November surveys provided the highest abundances of Guillemots/Razorbills in the study period. The species was present in the area during all months surveyed, with highest numbers present during autumn and winter (Fig. 42). Of the total data set 7% of these birds were identified to Guillemot, while 3% were identified to Razorbills.

An analysis of the depth frequency distribution of Guillemot/Razorbill encountered at Horns Rev showed a peak of 47% of the birds in the depth interval from 20 to 26 m (Fig. 43).

These alcid species mainly feed on pelagic fish. This means that they distribute according to concentrations of suitable prey, which in turn is determined by hydrographic features of the sea. Therefore large variations in numbers as well as distributions have been observed between surveys. Generally the study area only covers the fringe of the wider distribution of Guillemots and Razorbills in the Danish part of the North Sea.

Table 11. The number of encountered Guillemots/Razorbills at Horns Rev by year and month. The number of surveys per month is indicated in the bottom row. In February 2000 and in December 2003 two surveys were carried out within the same month.

Year	Total	JAN	FEB	MAR	APR	MAY	AUG	SEP	OCT	NOV	DEC
1999	**446**						0	62		384	
2000	**437**		136	20	5		60		180		36
2001	**111**		32	16	10		17	36			
2002	**191**	109		59	3		20				
2003	**415**		85	1	0			100			229
2004	**255**		89	133		1		32			
2005	**575**			76	19	3	119			358	
Total	**2430**	**109**	**342**	**305**	**37**	**4**	**216**	**230**	**180**	**742**	**265**
No. of Surveys	34	1	5	6	5	2	5	4	1	2	3

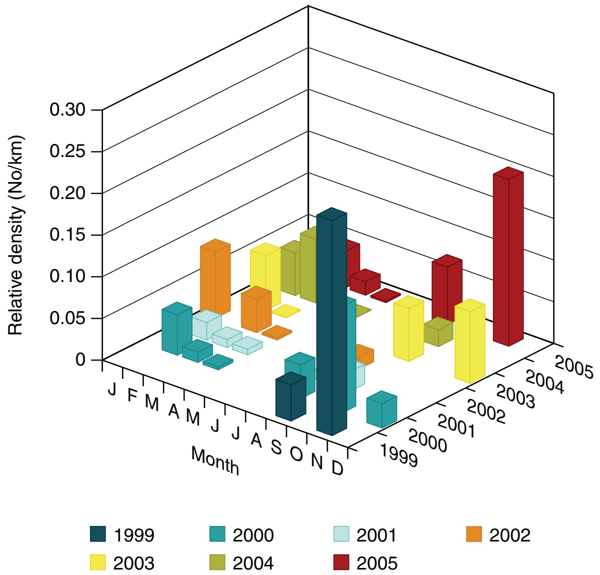


Figure 42. Phenology chart of occurrence for Guillemot/Razorbill in the Horns Rev study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

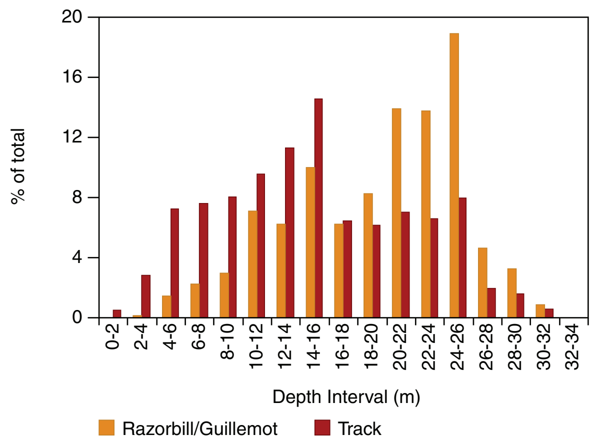


Figure 43. Water depth frequency distribution, in 2 m depth intervals, of Guillemot/Razorbil in the Horns Rev study area, compared to the corresponding frequency distribution of the survey track line. N = 2,316.

The overall distribution of Guillemot and Razorbill at Horns Rev showed a concentration in the western and southern central parts of the study area, with low numbers encountered in the eastern parts of the study area. Peak numbers were 0.64 birds per surveyed transect kilometre (Fig. 44). Between single surveys these distribution patterns could differ considerably.

4.1.2 Species account for the Nysted study area

Red- and Black-throated Diver *Gavia stellata/arctica*

A total of 533 divers were observed during the 32 aerial surveys (Table 12 and see Kahlert et al. 2006). Of these 84% was unidentified diver sp., while 15% was Red-throated Diver and less than 0.4% was Black-throated Diver.

Maximum numbers encountered during one survey was 71 birds on 5 January 2004 (see Kahlert et al. 2006). Divers were most abundant in the Nysted study area during the period from December to March. In the autumn and early winter divers were recorded in lower numbers (Fig. 45).

Divers were found at a wide range of depths in the Nysted study area. Most birds (38%) were recorded in the depth interval from 4 to 8 m (Fig. 46).

Divers were observed scattered across the study area, with more birds in the offshore areas south of the sand bar and in the deep area from the Rødsand Reef towards Guldborgsund (Fig. 47). A concentration in the south-western corner of the study area was found in the post-construction period.

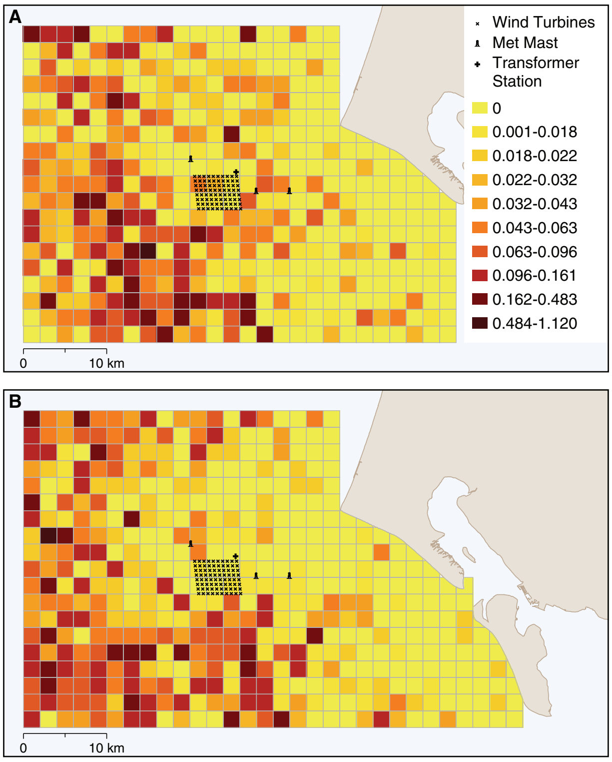


Figure 44. Relative density of Guillemot/Razorbill in the Horns Rev study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

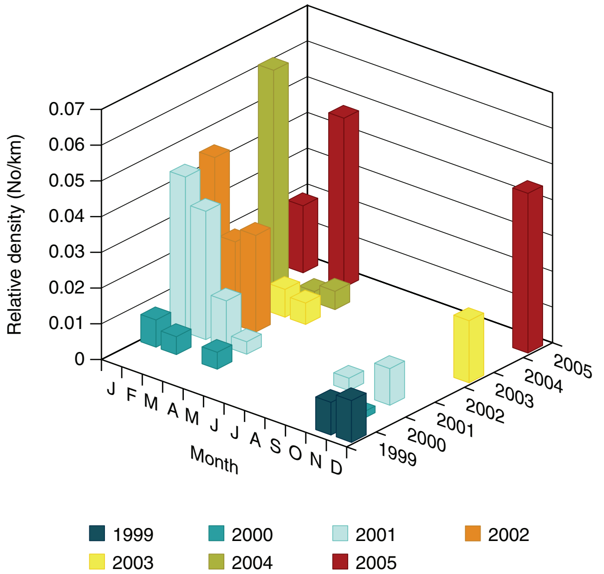


Figure 45. Phenology chart of occurrence for Red-throated/Black-throated Diver in the Nysted study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

Table 12. The number of encountered diver sp. around Nysted by year and month. The number of surveys per month and by year is indicated. In April 2000 and in March 2004 two surveys were carried out within the same month.

YEAR	Total number	No. of Surveys	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1999	22	3											10	12
2000	25	7	9	3		11							2	
2001	120	7	45	42	15	4					2		12	
2002	110	4	52	27	31									
2003	43	4	7		9	7								20
2004	84	4	71		7	6								
2005	129	3	22		55									52
Total	533		206	72	117	28					2		24	84
No. of Surveys		32	6	3	6	5	0	0	0	3	2	1	3	3

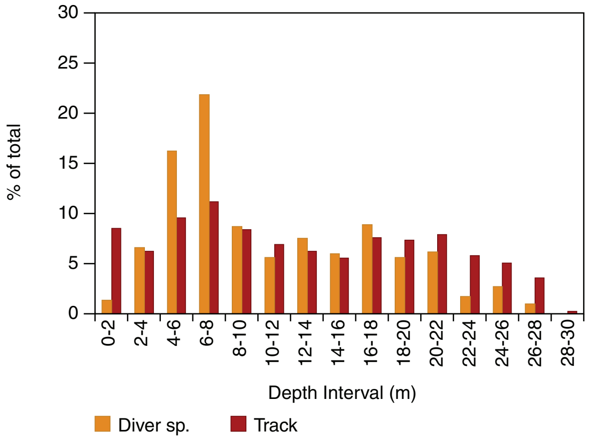


Figure 46. Water depth frequency distribution, in 2 m depth intervals, of Red-throated/Black-throated Diver in the Nysted study area, compared to the corresponding frequency distribution of the survey track line. N = 517.

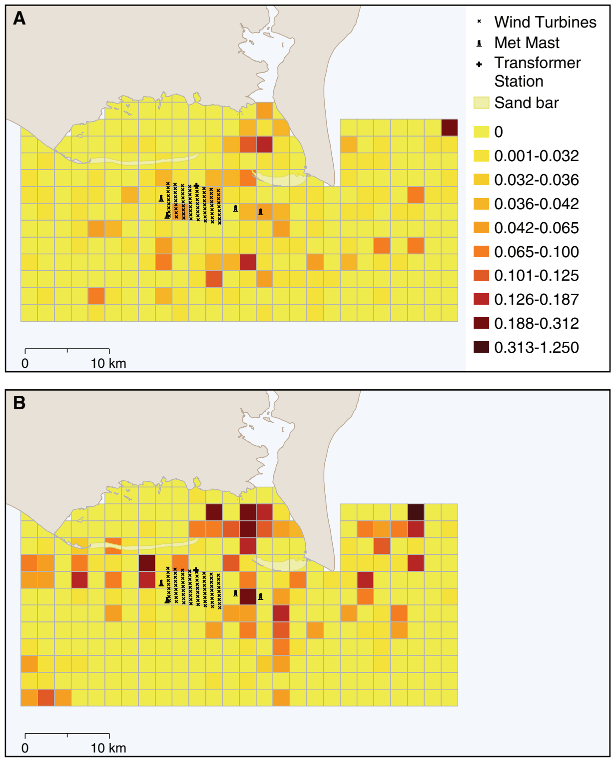


Figure 47. Relative density of Red-throated/Black-throated Diver in the Nysted study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

Red-necked Grebe *Podiceps griseigena*

A total of 237 Red-necked Grebes were recorded during the 32 surveys (Table 13 and see Kahlert et al. 2006). The species was generally seen in low numbers, with 65 birds being the highest number recorded during a single survey (15 November 1999).

The species occurred in fluctuating numbers between years, and was recorded in all surveyed months, but again with highly fluctuating numbers between corresponding months of different years (Fig. 48). Highest relative density was 0.06 birds/surveyed kilometre in November 1999.

Red-necked Grebes were found in the central parts of the study area, south of the sand bar, and with some observations from the deep parts of the lagoon, between the Rødsand Rev and Guldborgsund (Fig. 49), with scattered observations outside of this area.

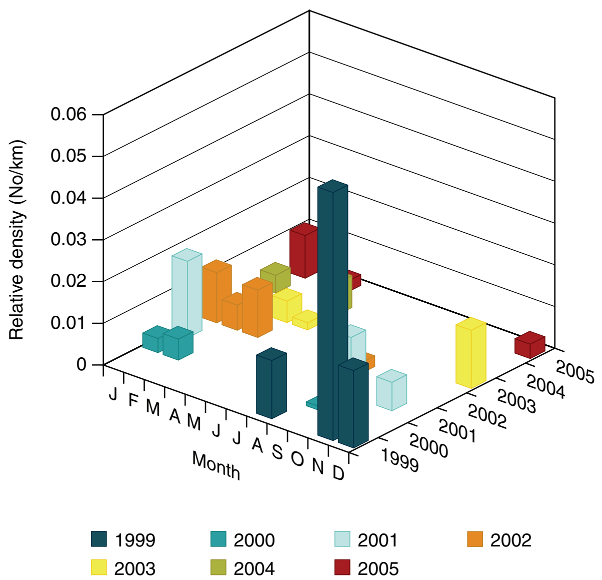


Figure 48. Phenology chart of occurrence for Red-necked Grebe in the Nysted study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

Table 13. The number of encountered Red-necked Grebes around Nysted by year and month. The number of surveys per month and by year is indicated. In April 2000 and in March 2004 two surveys were carried out within the same month.

YEAR	Total	No. of Surveys	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1999	98	3								14			65	19
2000	10	7	4	3							1	2		
2001	35	7	19								8		8	
2002	37	4	14	7	13					3				
2003	24	4			6	2								16
2004	14	4	5			9								
2005	19	3	12		3									4
Total	237		54	10	22	11					9		73	39
No. of Surveys		32	6	3	6	5	0	0	0	3	2	1	3	3

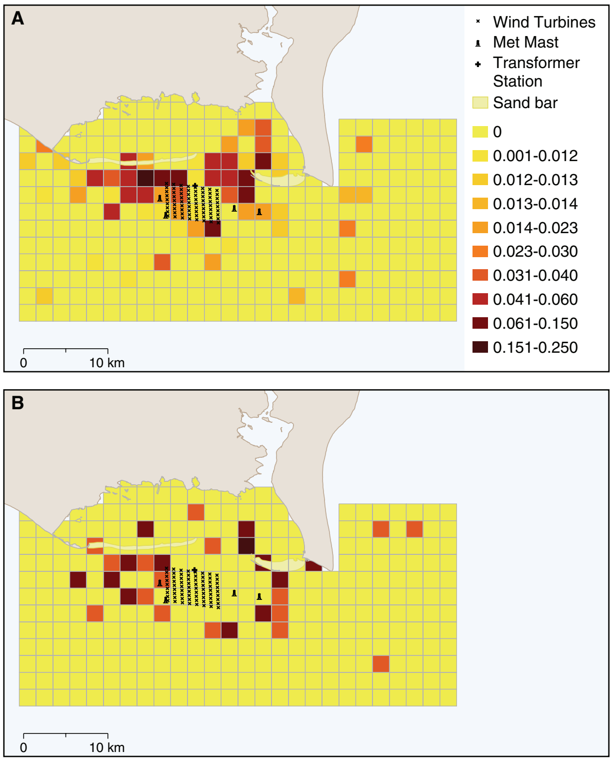


Figure 49. Relative density of Red-necked Grebe in the Nysted study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

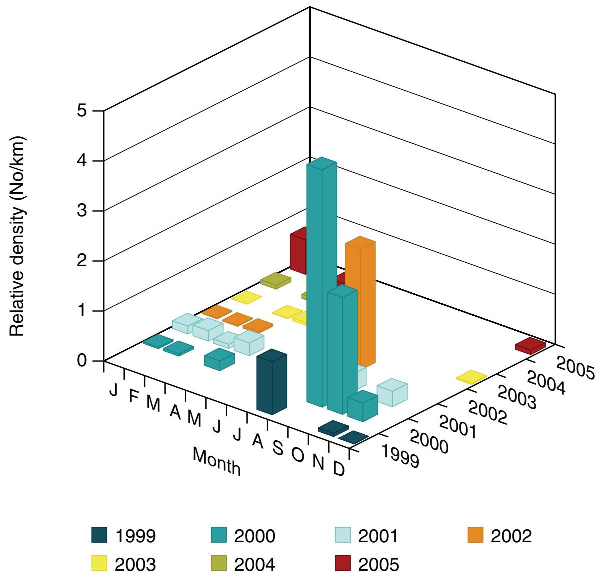


Figure 50. Phenology chart of occurrence for Cormorant in the Nysted study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

Cormorant *Phalacrocorax carbo*

A total of 17,287 Cormorants were recorded during the 32 aerial surveys, with highest numbers of observed birds being 5,224 on 11 September 2000 and 2,812 birds on 22 August 2002 (Table 14 and see Kahlert et al. 2006).

Cormorants were most numerous in the study area in autumn, with a maximum of 4.7 birds per surveyed kilometre of transect line in September 2000 (Fig. 50).

Cormorants were seen in highest numbers along the sand bar extending eastwards from Hyllekrog and on Rødsand Rev as well as around islands in the shallow parts of the lagoon (Fig. 51). In the offshore area social feeding groups have been recorded in a few cases, both during the pre- and post-construction phase of the wind farm.

The fact that a number of surveys were performed in autumn during the pre-construction years, but ceased during the post-construction phase, makes comparisons between the two phases difficult.

Table 14. The number of encountered Cormorants around Nysted by year and month. The number of surveys per month and by year is indicated. In April 2000 and in March 2004 two surveys were carried out within the same month.

YEAR	Total	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	No. of Surveys
1999	1140								1063			72	5	3
2000	8664	38	27		452					5224	2519	404		7
2001	2911	160	245	97	292				1554	198		365		7
2002	2901	21	19	49					2812					4
2003	101	1		11	62								27	4
2004	553	91		189	273									4
2005	1017	812		104									101	3
Total	17287	1123	291	450	1079					5422		841	133	
No. of Surveys		6	3	6	5	0	0	0	3	2	1	3	3	32

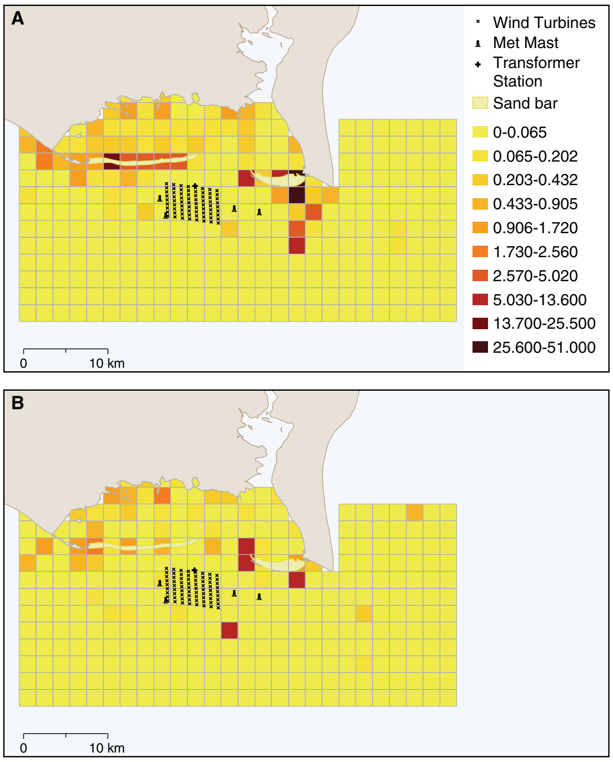


Figure 51. Relative density of Cormorant in the Nysted study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

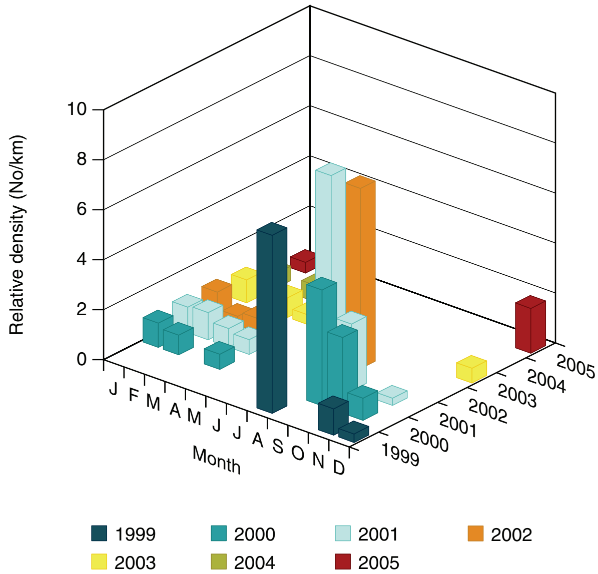


Figure 52. Phenology chart of occurrence for Mute Swan in the Nysted study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

Mute swan *Cygnus olor*

A total of 56,292 Mute Swans were recorded during the 32 aerial surveys, with the highest numbers recorded during one survey being 9,691 on 15 August 2001, 8,387 on 22 August 2002 and 7,157 on 29 August 1999 (Table 15 and see Kahlert et al. 2006).

Mute Swans are far most numerous in the study area during the early autumn, with up to 8.3 birds per surveyed transect kilometre, but the species is present in the area throughout the year (Fig. 52).

Mute swans are found in shallow waters, where they bottom up to feed on submerged vegetation. An analysis of the depth frequency distribution of mute swan encountered in the Nysted study area showed that 92% of the birds were recorded in the depth interval from 0 to 2 m (Fig. 53). Thus, Mute Swans were found almost exclusively in the northern and eastern parts of the lagoon, as well as around the Rødsand reef (Fig. 54).

Table 15. The number of encountered Mute Swans around Nysted by year and month. The number of surveys per month and by year is indicated. In April 2000 and in March 2004 two surveys were carried out within the same month.

YEAR	Total	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	No. of Surveys
1999	8662								7157			1154	351	3
2000	12334	1148	467		1408					5097	3259	955		7
2001	15419	1052	1273	870	671				9691	1523		339		7
2002	10604	1192	402	623					8387					4
2003	2882	842		911	455								674	4
2004	2913	678		1529	706									4
2005	3478	497		895									2086	3
Total	56292	5409	2142	4828	3240					6620		2448	3111	
No. of Surveys		6	3	6	5	0	0	0	3	2	1	3	3	32

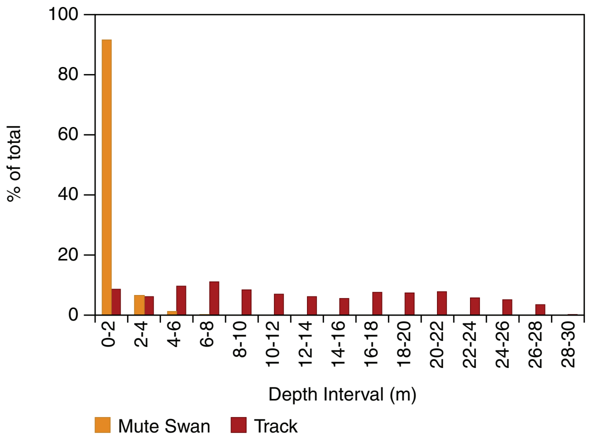


Figure 53. Water depth frequency distribution, in 2 m depth intervals, of Mute Swan in the Nysted study area, compared to the corresponding frequency distribution of the survey track line. N = 40,611.

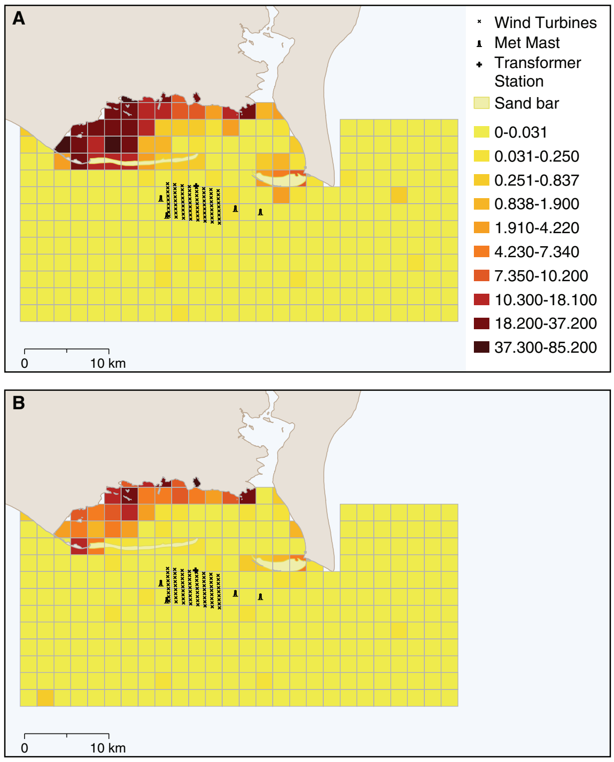


Figure 54. Relative density of Mute Swan in the Nysted study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

The high numbers of Mute Swan recorded in the early autumn primarily consist of moulting birds that gather here while flightless for approximately three weeks.

Goldeneye *Bucephala clangula*

A total of 13,886 Goldeneye were recorded during the 32 aerial surveys. The highest numbers recorded during single surveys were 2,291 on 10 February 2001, 1,898 on 10 January 2001 and 1,529 on 3 January 2002 (Table 16 and see Kahlert et al. 2006).

Goldeneye were most numerous in the study area from December into March. Highest relative density was recorded in February 2002 with 2.0 birds per surveyed transect kilometre (Fig. 55). Lower numbers were recorded in April and from August into October.

Table 16. The number of encountered Goldeneye around Nysted by year and month. The number of surveys per month and by year is indicated. In April 2000 and in March 2004 two surveys were carried out within the same month.

YEAR	Total	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	No. of Surveys
1999	326											255	71	3
2000	1316	952	122		180						25	37		7
2001	4958	1898	2291	328	55							386		7
2002	2081	1529	360	192										4
2003	1285	198		94	5								988	4
2004	1668	1199		451	18									4
2005	2252	621		778									853	3
Total	13886	6397	2773	1843	258					0	25	678	1912	
No. of Surveys		6	3	6	5	0	0	0	3	2	1	3	3	32

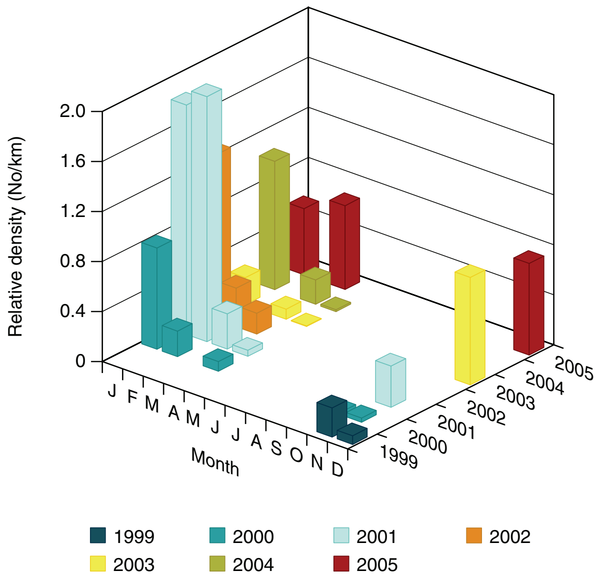


Figure 55. Phenology chart of occurrence for Goldeneye in the Nysted study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

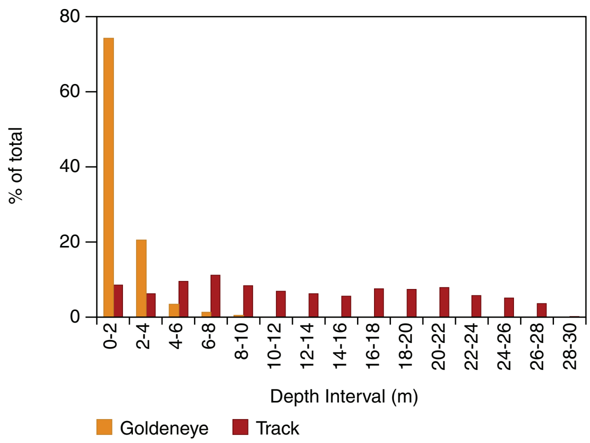


Figure 56. Water depth frequency distribution, in 2 m depth intervals, of Goldeneye in the Nysted study area, compared to the corresponding frequency distribution of the survey track line. N = 7,500.

Goldeneye are generally found on shallow waters. An analysis of the depth frequency distribution of Goldeneye encountered in the Nysted study area showed that 95% of the birds were recorded in the depth interval from 0 to 4 m, and with the remaining 5% recorded in the depth interval between 4 and 10 m (Fig. 56). Most Goldeneye therefore occurred in the lagoon, and particularly in the western and central parts of it, with few records outside of this area. Another concentration was found around the Rødsand Rev. Only few observations of Goldeneye in the offshore areas of the study area (Fig. 57).

Long-tailed Duck *Clangula hyemalis*

A total of 19,972 Long-tailed Ducks were recorded during the 32 aerial surveys. The highest numbers recorded during a single survey were 3,053 on 26 March 2002, 1,998 on 20 March 2005 and 1,854 on 5 March 2004 (Table 17 and see Kahlert et al. 2006).

Long-tailed Ducks were recorded in highest densities in March and April, with no birds or very low numbers in the autumn, but gradually increasing from December towards early spring (Fig. 58).

Long-tailed Ducks were mainly found on intermediate water depths, with 85% of the birds recorded in the depth interval between 4 and 12 m, where they feed on benthic mollusc species. 7% of the birds were recorded on the depth interval from 0 to 4 m, while 8% were found on water depths greater than 12 m (Fig. 59).

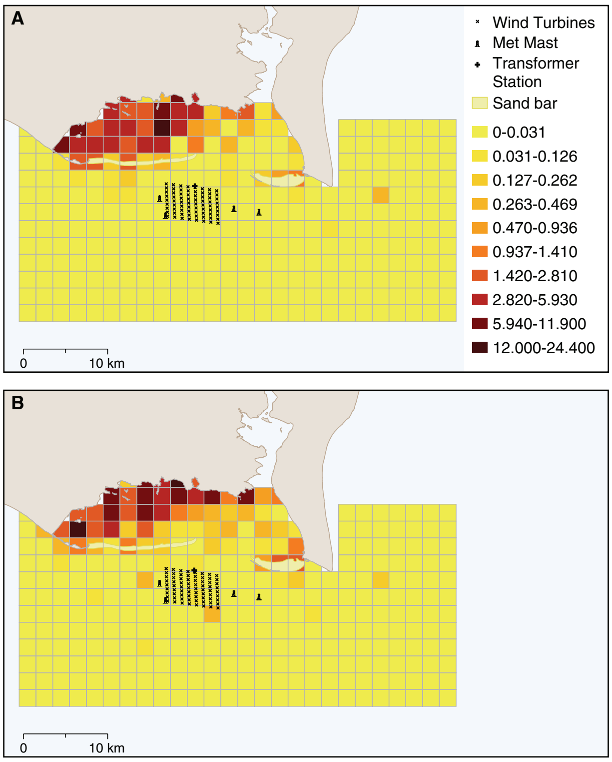


Figure 57. Relative density of Goldeneye in the Nysted study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

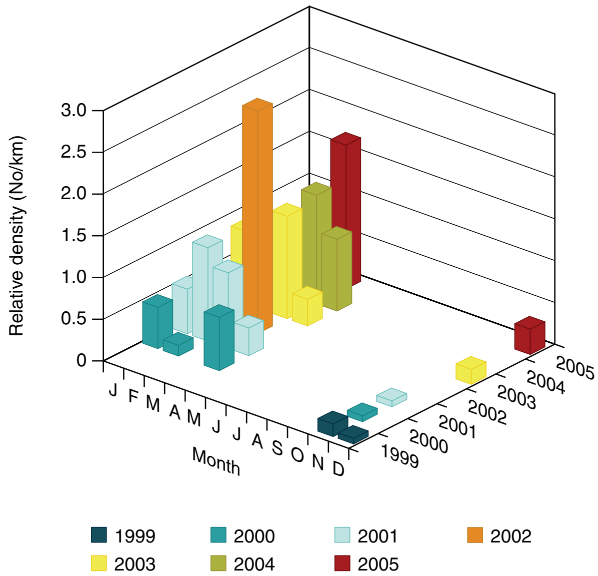


Figure 58. Phenology chart of occurrence for Long-tailed Duck in the Nysted study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

Table 17. The number of encountered Long-tailed Ducks around Nysted by year and month. The number of surveys per month and by year is indicated. In April 2000 and in March 2004 two surveys were carried out within the same month.

YEAR	Total	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	No. of Surveys
1999	234								0			166	68	3
2000	2216	582	77		1481					0	0	76		7
2001	3376	554	1308	1055	377				0	0		82		7
2002	3843	393	397	3053					0					4
2003	2797	798		1423	371								205	4
2004	4474	464		3006	1004									4
2005	3032	682		1998									352	3
Total	19972	3473	1782	10535	3233	0	0	0	0	0	0	324	625	
No. of Surveys		6	3	6	5	0	0	0	3	2	1	3	3	32

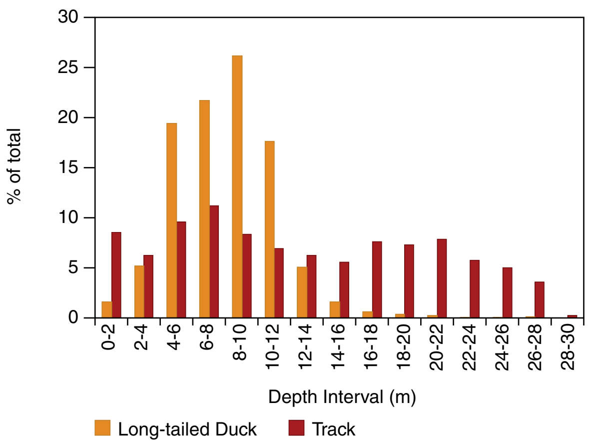


Figure 59. Water depth frequency distribution, in 2 m depth intervals, of Long-tailed Duck in the Nysted study area, compared to the corresponding frequency distribution of the survey track line. N = 18,278.

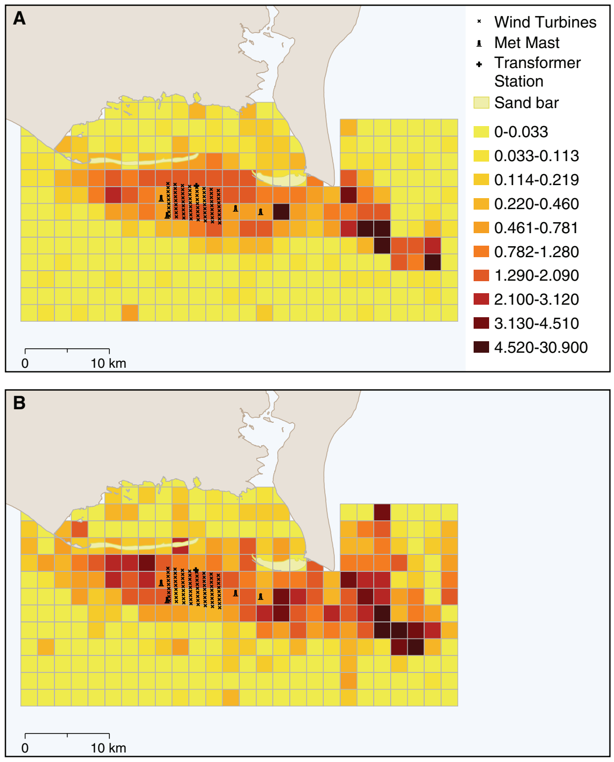


Figure 60. Relative density of Long-tailed Duck in the Nysted study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

The main distribution of this species was in the offshore parts of the study area, notably on Gedser Rev, but also in a zone extending from Gedser westwards to the Hyllekrog peninsula. Few birds were recorded inside the lagoon. In the post-construction phase there was a tendency for birds being more widely distributed in the easternmost parts of the study area (Fig. 60).

Common Eider *Somateria mollissima*

A total of 45,994 Common Eiders were recorded during the 32 aerial surveys, and thus the second most abundant species recorded. Maximum numbers recorded during a single survey were 8,706 birds on 26 April 2000, 5,362 on 26 March 2002 and 4,153 on 20 March 2005 (Table 18 and see Kahlert et al. 2006).

Common Eiders were recorded in highest numbers in March and April and in September to November, while lower numbers were recorded from December through to February. The Common Eiders present in this area were mainly migratory birds. Common Eiders do breed in the Rødsand lagoon, and the species was recorded during all surveys (Fig. 61).

Common Eiders were mainly found on shallow and intermediate water depths, with 72% of the birds recorded in the depth interval between 2 and 10 m, where they primarily feed on Blue Mussel *Mytilus edulis*. 11% of the birds were recorded on the depth interval from 0 to 2 m, while 17% were found on water depths greater than 10 m (Fig. 62).

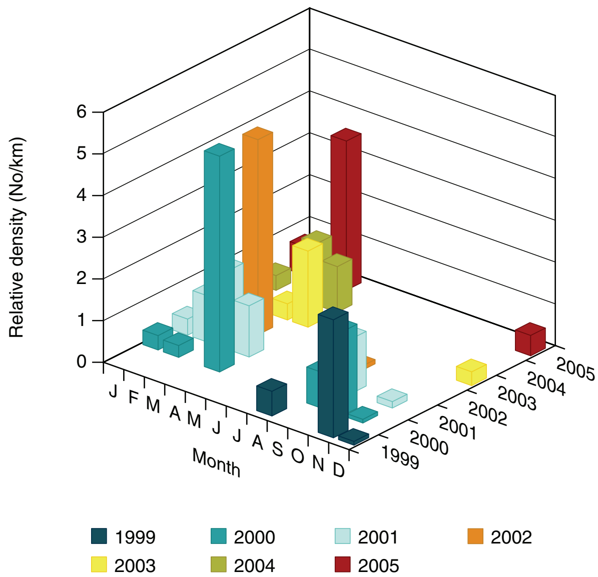


Figure 61. Phenology chart of occurrence for Common Eider in the Nysted study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

Table 18. The number of encountered Common Eiders around Nysted by year and month. The number of surveys per month and by year is indicated. In April 2000 and in March 2004 two surveys were carried out within the same month.

YEAR	Total	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	No. of Surveys
1999	3784								595			3097	92	3
2000	15844	410	169		12046					950	2173	96		7
2001	6422	399	1301	2214	1398				183	747		180		7
2002	6161	221	457	5362					121					4
2003	3142	191		447	2126								378	4
2004	5116	416		3416	1284									4
2005	5525	804		4153									568	3
Total	45994	2441	1927	15592	16854	0	0	0	899	1697	2173	3373	1038	
No. of Surveys		6	3	6	5	0	0	0	3	2	1	3	3	32

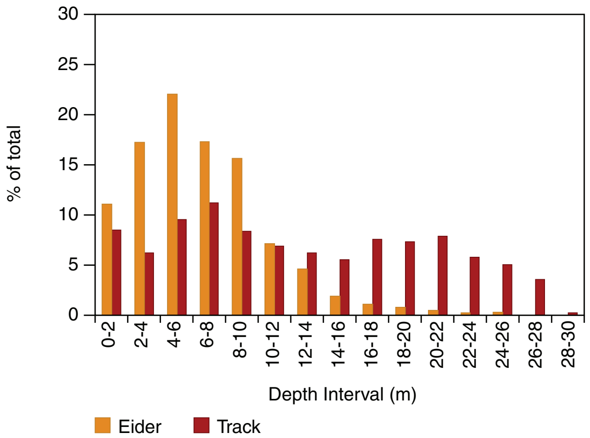


Figure 62. Water depth frequency distribution, in 2 m depth intervals, of Common Eider in the Nysted study area, compared to the corresponding frequency distribution of the survey track line. N = 36,707.

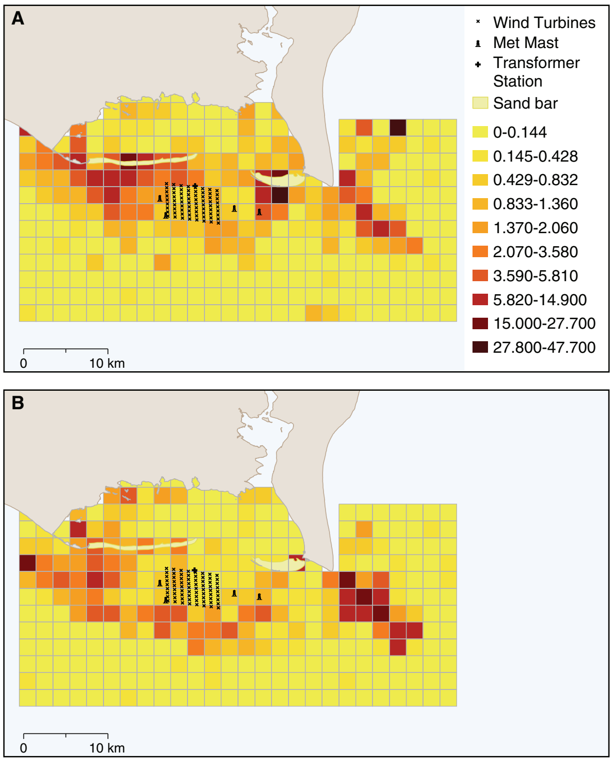


Figure 63. Relative density of Common Eider in the Nysted study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

The major concentrations of Common Eiders were found on the offshore parts of the study area. Gedser Rev had a concentration, but areas southeast and east of Hyllekrog also held high numbers of Common Eiders, with lower numbers in the vicinity of the wind farm (Fig. 63).

Common Scoter *Melanitta nigra*

A total of 2,710 Common Scoters were recorded during the 32 aerial surveys. Maximum numbers recorded during a single survey were 412 on 26 March 2002 and 358 on 14 January 2000 (Table 19 and see Kahlert et al. 2006).

The low relative densities of Common Scoters in the area revealed high monthly variations in densities when compared between years. The species was most abundant in late winter and early spring, and was found in lower densities during the autumn (Fig. 64).

Table 19. The number of encountered Common Scoters around Nysted by year and month. The number of surveys per month and by year is indicated. In April 2000 and in March 2004 two surveys were carried out within the same month.

YEAR	Total	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	No. of Surveys
1999	67											38	29	3
2000	1101	358	83		310					92	122	136		7
2001	407	45	182	4	106				26	0		44		7
2002	516	14	81	412					9					4
2003	128	16		46	23								43	4
2004	185	34		133	18									4
2005	306	40		222									44	3
Total	2710	507	346	817	457	0	0	0	35	92	122	218	116	
No. of Surveys		6	3	6	5	0	0	0	3	2	1	3	3	32

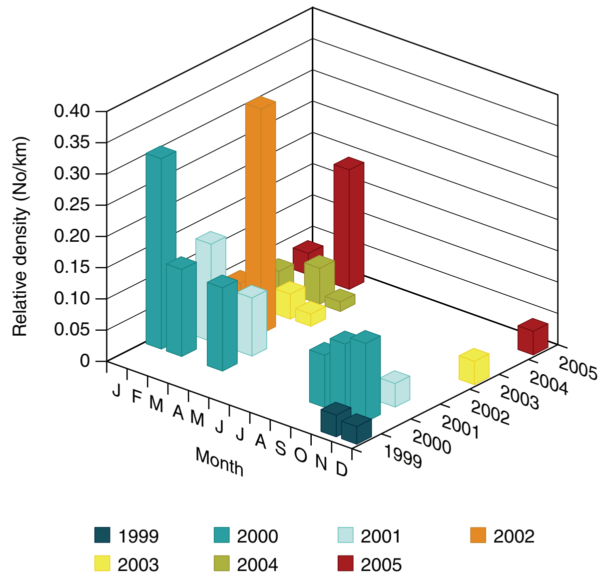


Figure 64. Phenology chart of occurrence for Common Scoter in the Nysted study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

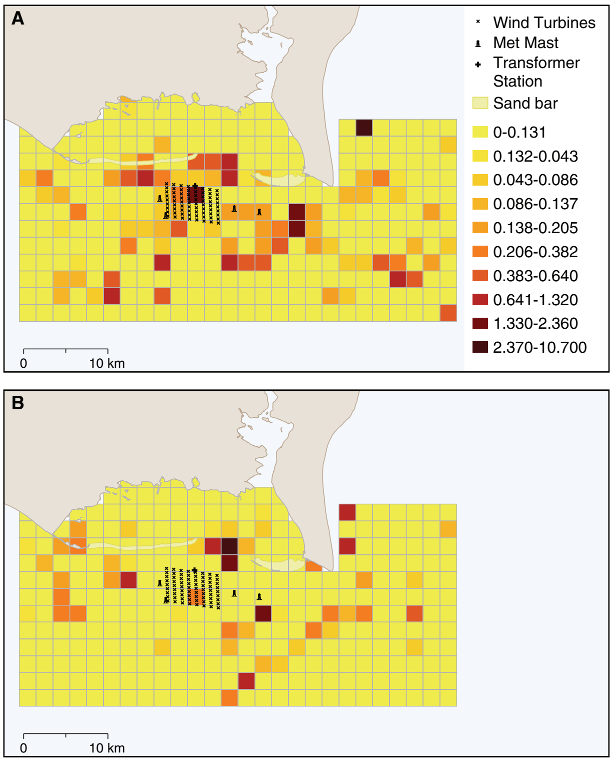


Figure 65. Relative density of Common Scoter in the Nysted study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

The distribution pattern of Common Scoter was patchy. Many of the birds encountered in this area were likely to have been on passage between wintering and breeding areas. The species was most abundant in the offshore parts of the study area, with a distribution pattern similar to that of Common Eider and Long-tailed Duck (Fig. 65).

Red-breasted Merganser *Mergus serrator*

A total of 5,771 Red-breasted Mergansers were recorded during the 32 aerial surveys. Maximum numbers recorded during a single survey were 1,685 on 15 November 1999, 516 on 5 March 2004 and 458 on 20 March 2005 (Table 20 and see Kahlert et al. 2006).

Table 20. The number of encountered Red-breasted Merganser around Nysted by year and month. The number of surveys per month and by year is indicated. In April 2000 and in March 2004 two surveys were carried out within the same month.

YEAR	Total	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	No. of Surveys
1999	1745								45			1685	15	3
2000	373	102	131		84					26	18	12		7
2001	604	258	140	102	44				1	21		38		7
2002	603	253	80	269					1					4
2003	1061	105		278	142								536	4
2004	738	93		577	68									4
2005	647	139		458									50	3
Total	5771	950	351	1684	338					47		1735	601	
No. of Surveys		6	3	6	5	0	0	0	3	2	1	3	3	32

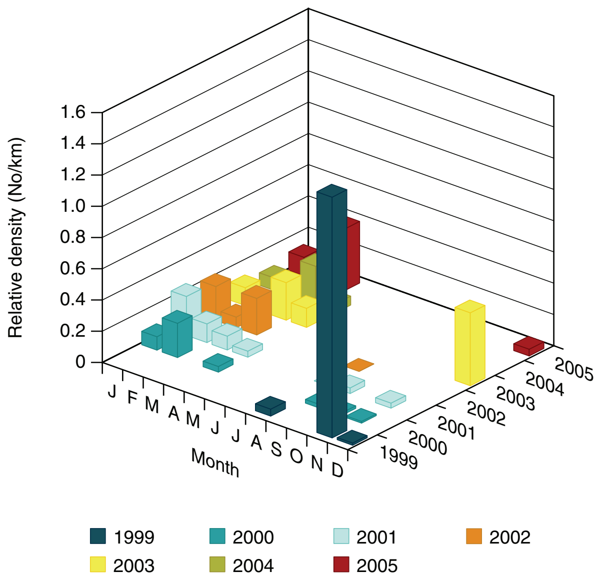


Figure 66. Phenology chart of occurrence for Red-breasted Merganser in the Nysted study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

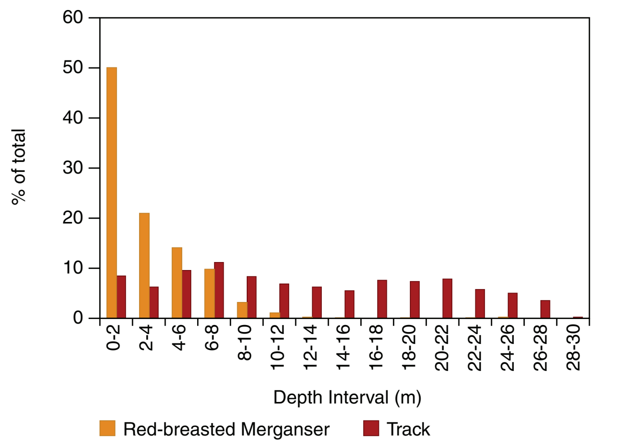


Figure 67. Water depth frequency distribution, in 2 m depth intervals, of Red-breasted Merganser in the Nysted study area, compared to the corresponding frequency distribution of the survey track line. N = 3,636.

Red-breasted Mergansers were most numerous in winter and early spring, and less numerous in autumns (Fig. 66). Highest density was on 15 November 1999, where 1.5 birds per covered transect kilometre was recorded. The species was found mainly on shallow waters, with 50% of the observed birds being present at the 0-2 m depth interval, and 21% in the 2-4 m interval. 98% of all birds were recorded on less than 10 m of water depth (Fig. 67). The majority of the Red-breasted Mergansers were recorded in the lagoon, although concentrations were also seen in the offshore areas south of the lagoon (Fig. 68).

Herring Gull *Larus argentatus*

A total of 36,125 Herring Gulls were recorded during the 32 aerial surveys. Maximum numbers were 6,149 on 5 January 2004 and 3,214 on 10 February 2001 (Table 21 and see Kahlert et al. 2006).

Herring Gulls were found in the area all year, being abundant in autumn, winter and spring. Exceptionally many birds were recorded in January 2004 (Fig. 69). The depth frequency distribution of Herring Gull showed two peaks. One peak in shallow water depths, with 36% of the birds recorded in the 0-4 m depth interval and another in the 18-26 m depth interval, embracing 33% of the birds (Fig. 70). Herring Gulls from the deep waters were most often associated with active fishing vessels.

The majority of Herring Gulls present offshore were found in the southwestern and southern parts of the study area, while coastal concentrations of Herring Gulls were found along the sand and the Rødsand Rev, as well as around islands in the lagoon (Fig. 71).

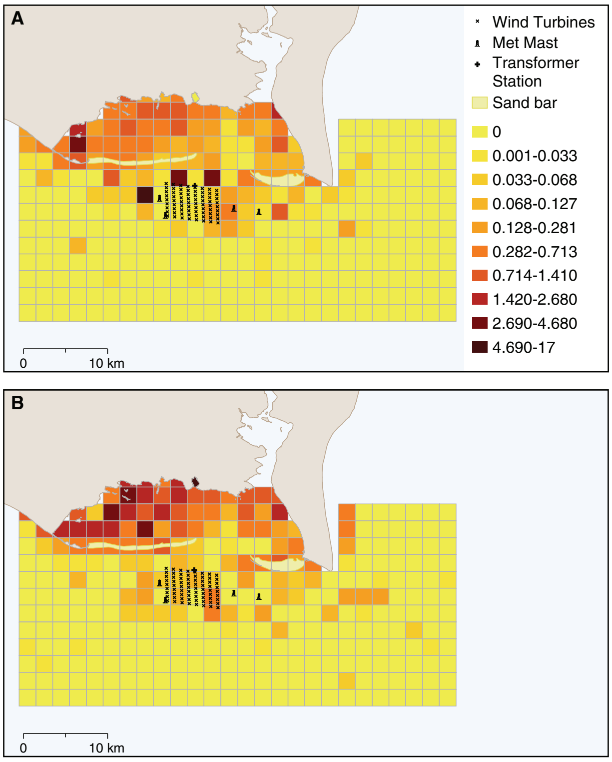


Figure 68. Relative density of Red-breasted Merganser in the Nysted study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

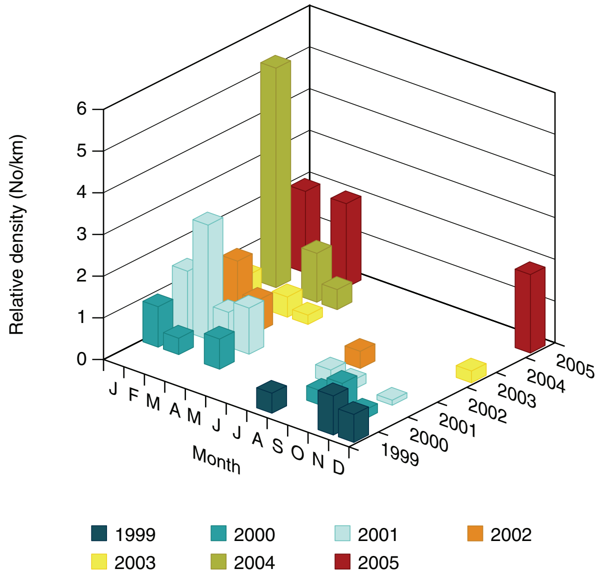


Figure 69. Phenology chart of occurrence for Herring Gull in the Nysted study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

Table 21. The number of encountered Herring Gulls around Nysted by year and month. The number of surveys per month and by year is indicated. In April 2000 and in March 2004 two surveys were carried out within the same month.

YEAR	Total	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	No. of Surveys
1999	2198								482			1028	688	3
2000	4434	1141	235		1681					380	763	234		7
2001	7606	1520	3214	965	1261				373	130		143		7
2002	3912	785	1776	872					479					4
2003	1737	589		564	260								324	4
2004	9429	6149		2718	562									4
2005	6809	2291		2330									2188	3
Total	36125	12475	5225	7449	3764					510		1405	3200	
No. of Surveys		6	3	6	5	0	0	0	3	2	1	3	3	32

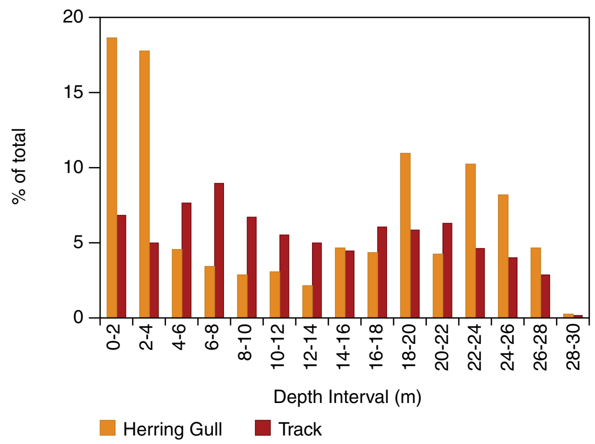


Figure 70. Water depth frequency distribution, in 2 m depth intervals, of Herring Gull in the Nysted study area, compared to the corresponding frequency distribution of the survey track line. N = 36,102.

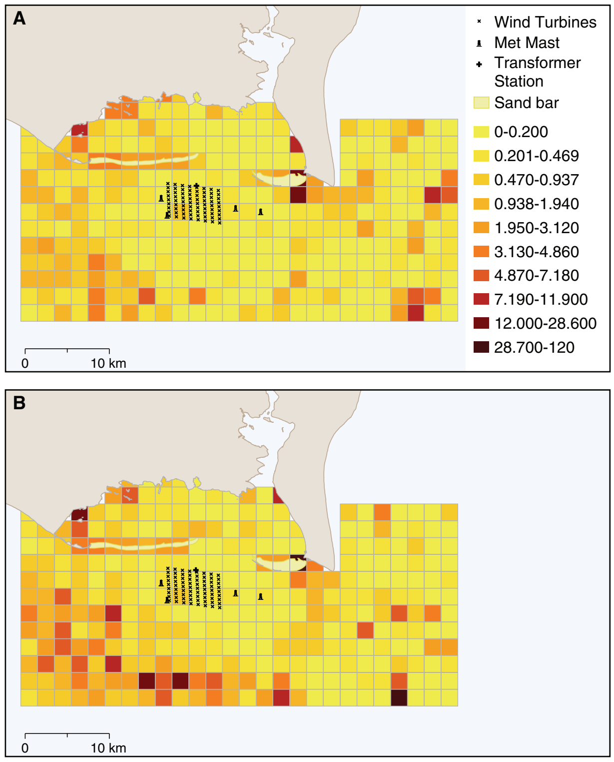


Figure 71. Relative density of Herring Gull in the Nysted study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

Great Black-backed Gull *Larus marinus*

A total of 1,464 Great Black-backed Gulls were recorded during the 32 aerial surveys. Maximum numbers were 238 on 10 February 2002 and 211 on 28 January 2005 (Table 22 and Kahlert et al. 2006).

Great Black-backed Gull was present in the study area during all surveyed months. It was most abundant in January and February, though high numbers was also found in autumn and early winter. Lowest abundance occurred in March and April (Fig. 72).

The depth frequency distribution of Great Black-backed Gull showed an unclear picture. At the depth interval 0-2 m 23% of the birds were recorded. Between 2 and 18 m percentage values of c. 5% were seen, with 38% of birds recorded from 18-28 m (Fig. 73).

Great Black-backed Gulls were mainly found in the southwestern parts of the study area, as well as in the western parts of the lagoon (Fig. 74).

Table 22. The number of encountered Great Black-backed Gulls around Nysted by year and month. The number of surveys per month and by year is indicated. In April 2000 and in March 2004 two surveys were carried out within the same month.

YEAR	Total	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	No. of Surveys
1999	143								68			34	41	3
2000	319	178	5		22					52	31	31		7
2001	380	78	238	9	7				12	7		29		7
2002	80	30	34	9					7					4
2003	148	89		38	5								16	4
2004	137	59		69	9									4
2005	257	211		24									22	3
Total	1464	645	277	149	43					59		94	79	
No. of Surveys		6	3	6	5	0	0	0	3	2	1	3	3	32

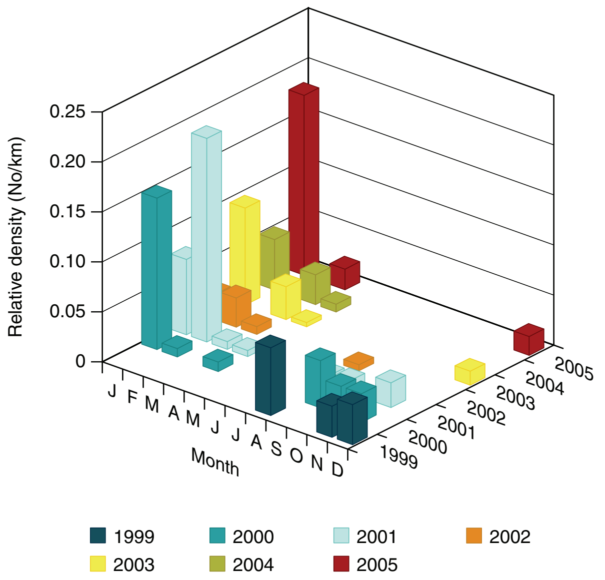


Figure 72. Phenology chart of occurrence for Great black-backed Gull in the Nysted study area. Plotted monthly values indicate the mean number of individuals recorded per kilometre of surveyed transect for each survey.

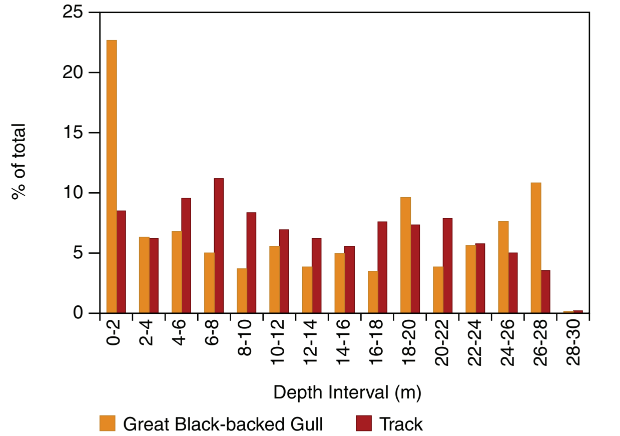


Figure 73. Water depth frequency distribution, in 2 m depth intervals, of Great black-backed Gull in the Nysted study area, compared to the corresponding frequency distribution of the survey track line. N = 1,457.

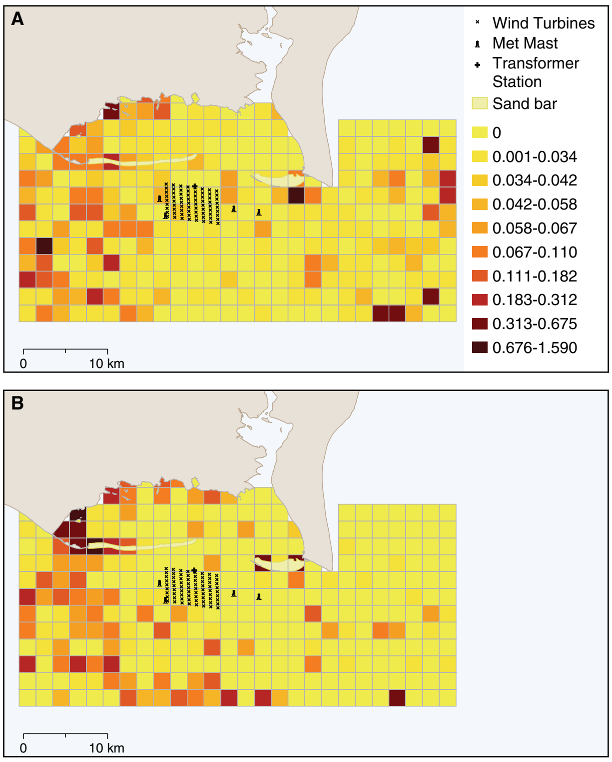


Figure 74. Relative density of Great black-backed Gull in the Nysted study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

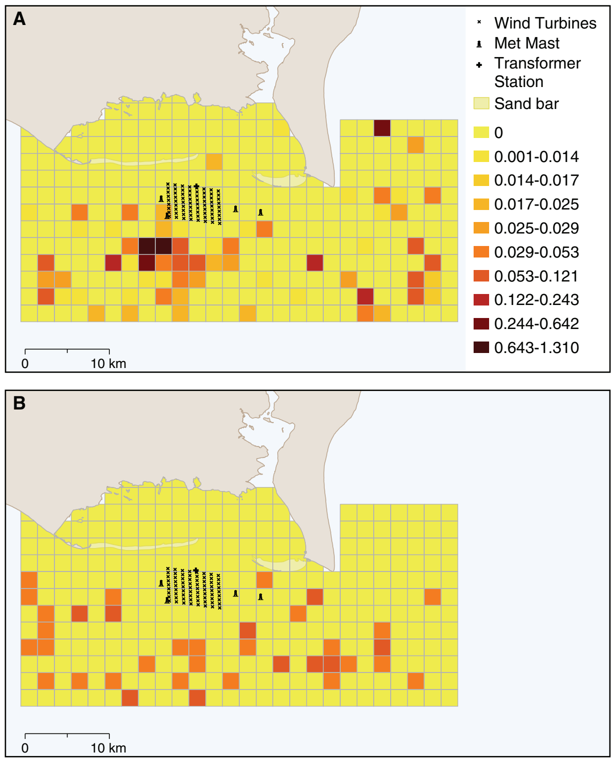


Figure 75. Relative density of Little Gull in the Nysted study area, based on 16 surveys performed during the pre-construction phase (A) and 15 surveys performed during the post-construction phase (B). Data expressed as number of observed birds per kilometre of flown transect coverage in each 2 x 2 km grid square.

Little Gull *Larus minutus*

A total of 532 Little Gulls were recorded during the 32 surveys, of which 259 birds (49%) were recorded on 28 September 2001 (see Kahlert et al. 2006). Little gulls were almost exclusively seen in the offshore parts of the study area, and particularly in the southern parts of the area (Fig. 75).

4.1.3 Utilisation of the Horns Rev wind farm area and surroundings by birds, pre- and post-construction of wind turbines

A total of 34 surveys of birds have been carried out in the Horns Rev area between August 1999 and December 2005. The wind farm construction phase was initiated in September 2001, but construction activities ceased between October 2001 and March 2002. This period was treated as the pre-construction period in this report, consisting of a total of 16 surveys. The operation (post-construction) phase started in late autumn of 2002, and the first aerial survey data obtained during wind farm operation was in February 2003. Thus a total of 15 surveys from 2003 to 2005 are available to describe bird distributions after the appearance of the wind turbines (see Christensen et al. 2006).

The importance of the wind farm area and of the adjacent 2 and 4 km zones to birds occurring at Horns Rev was assessed from the preference of the birds for these areas using Jacobs's selectivity index. The index indicates whether a species occurred in a higher or lower proportion in an area than expected, assuming a geographically even distribution. Changes in this index between pre- and post-construction phase was used to describe changes in bird distributions in the vicinity of the wind turbines.

Most of the birds treated here appear in flocks (clusters), in some cases comprising several thousand individuals. A χ^2-test requires independent samples, which the individual birds can not considered to be. In Tables 23 and 24 the significance level of the χ^2-test is indicated using individual numbers as sample size anyway, because weighting an observation of a single Common Scoter equally with an observation of, say, 10,000 Common Scoters seems unwise. Parallel calculations, using clusters as the sample unit, are also presented (Tables 25 and 26).

Table 23. Percentage of birds (number of individuals) encountered in the Horns Rev wind farm area (MA) based on 16 pre-construction aerial surveys, as compared to the entire survey area, and in wind farm area plus zones of 2 and 4 km radius from the wind farm site (MA+2 and MA+4). Also shown are the total numbers of birds for each species/species group recorded throughout the surveys from the total study area from the pre-construction period (N). For each species and area, the Jacobs Index value (D) is given which varies between -1 (complete avoidance) and 1 (complete selection). The last column for each species category and area is the probability that these encounter rates differ from those of the entire area, based on one sample χ^2-tests. Values (P) are probabilities using standard statistical notation, n.s. represents P > 0.05, * P<0.05, ** P<0.01, *** P<0.001.

Species	MA	D for MA+0	P	MA+2	D for MA+2	P	MA+4	D for MA+4	P	N
Diver sp.	1.58	0.00	n.s.	4.81	-0.01	n.s.	7.66	-0.13	**	1,331
Gannet	0.00	-1.00	**	1.94	-0.45	***	9.51	-0.02	n.s.	515
Common Eider	0.01	-0.99	***	0.01	-1.00	***	0.02	-1.00	***	12,600
Common Scoter	0.40	-0.60	***	2.44	-0.35	***	8.59	-0.07	***	128,786
Herring Gull	0.06	-0.93	***	0.38	-0.86	***	1.47	-0.76	***	18,005
Little Gull	0.79	-0.34	n.s.	3.15	-0.23	n.s.	7.87	-0.12	n.s.	127
Kittiwake	0.79	-0.34	***	2.70	-0.30	***	6.51	-0.22	***	2,520
Arctic/Common Tern	1.00	-0.23	*	2.13	-0.41	***	5.75	-0.28	***	2,400
Guillemot/Razorbill	0.91	-0.28	n.s.	2.63	-0.32	***	7.79	-0.13	*	1,104
% of total survey cov.	1.59			4.93			9.81			

Table 24. Percentage of birds (number of individuals) encountered in the Horns Rev wind farm area (MA) based on 15 post-construction aerial surveys, as compared to the entire survey area, and in wind farm area plus zones of 2 and 4 km radius from the wind farm site (MA+2 and MA+4). Also shown are the total numbers of birds for each species/species group recorded throughout the surveys from the total study area from the post-construction period (N). For each species and area, the Jacobs Index value (D) is given which varies between -1 (complete avoidance) and 1 (complete selection). The last column for each species category and area is the probability that these encounter rates differ from those of the entire area, based on one sample χ^2-tests. Values (P) are probabilities using standard statistical notation, n.s. represents P > 0.05, * P<0.05, ** P<0.01, *** P<0.001.

Species	MA	D for MA+0	P	MA+2	D for MA+2	P	MA+4	D for MA+4	P	N
Diver sp.	0.00	-1.00	***	0.39	-0.85	***	2.59	-0.58	***	2321
Gannet	0.00	-1.00	**	0.32	-0.88	***	1.44	-0.75	***	627
Common Eider	0.00	-1.00	***	0.06	-0.98	***	0.15	-0.97	***	8592
Common Scoter	0.04	-0.95	***	1.05	-0.64	***	2.40	-0.61	***	773260
Herring Gull	0.24	-0.72	***	1.05	-0.64	***	2.26	-0.63	***	23732
Little Gull	3.09	0.36	***	10.27	0.41	***	17.73	0.36	***	1100
Kittiwake	1.92	0.13	n.s.	5.43	0.09	n.s.	8.15	-0.06	n.s.	626
Arctic/Common Tern	0.00	-1.00	**	7.27	0.24	***	13.78	0.23	***	798
Auk/Guillemot	0.16	-0.81	***	1.37	-0.55	***	5.70	-0.25	***	1245
% of total survey cov.	1.48			4.58			9.14			

Table 25. Percentage of bird flocks (clusters) encountered in the Horns Rev wind farm area (MA) based on 16 pre-construction aerial surveys, as compared to the entire survey area, and in wind farm area plus zones of 2 and 4 km radius from the wind farm site (MA+2 and MA+4). Also shown are the total numbers of clusters for each species/species group recorded throughout the surveys from the total study area from the pre-construction period (N). For each species and area, the Jacobs Index value (D) is given which varies between -1 (complete avoidance) and 1 (complete selection). The last column for each species category and area is the probability that these encounter rates differ from those of the entire area, based on one sample χ^2-tests. Values (P) are probabilities using standard statistical notation, n.s. represents P > 0.05, * P<0.05, ** P<0.01, *** P<0.001.

Species	MA	D for MA+0	P	MA+2	D for MA+2	P	MA+4	D for MA+4	P	N
Diver sp.	1.94	0.10	n.s.	5.08	0.02	n.s.	8.21	-0.10	n.s.	926
Gannet	0.00	-1.00	n.s.	2.90	-0.27	n.s.	7.47	-0.15	n.s.	241
Common Eider	0.17	-0.81	*	0.17	-0.94	***	0.34	-0.94	***	593
Common Scoter	0.25	-0.73	***	1.26	-0.61	***	3.95	-0.45	***	3,977
Herring Gull	0.24	-0.75	***	1.15	-0.63	***	3.68	-0.48	***	3,828
Little Gull	1.03	-0.22	n.s.	4.12	-0.09	n.s.	10.31	0.03	n.s.	97
Kittiwake	0.98	-0.24	n.s.	3.85	-0.13	n.s.	10.29	0.03	n.s.	1,118
Arctic/Common Ttern	1.44	-0.05	n.s.	3.36	-0.20	**	8.64	-0.07	n.s.	1,042
Guillemot/Razorbill	1.19	-0.15	n.s.	3.56	-0.17	n.s.	8.64	-0.07	n.s.	590
% of total survey cov.	1.59			4.93			9.81			

Table 26. Percentage of bird flocks (clusters) encountered in the Horns Rev wind farm area (MA) based on 15 post-construction aerial surveys, as compared to the entire survey area, and in wind farm area plus zones of 2 and 4 km radius from the wind farm site (MA+2 and MA+4). Also shown are the total numbers of clusters for each species/species group recorded throughout the surveys from the total study area from the post-construction period (N). For each species and area, the Jacobs Index value (D) is given which varies between -1 (complete avoidance) and 1 (complete selection). The last column for each species category and area is the probability that these encounter rates differ from those of the entire area, based on one sample χ^2-tests. Values (P) are probabilities using standard statistical notation, n.s. represents P > 0.05, * P<0.05, ** P<0.01, *** P<0.001.

Species	MA	D for MA+0	P	MA+2	D for MA+2	P	MA+4	D for MA+4	P	N
Diver sp.	0.00	-1.00	***	0.62	-0.77	***	3.22	-0.50	***	1458
Gannet	0.00	-1.00	n.s.	0.75	-0.73	**	3.02	-0.53	**	265
Common Eider	0.00	-1.00	**	0.44	-0.83	***	0.88	-0.84	***	681
Common Scoter	0.21	-0.76	***	2.43	-0.32	***	4.22	-0.39	***	10653
Herring Gull	1.01	-0.19	*	3.33	-0.17	***	6.77	-0.16	***	4179
Little Gull	2.08	0.17	n.s.	9.53	0.37	***	19.41	0.41	***	577
Kittiwake	1.57	0.03	n.s.	4.08	-0.06	n.s.	7.52	-0.11	n.s.	319
Arctic/Common Tern	0.00	-1.00	*	5.87	0.13	n.s.	11.22	0.11	n.s.	392
Guillemot/Razorbill	0.27	-0.70	*	1.88	-0.43	**	6.06	-0.22	**	743
% of total survey cov.	1.48			4.58			9.14			

For a number of species a calculation of the cumulative percentage of birds within a given radius away from the wind turbines was carried out, based on distance categories of 500 m and for each of the pre- and post-construction phase data sets.

The above analyses are capable of describing potential changes in distribution between the pre- and post-construction phase, but fail to test for a statistically significant impact from the wind farm. For selected species a comparison of the bird encounter rate per survey coverage intensity pre- and post construction of the wind farms was carried out.

Red- and Black-throated Diver *Gavia stellata/arctica*

During the pre-construction period divers were encountered in the wind farm area and the 2 km zone around the farm at frequencies that did not differ significantly from the average in the entire study area. When including the area out to 4 km from the wind farm divers were present in slightly less than expected numbers, with 8.2% of the observed groups recorded during 9.8% of the survey effort, giving rise to D-values of +0.10, +0.02 and –0.10 for the three distance zones (Table 25). During the post-construction period a marked avoidance of the wind farm area, including also the 2 and 4 km zones around it, with D values of –1.00, -0.77 and –0.50 for the wind farm area, the 2 and 4 km zones, respectively (Table 26). These results indicate an increased avoidance of the wind farm area after the erection of the turbines. The overall number of divers in the study area during the post-construction surveys was high, compared to pre-construction surveys (see Christensen et al. 2006).

A calculation of the cumulative percentage of number of divers within distance intervals of 500 m from nearest wind turbine, out to a distance of 8 km, was made on the basis of pre- and post-construction data (Fig. 76). A comparison between the two scenarios showed a significant difference between the pre- and post-construction phase, using a Kolmogorov-Smirnov Two-sample test (Pr > KSa 0.0003), with decreased proportions of divers found in the vicinity of the turbines. The maximum difference between the pre- and post-construction phase was found at a distance of 2 km.

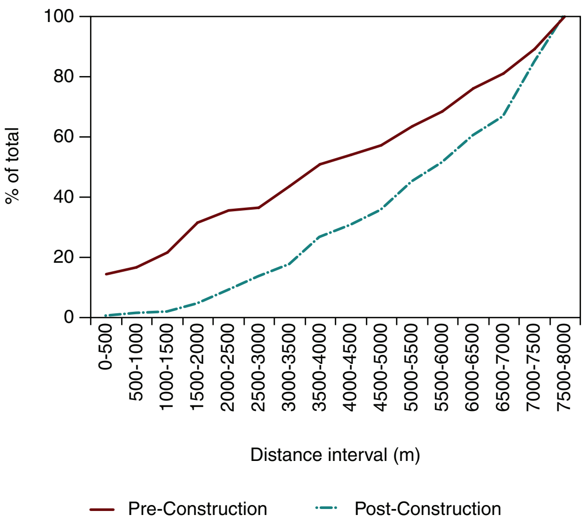


Figure 76. Cumulated frequency distribution of Red-throated/Black-throated Diver around the Horns Rev wind farm, calculated by distance to nearest wind turbine in 500 m intervals, pre- and post-construction. Data was weighted by numbers and based on birds observed within 5 km of the wind turbines in the months from December to April (both included).

The statistical significance of this apparent change in distribution between the pre- and post-construction phases was tested using data from March between 2000 and 2005, comparing bird encounter rates per surveyed transect kilometre, and tested using a students t-test (Fig. 77). There was statistically significant reduction in the number of bird encounters within the wind farm and in the strip of water 2 km around the outside of the wind farm. At distances between 2 km and 4 km from the outer turbines there was no detectable difference between encounter rates pre- and post-construction. There was a tendency for increased abundance of divers in the control zone and in the study area as a whole post construction, although the differences were not statistically significant.

Gannet *Sula bassana*

Gannets were observed in the wind farm area and the two zones around it in less than expected numbers, assuming a geographically even distribution, both during pre- and post-construction of the wind farm. There were no observations of Gannets in the actual wind farm area pre- or post-construction. D-values for the 2 and 4 km zones indicated an increased avoidance of the wind farm area after erection of the turbines, with values going from –0.27 to –0.73 for the two km zone and –0.15 to –0.53 for the four km zone (Tables 25 and 26).

A calculation of the cumulated percentage of number of gannets within distance intervals of 500 m from nearest wind turbine, out to a distance of 8 km, was made on the basis of pre- and post-construction data (Fig. 78). A comparison between the two scenarios showed non-significant difference between the pre- and post-construction phase when calculated on the basis of number of clusters, using a Kolmogorov-Smirnov Two-sample test (Pr > KSa 0.0664), but a significant difference when calculated on the basis of number of individuals (Pr > KSa < 0.0001), with maximum difference between the pre- and post-construction phase found at a distance of 3.5 km.

For this species (as for many others in the following accounts) there were insufficient data to test for differences in encounter rates between the pre- and post-construction phases.

Common Eider *Somateria mollissima*

Common Eider showed a clear avoidance of the area of the Horns Rev wind farm and the two zones around it, both pre- and post-construction and calculated on number of individuals as well as number of clusters. The D-values differed very little between the pre- and post-construction situation (Tables 23 to 26).

Common Scoter *Melanitta nigra*

The number of Common Scoters increased in the survey area overall, with higher numbers observed during the post-construction phase than during the pre-construction phase, and with particularly high numbers in 2003. Common Scoter were encountered within the wind farm area, as well as the 2 and 4 km zones around it, significantly less than expected, assuming a geographically even distribution, both prior to and following the erection of the wind turbines.

When calculating site selectivity indices on the basis of clusters the degree of avoidance changed from the pre- to post-construction situation, changing from a D value of -0.73 to -0.76 in the wind farm area itself, from -0.61 to –0.32 when including the two km zone and from -0.45 to -0.39 when including the four km zone (Tables 25 and 26). When calculating on number of individuals the corresponding D value decreased from -0.60 to -0.95 in the wind farm area itself, from -0.35 to –0.64 when including the two km zone and from -0.07 to -0.61 when including the four km zone. For both pre- and post-construction the distribution between wind farm site and the surrounding areas were significantly different from a geographically even distribution (Tables 23 to 26).

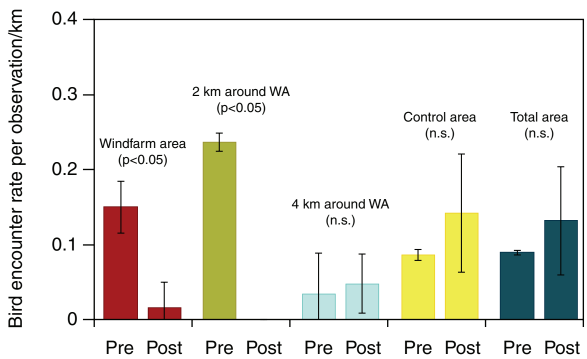


Figure 77. Comparison of pre- and post-construction diver encounter rate per survey effort (corrected for observer coverage) at Horns Rev for the wind farm area, the 2 and 4 km zones around the farm, the control area and the total area respectively. 95% confidence intervals and level of statistical significance are given.

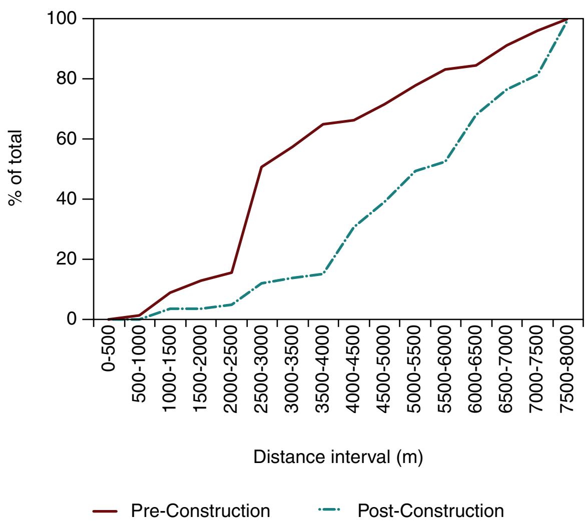


Figure 78. Cumulated frequency distribution of Gannet around the Horns Rev wind farm, calculated by distance to nearest wind turbine in 500 m intervals, pre- and post-construction. Data was weighted by numbers and based on birds observed within 8 km of the wind turbines in the months from December to April (both included).

In earlier reports a seasonal pattern has been described, with birds being concentrated close to land from September until January/February, but showing a gradual movement towards the southeastern parts of Horns Rev from March through April (Christensen et al. 2003, Petersen et al. 2004). In March and April 2003 this general movement was again observed. However, there was a general shift in distribution away from the area southeast of the wind farm to areas west and particularly north of the wind farm, into areas where very few Common Scoters had previously been observed (Fig. 79, Petersen et al. 2004). Furthermore, during the 2004 surveys, this general pattern was maintained, with only few birds in the area southeast of the wind farm and with a concentration of birds around the northwestern corner of the wind farm. During surveys in both 2004 and 2005, in contrast to the earlier years, concentrations of Common Scoters were recorded throughout the non-breeding period out to the westernmost extension of the study area, and almost exclusively north of the reef. In this area Common Scoters had not been recorded during previous years. Hence, in the latter (post-construction) years, birds showed very different patterns of distribution in time and space than they had done in the pre-construction years.

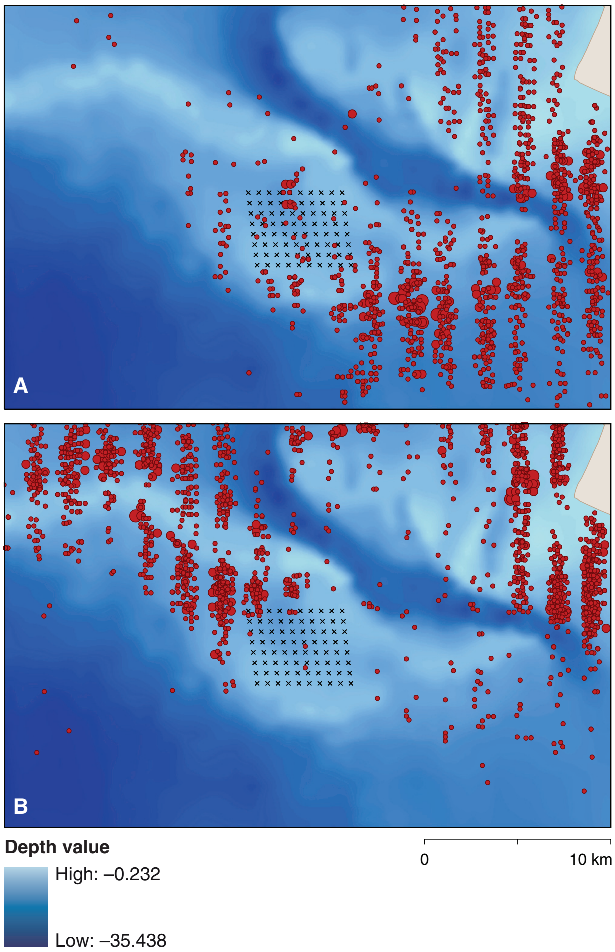


Figure 79. The distribution of Common Scoter in the area around Horns Rev wind farm, pre-construction (A) and post-construction (B). Observations are actual observations, concentrated along the pre-defined transect lines, which explains the observations being ordered along north-south oriented lines.

A comparison of the pre- and post-construction frequency distribution of Common Scoter at increasing distances from the wind turbines was made, based on data from all surveys. Based on the analysis of distance frequency distributions of all observations out to a distance of 8 km from the wind farm showed that the distance interval between 0 and 500 m from any turbine was used by a slightly higher percentage of the birds during pre-construction as compared to the post-construction phase. In the increasing distance intervals from 500 m to 6 km a higher percentage of the birds were recorded during the post-construction phase than during the pre-construction phase (Fig. 80).

A direct disturbance effect out to a distance of 8 km from the turbines is regarded as highly unlikely. An explanation for the above results involves the patchiness of the habitat exploited by Common Scoter. The species is highly gregarious, so birds tend to aggregate in local concentrations in response to rich feeding patches, and probably react as groups to changes in local foraging success. Since substantial distances may separate these patches, responses to declining feeding success (including, for example, increases in human disturbance) at one site may result in local abandonment of one area in favour of a distant feeding area. These feeding areas may be less suitable than the original ones because food intake rates are decreased as a result of increased bird densities and hence competition, deeper water or lower food quality (Nehls & Ketzenberg 2002).

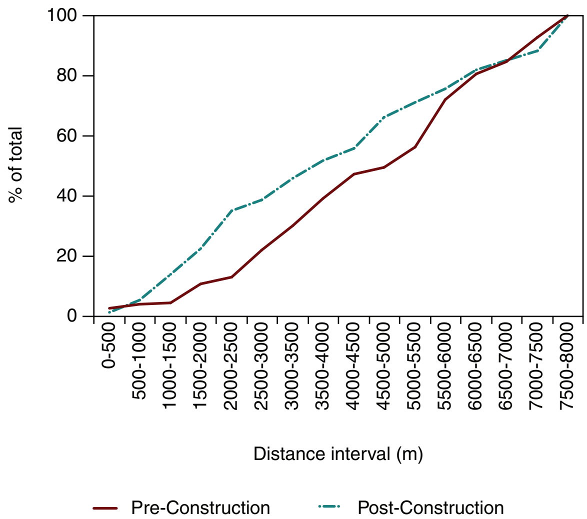


Figure 80. Cumulated frequency distribution of Common Scoter around the Horns Rev wind farm, calculated by distance to nearest wind turbine in 500 m intervals, pre- and post-construction. Data was weighted by numbers and based on birds observed within 8 km of the wind turbines in the months from December to April (both included).

The statistical significance of the change in distribution between the pre- and post-construction phases was tested using data from March between 2000 and 2005, comparing bird encounter rates per surveyed transect kilometre, tested using a students t-test (Fig. 81). The analysis showed no significant difference between the pre- and post construction phases, but with a tendency for increased numbers of birds in the wind farm area after the erection of the turbines. This shift is caused by the overall change in distribution that was observed through the study period.

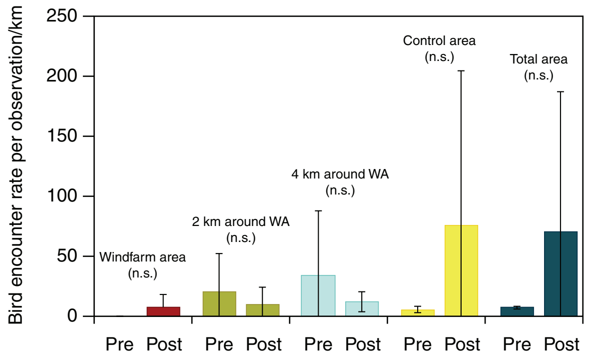


Figure 81. Comparison of pre- and post-construction Common Scoter encounter rate per survey effort (corrected for observer coverage) at Horns Rev for the wind farm area, the 2 and 4 km zones around the farm, the control area and the total area respectively. 95% confidence intervals and level of statistical significance are given.

Herring Gull *Larus argentatus*

Herring Gulls showed a reduced avoidance of the wind farm area after erection of the turbines. Pre-construction D-values based on flocks of -0.75, -0.63 and -0.48 for the 0, 2 and 4 km zones around the farm were found, with corresponding post-construction D-values of -0.19, -0.17 and -0.16 (Tables 25 and 26). When calculated on number of individuals the tendency for reduced avoidance of the wind farm area was also found (Tables 23 and 24).

A calculation of the cumulated percentage of number of Herring Gulls within distance intervals of 500 m from nearest wind turbine, out to a distance of 8 km, was made on the basis of pre- and post-construction data (Fig. 82). A comparison between the two scenarios showed a significant difference between the pre- and post-construction phase when calculated on the basis of number of clusters, using a Kolmogorov-Smirnov Two-sample test (Pr > KSa < 0.0001, with maximum difference between the pre- and post-construction phase found at a distance of 3 km, and with generally higher post-construction percentages close to the turbines out to a distance of 5.0 to 5.5 km. From that point pre-construction percentages were higher than the post-construction values.

The statistical significance of this indication of a change in distribution between the pre- and post-construction phases was tested using data from March between 2000 and 2005, comparing bird encounter rates per surveyed transect kilometre, tested using a students t-test (Fig. 83). The analysis showed no significant difference between the pre- and post construction phases. Herring Gulls showed increased preference for the wind farm area during the construction phase (Christensen et al. 2003). The above results conclude that this increased attraction did not continue after the construction of the wind farm.

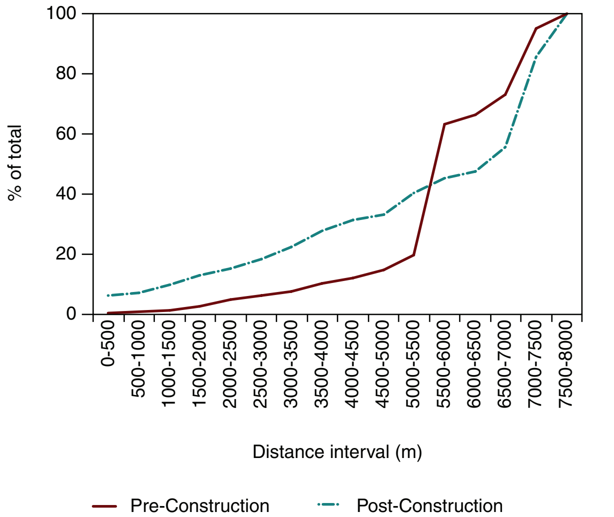


Figure 82. Cumulated frequency distribution of Herring Gull around the Horns Rev wind farm, calculated by distance to nearest wind turbine in 500 m intervals, pre- and post-construction. Data was weighted by numbers and based on birds observed within 8 km of the wind turbines in the months from December to April (both included).

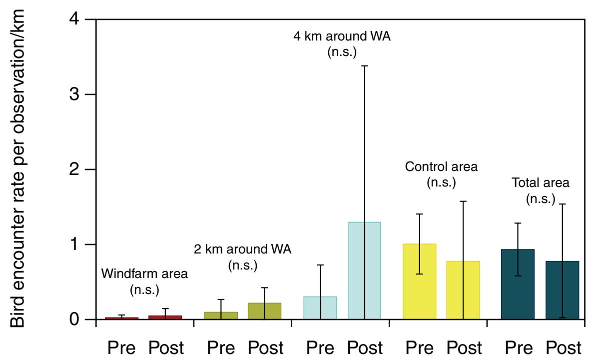


Figure 83. Comparison of pre- and post-construction Herring Gull encounter rate per survey effort (corrected for observer coverage) at Horns Rev for the wind farm area, the 2 and 4 km zones around the farm, the control area and the total area respectively. 95% confidence intervals and level of statistical significance are given.

Little Gull *Larus minutus*

Little Gull showed a shift from avoidance to preference for the wind farm area. Due to the low number of records during the pre-construction period the avoidance of the wind farm area failed to reach levels that were statistically significant. The result from post-construction surveys showed a significant preference for the wind farm area, but also when including the 2 and 4 km zones around the wind farm. D-values based on clusters for the wind farm area increased from –0.22 to 0.17, and similarly increase from –0.09 to 0.37 when including the 2 km zone and from 0.03 to 0.41 when including the 4 km zone. This indication was more pronounced when calculated on the basis of individuals (Tables 23 to 26).

The statistical significance of this indication of a change in distribution between the pre- and post-construction phases was tested using data from March between 2000 and 2005, comparing bird encounter rates per surveyed transect kilometre, tested using a students t-test (Fig. 84). The analysis showed no significant difference between the pre- and post construction phases for the wind farm area and the 4 km distance zone, but with a statistically significant increase in encounter rates during post-construction for the 2 km distance zone. Thus no firm conclusions can be drawn for this species.

Arctic/Common Tern *Sterna paradisaea/hirundo*

Arctic/Common Tern showed a shift from a selection value close to 0 (neutral), indicating that the selection for the wind farm area was almost equal to the preference for the entire study area, for the pre-construction situation to total absence of these species for the wind farm area in the post-construction situation, with a D-value of -1.00 (Tables 23 to 26). When including the 2 and 4 km zones around the wind farm the pattern was different. Here, for both distance zones, the selection values based on clusters changed from -0.20 and -0.07 for the 2 and 4 km zones respectively in the pre-construction phase to 0.13 and 0.11 in the post-construction phase.

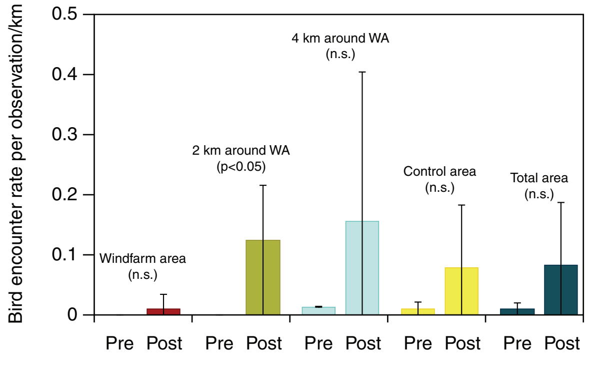


Figure 84. Comparison of pre- and post-construction Little Gull encounter rate per survey effort (corrected for observer coverage) at Horns Rev for the wind farm area, the 2 and 4 km zones around the farm, the control area and the total area respectively. 95% confidence intervals and level of statistical significance are given.

A calculation of the cumulated percentage of number of Arctic/Common Terns within distance intervals of 500 m from nearest wind turbine, out to a distance of 8 km, was made on the basis of pre- and post-construction data (Fig. 85). A comparison between the two scenarios showed a significant difference between the pre- and post-construction phase when calculated on the basis of number of clusters, using a Kolmogorov-Smirnov Two-sample test ($Pr > KSa < 0.0057$), with maximum difference between the pre- and post-construction phase found at a distance of 5 km, and with generally lower post-construction percentages close to the turbines out to a distance of 1.0 km. From that point post-construction percentages were higher than the pre-construction values, although values for the closest distance intervals did not differ greatly.

The statistical significance of this change in distribution between the pre- and post-construction phases was tested using data from April and May between 2000 and 2005, comparing bird encounter rates per surveyed transect kilometre, tested using a students t-test (Fig. 86). The analysis showed no significant difference between the pre- and post construction phases, but within the wind farm area there was total absence of Arctic/Common Terns during the post-construction phase for the selected months. Because of large variation in the data set it was not possible to demonstrate significant changes between pre- and post-construction encounter rates.

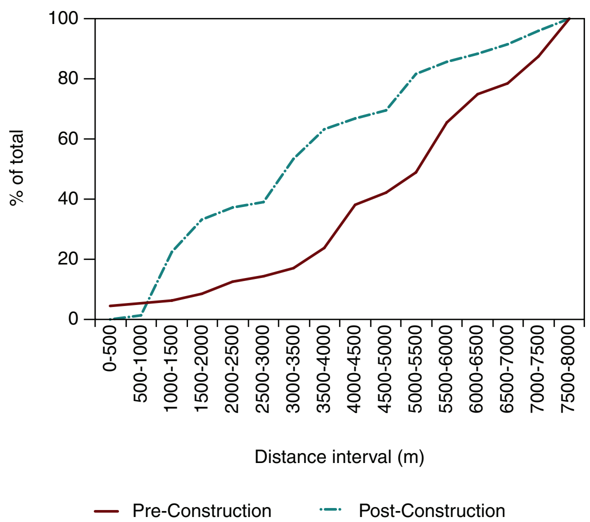


Figure 85. Cumulated frequency distribution of Arctic/Common Tern around the Horns Rev wind farm, calculated by distance to nearest wind turbine in 500 m intervals, pre- and post-construction. Data was weighted by numbers and based on birds observed within 8 km of the wind turbines in the months from December to April (both included).

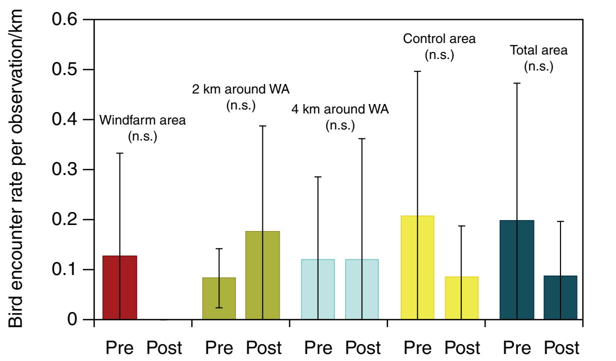


Figure 86. Comparison of pre- and post-construction Arctic/Common Tern encounter rate per survey effort (corrected for observer coverage) at Horns Rev for the wind farm area, the 2 and 4 km zones around the farm, the control area and the total area respectively. 95% confidence intervals and level of statistical significance are given.

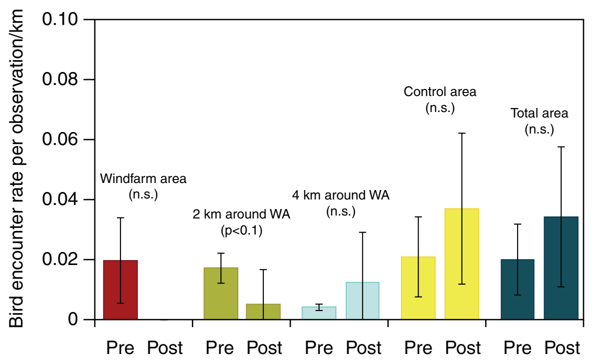


Figure 87. Comparison of pre- and post-construction Guillemot/Razorbill encounter rate per survey effort (corrected for observer coverage) at Horns Rev for the wind farm area, the 2 and 4 km zones around the farm, the control area and the total area respectively. 95% confidence intervals and level of statistical significance are given.

Guillemot *Uria aalge/* Razorbill *Alca torda*

Guillemots/Razorbills showed an increased avoidance of the wind farm area, in particular for the wind farm area itself, but to a smaller degree also when including the adjacent 2 and 4 km zones, with pre-construction D-values, based on clusters, of –0.15, -0.17 and -0.07 for the three distance zones, as compared to post-construction D-values of –0.70, -0.43 and –0.22 for the three zones (Tables 25 and 26). Similar increased post-construction avoidance was found when calculating on the basis of individual birds (Tables 23 and 24).

The statistical significance of this change in distribution between the pre- and post-construction phases was tested using data from February, March and April between 2000 and 2005, comparing bird encounter rates per surveyed transect kilometre, tested using a students t-test (Fig. 87). The analysis showed no significant difference between the pre- and post construction phases, but within the wind farm area there was total absence of Razorbill/Guillemot during the post-construction phase for the selected months. Because of large variation in the data set it was not possible to demonstrate significant changes between pre- and post-construction encounter rates.

4.1.4 Utilisation of the Nysted wind farm area and surroundings by birds, pre- and post-construction of wind turbines

A total of 32 surveys of birds have been carried out in Nysted area between August 1999 and December 2005. The wind farm construction phase was initiated in the autumn of 2002, and thus the last aerial survey covering the pre-construction phase was in August 2002. The operational (post-construction) phase started in autumn of 2003, and thus the first aerial survey data obtained during wind farm operation was in December 2003.

From the pre-construction phase a total of 21 aerial surveys are available, was compared to 8 post-construction surveys. During the pre-construction phase aerial surveys were performed from August through November. These autumn surveys were ceased during the post-construction phase.

For the purpose of analysing potential differences between the pre- and post-construction phases it was decided to use survey data from comparable months. Since the eight post-construction phase surveys were carried out from December into April, pre-construction phase surveys from these corresponding months were chosen. A total of 12 pre-construction surveys are available from these months (see Kahlert et al. 2006).

Red-throated/Black-throated Diver *Gavia stellata/arctica*

Divers occurred in the Nysted study area in low numbers. The overall distribution pattern of pre- and post-construction observations was similar, and local changes in distribution around the wind farm were not apparent based on cumulated distribution maps (Fig. 47).

The selectivity indices for the wind farm area was +0.36 during pre-construction when calculated on the basis of number of clusters, decreasing to -0.54 for the post-construction phase (Tables 27 and 29). When including the 2 km zone around the wind farm the corresponding values were +0.14 for the pre-construction phase as compared to -0.23 for the post-construction phase. When including the 4 km zone there was almost no difference between the selectivity indices, with +0.29 for the pre-construction phase and +0.24 for the post-construction phase (Table 27 and 29). A very similar pattern was found when calculating selectivity indices on the basis of number of individuals (Table 28 and 30).

Table 27. Percentage of birds (number of clusters) encountered in the Nysted wind farm area (MA) based on 12 pre-construction aerial surveys, as compared to the entire survey area, and in wind farm area plus zones of 2 and 4 km radius from the wind farm site (MA+2 and MA+4). Also shown are the total numbers of birds for each species/species group recorded throughout the surveys from the total study area from the pre-construction period (N). For each species and area, the Jacobs Index value (D) is given which varies between -1 (complete avoidance) and 1 (complete selection). The last column for each species category and area is the probability that these encounter rates differ from those of the entire area, based on one sample χ^2-tests. Values (P) are probabilities using standard statistical notation, n.s. represents P > 0.05, * P<0.05, ** P<0.01, *** P<0.001.

Species	MA	D for MA+0	P	MA+2	D for MA+2	P	MA+4	D for MA+4	P	N
Diver sp.	4.42	0.36	n.s.	8.84	0.14	n.s.	22.65	0.29	**	181
Mute Swan	0.26	-0.79	***	0.39	-0.90	***	0.77	-0.91	***	777
Goldeneye	0.22	-0.82	*	0.43	-0.89	***	1.95	-0.78	***	462
Long-tailed Duck	11.09	0.71	***	29.16	0.70	***	44.38	0.67	***	2037
Common Eider	3.61	0.27	***	11.73	0.29	***	23.33	0.31	***	1663
Common Scoter	5.03	0.42	*	22.01	0.59	***	40.88	0.62	***	159
Red-breasted Merganser	0.95	-0.38	n.s.	3.61	-0.33	*	9.30	-0.22	*	527
Herring Gull	1.34	-0.23	**	3.31	-0.37	***	8.52	-0.27	***	3358
Great black-backed Gull	1.22	-0.27	n.s.	3.98	-0.28	n.s.	8.87	-0.25	*	327
% of total survey cov.	2.11			6.86			13.83			

Table 28. Percentage of birds (number of individuals) encountered in the Nysted wind farm area (MA) based on 12 pre-construction aerial surveys, as compared to the entire survey area, and in wind farm area plus zones of 2 and 4 km radius from the wind farm site (MA+2 and MA+4). Also shown are the total numbers of birds for each species/species group recorded throughout the surveys from the total study area from the pre-construction period (N). For each species and area, the Jacobs Index value (D) is given which varies between -1 (complete avoidance) and 1 (complete selection). The last column for each species category and area is the probability that these encounter rates differ from those of the entire area, based on one sample χ^2-tests. Values (P) are probabilities using standard statistical notation, n.s. represents P > 0.05, * P<0.05, ** P<0.01, *** P<0.001.

Species	MA	D for MA+0	P	MA+2	D for MA+2	P	MA+4	D for MA+4	P	N
Diver sp.	3.98	0.32	n.s.	8.37	0.11	n.s.	20.32	0.23	**	251
Mute Swan	0.07	-0.93	***	0.11	-0.97	***	0.20	-0.98	***	9457
Goldeneye	0.01	-0.99	***	0.34	-0.91	***	0.59	-0.93	***	7978
Long-tailed Duck	7.62	0.59	***	19.57	0.54	***	30.32	0.46	***	9345
Common Eider	0.94	-0.39	***	5.37	-0.13	***	13.87	0.00	n.s.	24069
Common Scoter	14.04	0.77	***	21.18	0.57	***	40.33	0.62	***	1624
Red-breasted Merganser	0.47	-0.64	***	2.64	-0.46	***	6.36	-0.41	***	1478
Herring Gull	0.82	-0.45	***	1.46	-0.67	***	6.24	-0.41	***	14138
Great Black-backed Gull	0.92	-0.40	n.s.	3.23	-0.38	***	6.61	-0.39	***	651
% of total survey cov.	2.11			6.86			13.83			

Table 29. Percentage of birds (number of clusters) encountered in the Nysted wind farm area (MA) based on 8 post-construction aerial surveys, as compared to the entire survey area, and in wind farm area plus zones of 2 and 4 km radius from the wind farm site (MA+2 and MA+4). Also shown are the total numbers of birds for each species/species group recorded throughout the surveys from the total study area from the pre-construction period (N). For each species and area, the Jacobs Index value (D) is given which varies between -1 (complete avoidance) and 1 (complete selection). The last column for each species category and area is the probability that these encounter rates differ from those of the entire area, based on one sample χ^2-tests. Values (P) are probabilities using standard statistical notation, n.s. represents P > 0.05, * P<0.05, ** P<0.01, *** P<0.001.

Species	MA	D for MA+0	P	MA+2	D for MA+2	P	MA+4	D for MA+4	P	N
Diver sp.	0.60	-0.54	n.s.	4.19	-0.23	n.s.	19.76	0.24	*	167
Mute Swan	0.00	-1.00	**	0.35	-0.90	***	1.04	-0.87	***	577
Goldeneye	0.66	-0.51	n.s.	1.75	-0.59	***	3.28	-0.63	***	457
Long-tailed Duck	4.06	0.35	***	13.61	0.39	***	25.16	0.38	***	1550
Common Eider	2.69	0.15	n.s.	8.78	0.16	**	22.02	0.30	***	1299
Common Scoter	1.59	-0.11	n.s.	1.59	-0.62	n.s.	15.87	0.11	n.s.	63
Red-breasted Merganser	2.26	0.07	n.s.	5.56	-0.08	n.s.	10.08	-0.15	n.s.	486
Herring Gull	1.27	-0.23	*	3.56	-0.31	***	7.46	-0.30	***	3002
Great Black-backed Gull	0.44	-0.64	n.s.	2.65	-0.44	n.s.	7.96	-0.27	n.s.	226
% of total survey cov.	1.99			6.51			13.13			

Table 30. Percentage of birds (number of individuals) encountered in the Nysted wind farm area (MA) based on 8 post-construction aerial surveys, as compared to the entire survey area, and in wind farm area plus zones of 2 and 4 km radius from the wind farm site (MA+2 and MA+4). Also shown are the total numbers of birds for each species/species group recorded throughout the surveys from the total study area from the pre-construction period (N). For each species and area, the Jacobs Index value (D) is given which varies between -1 (complete avoidance) and 1 (complete selection). The last column for each species category and area is the probability that these encounter rates differ from those of the entire area, based on one sample χ^2-tests. Values (P) are probabilities using standard statistical notation, n.s. represents P > 0.05, * P<0.05, ** P<0.01, *** P<0.001.

Species	MA	D for MA+0	P	MA+2	D for MA+2	P	MA+4	D for MA+4	P	N
Diver sp.	0.43	-0.65	n.s.	3.86	-0.27	n.s.	20.17	0.25	***	233
Mute Swan	0.00	-1.00	***	0.10	-0.97	***	0.34	-0.96	***	7065
Goldeneye	0.31	-0.74	***	0.65	-0.83	***	1.12	-0.86	***	4908
Long-tailed Duck	2.07	0.02	n.s.	7.21	0.06	*	15.26	0.09	***	7711
Common Eider	0.78	-0.44	***	3.97	-0.26	***	13.40	0.01	n.s.	11019
Common Scoter	2.25	0.06	n.s.	2.25	-0.50	***	28.09	0.44	***	534
Red-breasted Merganser	0.94	-0.36	**	2.71	-0.43	***	6.82	-0.35	***	1921
Herring Gull	0.28	-0.75	**	0.77	-0.80	***	2.56	-0.70	***	16562
Great Black-backed Gull	0.24	-0.79	*	1.46	-0.65	***	4.88	-0.49	***	410
% of total survey cov.	1.99			6.51			13.13			

A calculation of the cumulated percentage of number of divers within distance intervals of 500 m from nearest wind turbine, out to a distance of 5 km, was made on the basis of pre- and post-construction data (Fig. 88). A comparison between the two scenarios indicates a reduced utilisation of the wind farm area during the post-construction phase as compared to the pre-construction phase, extending out to a distance of 2 km from the turbines. However, there was no significant difference between the pre- and post-construction values when using a Kolmogorov-Smirnov Two-sample test (Pr > KSa 0.6297 based on number of clusters and Pr > KSa 0.2063 based on number of individuals).

Cormorant *Phalacrocorax carbo*

An analysis of the potential distribution impact of Cormorants from the wind farm was not possible because the autumn bird surveys were ceased during the post-construction phase. Cormorants were much more abundant in the study area during the autumn than during the spring.

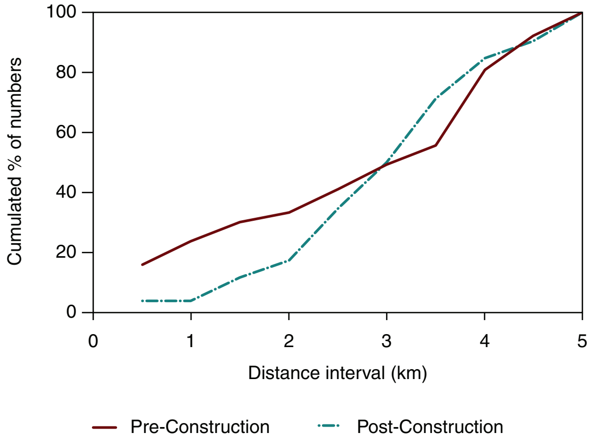


Figure 88. Cumulated frequency distribution of Red-throated/Black-throated Diver around the Nysted wind farm, calculated by distance to nearest wind turbine in 500 m intervals, pre- and post-construction. Data was weighted by numbers and based on birds observed within 5 km of the wind turbines in the months from December to April (both included).

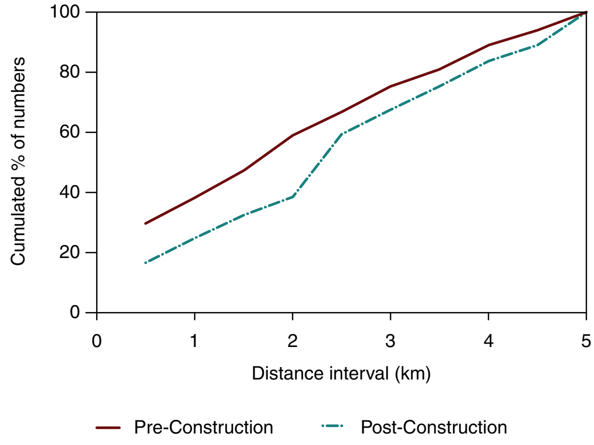


Figure 89. Cumulated frequency distribution of Long-tailed Duck around the Nysted wind farm, calculated by distance to nearest wind turbine in 500 m intervals, pre- and post-construction. Data was weighted by numbers and based on birds observed within 5 km of the wind turbines in the months from December to April (both included).

Long-tailed Duck *Clangula hyemalis*

Long-tailed Ducks occurred in relatively high numbers in the study area in winter and early spring. During the pre-construction phase the species was mainly found at Gedser Rev and in an offshore zone extending from Gedser to Hyllekrog. This general distribution pattern did not change during the post-construction phase (Fig. 60). In the near vicinity of the wind farm the distribution pattern changed from pre- to post-construction, with decreased relative densities in the wind farm area, while increased densities northwest and west of the wind farm.

This change was illustrated by changes in the selectivity indices pre- and post construction of the wind farm. The selectivity index for the wind farm area was +0.71 during pre-construction when calculated on the basis of number of clusters, decreasing to +0.35 for the post-construction phase. When including the 2 km zone around the wind farm the corresponding values were +0.70 for the pre-construction phase as compared to +0.39 for the post-construction phase. When including the 4 km zone the values were +0.67 for the pre-construction phase and +0.38 for the post-construction phase (Table 27 and 29). If the corresponding values are made on the basis of number of individuals the difference between the pre- and post-construction phases became slightly bigger, but describing a similar result (Table 28 and 30).

A calculation of the cumulated percentage of number of Long-tailed Ducks within distance intervals of 500 m from nearest wind turbine, out to a distance of 5 km, was made on the basis of pre- and post-construction data (Fig. 89). A comparison between the two scenarios indicates a reduced utilisation of the wind farm area during the post-construction phase as compared to the pre-construction phase, extending out to a distance of approximately 2 km from the turbines. The difference between the pre- and post-construction values was significant using a Kolmogorov-Smirnov Two-sample test ($Pr > KSa < 0.0001$).

The statistical significance of this apparent change in distribution between the pre- and post-construction phases was tested using data from January between 2000 and 2005, comparing bird encounter rates per surveyed transect kilometre, tested using a students t-test (Fig. 90). There were statistically significant reductions in numbers of bird encounters inside the wind farm and the 2 km broad zone around the farm comparing post-construction years with those prior to construction. There were weak indications of reductions in the 2 km - 4 km zone, but these failed to attain statistical significance.

Thus, Long-tailed Duck were displaced from the wind farm area and the surrounding waters out to 2 km. The most prominent reduction in relative density was found within the wind farm, with decreased difference between the pre- and post-construction phases with increased distance from the turbines, with a significant difference found out to at least 2 km from the wind farm. The density of Long-tailed Duck in the control zone increased significantly at the same time.

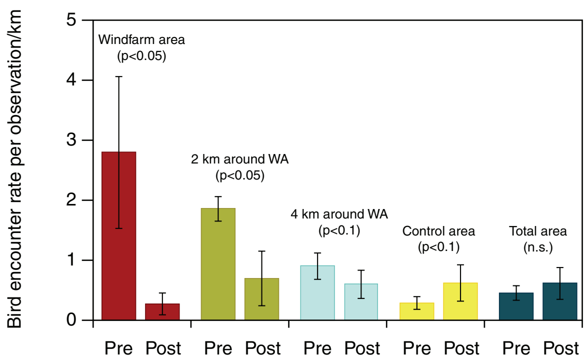


Figure 90. Comparison of pre- and post-construction Long-tailed Duck encounter rate per survey effort (corrected for observer coverage) at Nysted for the wind farm area, the 2 and 4 km zones around the farm, the control area and the total area respectively. 95% confidence intervals and level of statistical significance are given.

Common Eider *Somateria mollissima*

Common Eider was among the most numerous species in the study area. They were present in the area during all surveys, but mainly during autumn, late winter and early spring. The general distribution pattern changed little from pre- to post-construction of the wind farm, with the major concentrations at Gedser Rev and the offshore area south of Hyllekrog. The area just south of the wind farm was used by an increasing number of birds during the post-construction phase (Fig. 63).

A comparison between pre- and post construction selectivity indices, based on number of clusters, showed a slightly decreased selection for the wind farm and its 2 km zone, from +0.27 to +0.15 within the wind farm and from +0.29 to +0.16 when including the 2 km zone, while almost unchanged from +0.31 to +0.30 when including the 4 km zone around the wind farm (Table 27 and 29). A very similar pattern was found when calculating selectivity indices on the basis of individuals, but selectivity values generally decreased to negative for the wind farm area and the 2 km zone because cluster sizes were smaller in the wind farm area than in the rest of the study area (Table 28 and 30).

A calculation of the cumulated percentage of number of Common Eiders within distance intervals of 500 m from nearest wind turbine, out to a distance of 5 km, was made on the basis of pre- and post-construction data (Fig. 91). A comparison between the two scenarios showed significant differences between the pre- and post-construction phase, using a Kolmogorov-Smirnov Two-sample test (Pr > KSa 0.0022). The maximum difference between pre- and post-construction values was found at a distance of 2.5 km, with only slight percentage differences at the 500 m and 1 km distance interval. For this reason, it is reasonable to conclude that the difference can not be related to the construction of the wind farm. Thus there is no indication that Common Eider distribution has been altered by the presence of the Nysted wind farm.

Common Scoter *Melanitta nigra*

As a result of the relatively low number of observations of Common Scoter nothing conclusive can be said about difference between pre- and post-construction distribution of the species in the Nysted study area (Fig. 65).

A comparison between pre- and post construction selectivity indices, based on number of clusters, showed a decreased selection, both for the wind farm and its 2 km and 4 km zones, from +0.42 to -0.11 within the wind farm, from +0.59 to -0.62 when including the 2 km zone and from +0.62 to +0.11 when including the 4 km zone (Table 27 and 29). A similar pattern was found when calculating selectivity indices on the basis of individuals (Table 28 and 30).

A calculation of the cumulated percentage of number of Common Scoters within distance intervals of 500 m from nearest wind turbine, out to a distance of 5 km, was made on the basis of pre- and post-construction data (Fig. 92). A comparison between the two scenarios showed significant difference between the pre- and post-construction phase, using a Kolmogorov-Smirnov Two-sample test (Pr > KSa 0.0178). A difference was seen out to a distance of 3 km, with decreased percentages of birds present in that zone during the post-construction phase as compared to the pre-construction phase.

Red-breasted Merganser *Mergus serrator*

Red-breasted Mergansers were mainly found in the lagoon, with a more restricted distribution in the offshore areas south of the lagoon. There was no general difference between pre- and post-construction distribution. In the wind farm area and its immediate vicinity the species seemed to become more abundant during the post-construction phase (Fig. 68).

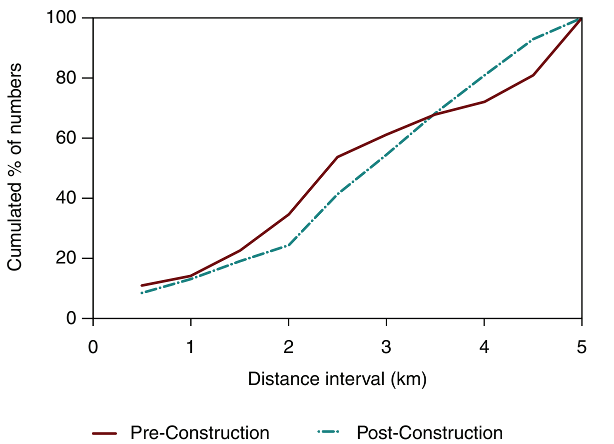


Figure 91. Cumulated frequency distribution of Common Eider around the Nysted wind farm, calculated by distance to nearest wind turbine in 500 m intervals, pre- and post-construction. Data was weighted by numbers and based on birds observed within 5 km of the wind turbines in the months from December to April (both included).

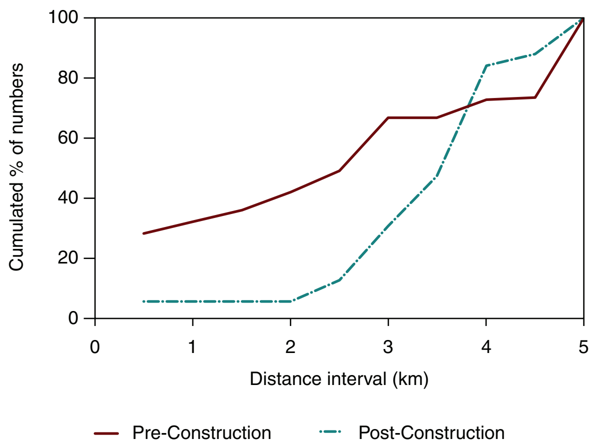


Figure 92. Cumulated frequency distribution of Common Scoter around the Nysted wind farm, calculated by distance to nearest wind turbine in 500 m intervals, pre- and post-construction. Data was weighted by numbers and based on birds observed within 5 km of the wind turbines in the months from December to April (both included).

A comparison between pre- and post-construction selectivity indices, based on number of clusters, showed an increased selection for the wind farm as well as its 2 and 4 km zones, from -0.38 to +0.07 within the wind farm, from -0.33 to -0.08 when including the 2 km zone and from -0.22 to -0.15 when including the 4 km zone (Table 27 and 29). A similar pattern was found for the wind farm area when calculating selectivity indices on the basis of individuals, but with little difference noticed for the 2 and 4 km zones (Table 28 and 30).

A calculation of the cumulated percentage of number of Red-breasted Mergansers within distance intervals of 500 m from nearest wind turbine, out to a distance of 5 km, was made on the basis of pre- and post-construction data (Fig. 93). A comparison between the two scenarios showed non-significant difference between the pre- and post-construction phase when calculating on number of clusters, using a Kolmogorov-Smirnov Two-sample test (Pr > KSa 0.1288), but significant when calculated on the basis of number of individuals (Pr > KSa 0.0109). A difference was seen out to a distance of 3.5 km. There is, based on the above tests, an indication that Red-breasted Merganser utilises the wind farm area and its close vicinity to a higher extent during the post-construction phase than during the pre-construction phase.

Herring Gull *Larus argentatus*

Herring Gull was among the most abundant species in the study area, present throughout the year. Herring Gulls were most numerous in the southwestern parts of the study area and in coastal areas, particularly along the sand bar and the Rødsand Rev. During the breeding season numerous birds were seen around breeding colonies on islands in the western part of the lagoon (Fig. 71). The most apparent change in distribution of Herring Gulls between the pre- and post-construction phases was that the southwesten parts of the study area was used to an increasing degree.

A comparison between pre- and post construction selectivity indices, based on number of clusters, showed almost unchanged selectivity for the wind farm as well as its 2 and 4 km zones, from -0.23 to -0.23 within the wind farm, from -0.37 to -0.31 when including the 2 km zone and from -0.27 to -0.30 when including the 4 km zone (Table 27 and 29). If selectivity indices were calculated on the basis of individuals the picture was different, as it showed a tendency for decreased selectivity for the wind farm as well as for the 2 and 4 km zones around it, with the following corresponding values: from -0.45 to -0.75 within the wind farm, from -0.67 to -0.80 when including the 2 km zone and from -0.41 to -0.70 when including the 4 km zone (Table 28 and 30).

A calculation of the cumulated percentage of number of Herring Gulls within distance intervals of 500 m from nearest wind turbine, out to a distance of 5 km, was made on the basis of pre- and post-construction data (Fig. 94). A comparison between the two scenarios showed non-significant difference between the pre- and post-construction phase when calculating on number of clusters, using a Kolmogorov-Smirnov Two-sample test (Pr > KSa 0.1256), but significant when calculated on the basis of number of individuals (Pr > KSa < 0.0001). The maximum difference was found at a distance of 2.5 km, but with little difference at the close distance intervals.

The statistical significance of the difference in distribution between the pre- and post-construction phases was tested using data from March between 2000 and 2005, comparing bird encounter rates per surveyed transect kilometre, and tested using a students t-test (Fig. 95). The analysis showed that no significant difference can be found in the wind farm area, in the 4 km zone or in the control zone, but with a significantly higher encounter rate in the 2 km zone. Given the inconsistency between distance zones we conclude that the wind farm had no effect on the distribution of Herring Gulls, neither attraction nor avoidance.

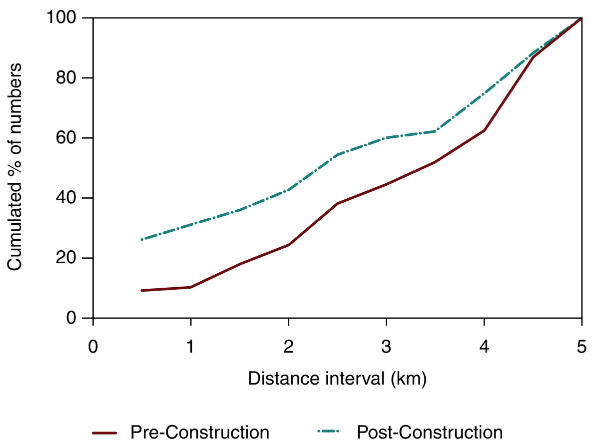


Figure 93. Cumulated frequency distribution of Red-breasted Merganser around the Nysted wind farm, calculated by distance to nearest wind turbine in 500 m intervals, pre- and post-construction. Data was weighted by numbers and based on birds observed within 5 km of the wind turbines in the months from December to April (both included).

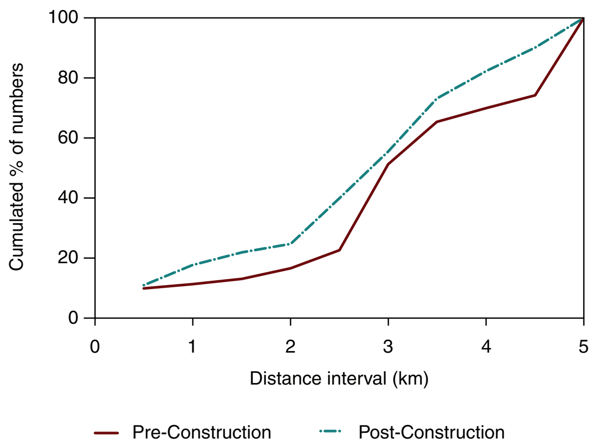


Figure 94. Cumulated frequency distribution of Herring Gull around the Nysted wind farm, calculated by distance to nearest wind turbine in 500 m intervals, pre- and post-construction. Data was weighted by numbers and based on birds observed within 5 km of the wind turbines in the months from December to April (both included).

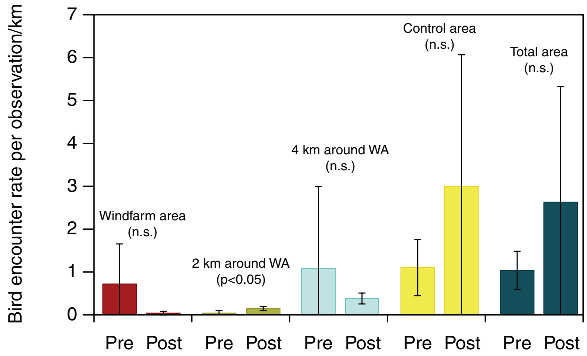


Figure 95. Comparison of pre- and post-construction Herring Gull encounter rate per survey effort (corrected for observer coverage) at Nysted for the wind farm area, the 2 and 4 km zones around the farm, the control area and the total area respectively. 95% confidence intervals and level of statistical significance are given.

Thus, during the operational phase, the wind farm did not alter the distribution of Herring Gulls in the study area, although the species had shown increased selectivity for the wind farm area during the construction phase (Kahlert et al. 2004).

4.2 Migratory bird studies at Nysted

Johnny Kahlert, Mark Desholm, Ole Therkildsen, Søren Haugaard

4.2.1 Migration pattern

The overall migration patterns were depicted in Fig. 96, from which specific information on the lateral flight patterns of species was extracted for the following base-line description of the migration patterns. Both during autumn and spring, migration was dominated by the westerly and easterly migrating waterbirds.

4.2.1.1 Species account

This section updates the information about the occurrence of various species or species groups, which migrate or move locally in the study area during spring and autumn. Hence, the results from present study undertaken from the observation tower during the period 1999-2005 were added to the existing historical data upon which the EIA was primarily based. The section focuses on numbers, the potential international importance of the area, local importance of individual species (Fig. 97), phenology, diurnal pattern, flock size and flight patterns laterally and vertically.

Cormorant *Phalacrocorax carbo*

The Cormorants, which occur at Rødsand belong to the sub-species *P. c. sinensis*. Cormorants occur at Rødsand both during spring and autumn. However, it is during the autumn that they occurred in greatest abundance with up to 5,200 individuals present (Table 31). The mean number of cormorants for the seven most recent autumn periods (4,232) corresponded to 1.2 to 1.5% of the biogeographical population. Thus, the study area is of international importance for this species.

Cormorants were already present in large numbers when the study started each autumn about 1 September (Fig. 98), as they were likely to have arrived during the summer after the breeding season. In late September, numbers declined markedly and again in early October, when Cormorants left the study area to undertake their annual migration to the wintering areas mainly around the Mediterranean Sea.

Cormorants are considered as almost exclusively day-active. In the study area, the Rødsand Sandbar constituted a consistent nocturnal roost site. During daytime, Cormorant was the secondmost numerously occurring species crossing the buoy-transect east of the wind farm area, and constituted one fifth of all western migrating birds during the base-line study (Fig. 97A). Although, Cormorants occasionally occurred in large flocks of several thousand individuals, the species were mostly observed in flocks of between 1 and 10 individuals (93% of all flocks). Mean flock size was 1.80 (95% confidence limits [1.74; 1.87] N = 3,468)

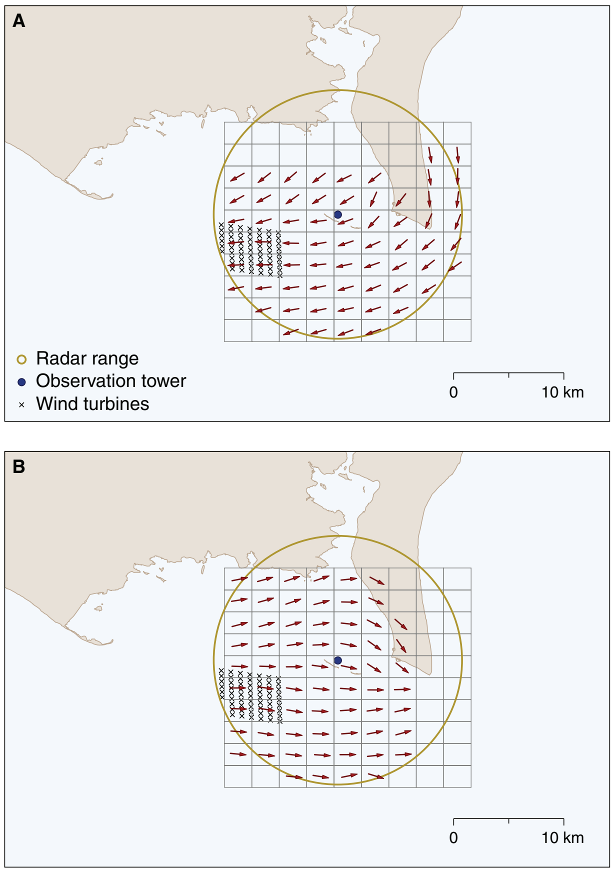


Figure 96. Mean orientation of all bird tracks (arrows) in the Nysted study area detected by radar and longer than 5 km during autumn (A) and spring (B).

Table 31. Maximum numbers of Cormorants counted per season from Rødsand northeast of the Nysted Offshore Wind Farm, during the autumn periods in 1999-2005. *) The study was terminated mid-September.

1999	2000	2001	2002	2003	2004	2005	Mean [95% confidence limits] 1999-2005
5,011	4,300	5,170	2,150*	4,390	3,400	5,200	4,232 [3,199; 5,264]

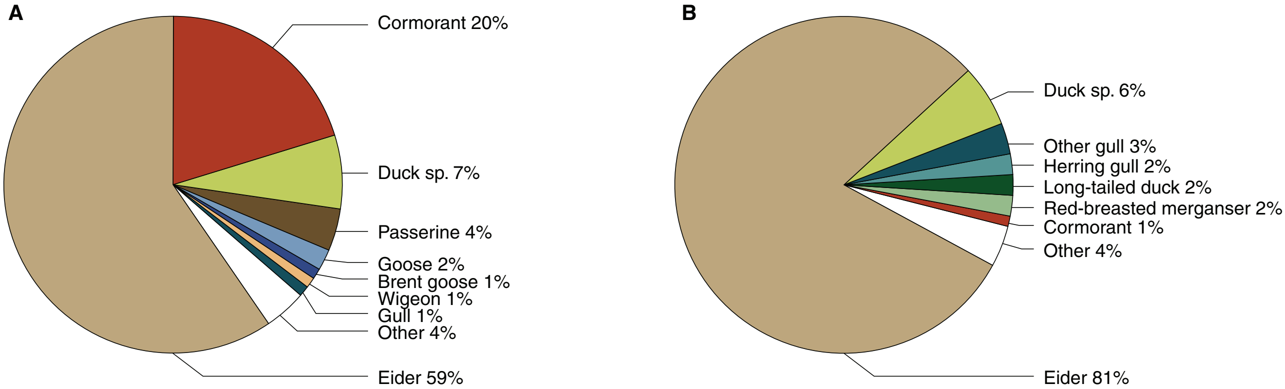


Figure 97. Relative species composition of all visual bird observations passing west in autumn 2004 (A) and passing east in spring 2004 (B) on the buoy-transect east of the Nysted Offshore Wind Farm.

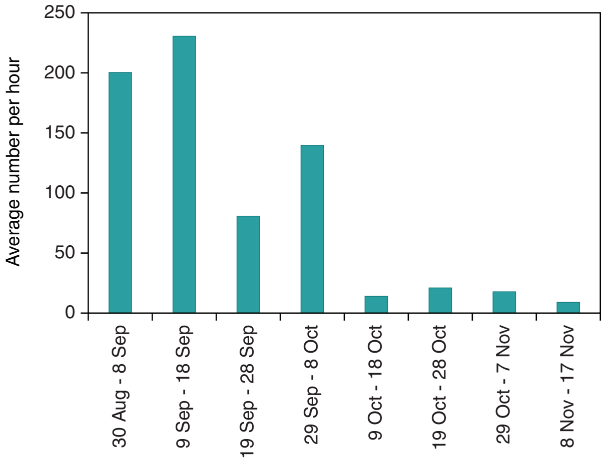


Figure 98. Autumn migration intensity of westerly migrating Cormorants on the buoy-transect east of the Nysted Offshore Wind Farm broken into 10-day periods.

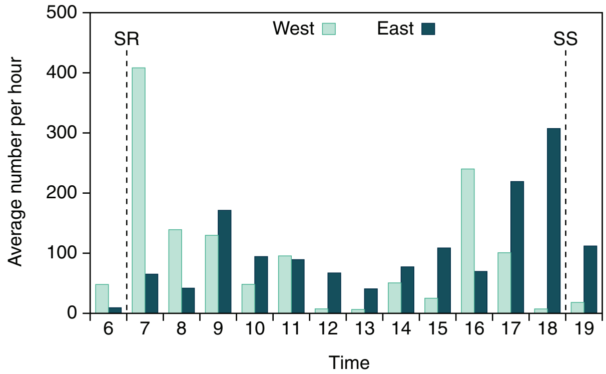


Figure 99. Autumn migration intensity of westerly and easterly migrating Cormorants on the buoy-transect east of the Nysted Offshore Wind Farm broken into hourly intervals. The time represents the following periods: 6 = 6:00-6:59, SR = sunrise and SS = sunset.

Cormorants did not occur equal abundant throughout the day (Fig. 99). Just after sunrise, substantial numbers crossed the buoy-transect in a westerly direction, as they left the nocturnal roost at the Rødsand Sandbar to forage in offshore areas. During the day, eastern migrating Cormorants became more abundant as cormorants gradually returned to the roost. In the afternoon, another peak count occurred amongst westerly migrating birds, seemingly as a result of another departure from the roost. In the subsequent period until sunset, cormorants finally returned to Rødsand to stay on the roost during the night. Accordingly, there seemed to be two major foraging bouts, one during the morning, and one in the late afternoon. There were no indications from the radar observations of nocturnal foraging bouts.

Social foraging events of hundreds or even thousands of Cormorants were recorded by radar. This facilitated a detailed description of Cormorant foraging behaviour on a wide spatial scale (Fig. 100). Large social foraging events were never observed in the shallows north of the Rødsand Sandbar, but occurred in a rather unpredictable pattern offshore. This may not be surprising given that they were likely to follow schools of fish – see Desholm *et al.* 2001 for further details on foraging behaviour. In total, 89% of Cormorant flights occurred at altitudes lower than 30 m (N = 153 flocks), and the wind regime did not affect this pattern (Kahlert et al. 2000).

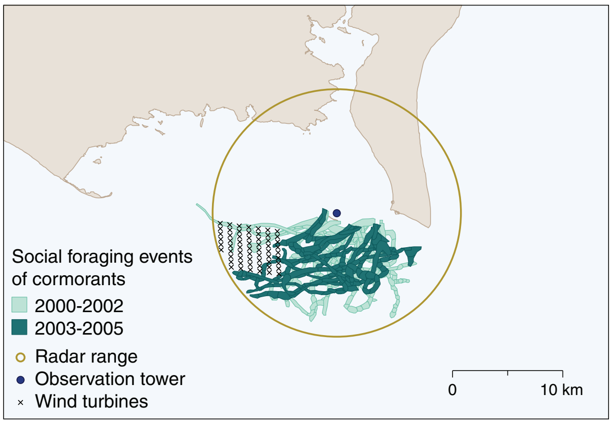


Figure 100. Social foraging events of Cormorants registered by radar from the observation tower in 2000, 2001 and 2002 (baseline) and 2003 (operation).

Geese *Anserinae*

Goose migration occurs both during autumn and spring. During autumn, Brent and Barnacle Goose were the most abundant species – 21 and 39% of all western-migrating geese, respectively. Both historical count data and estimates from the buoy-transect (Table 32) suggested that Barnacle Goose did not occur in international important numbers (threshold: 3,600 individuals, see Kahlert et al. 2006). However, there was some evidence that migrating Barnacle Geese may occasionally occur in the region in internationally important numbers. This may potentially involve the study area at Rødsand. Thus, on 9 October 2004, 42,000 Barnacle Geese were observed at Gedser Odde by local bird-watchers (www.dof-storstroem.dk). On the very same day, similar numbers were observed at the German island of Fehmarn southwest of the wind farm area (Koop 2004). Although, it is only indirect evidence, these observations suggest that 11.7% of the biogeographical population may have passed the study area. During spring, small numbers were observed at Rødsand.

During spring, the present study have suggested that up to 9,000 Brent Geese or 4.2% of the biographic population occur in the study area (see Kahlert et al. 2006). Both historical data and present estimates suggested that Brent Goose also occurs in internationally important numbers during autumn. The present estimate correponded to 2.0% of the biographic population.

While 92% of all autumn-migrating Barnacle Geese were observed on the buoy-transect during the period 9-18 October (peak in Fig. 101), Brent Goose migration mainly occurred during the period 9. September to 18. October (91% of all individuals). The spring migrating Brent Geese peak in late May (Desholm *et al.* 2003).

Geese are generally considered as daytime migrants. However, long-distance migrants such as Brent and Barnacle Geese may extend their migration into the dark hours (e.g. Green *et al.* 2002). During the day, the migration of geese comprised less than 5% of the total migration observed at the buoy-transect (Fig. 97). Mean flock size for autumn migrating Barnacle Geese was 27.65 (95% confidence limits [17.26; 44.30] N = 39), whereas flock size for Brent Goose was much lower 6.72 (95% confidence limits [5.87; 7.70] N = 268). During spring, mean flock size for Brent Goose was 107, and thus much larger than during autumn as typical for migrating Brent Geese in Southern Scandinavia (Hedenström *et al.* 2002). Migration of Barnacle Geese peaked just before noon and in the afternoon, whereas Brent Goose peaked in the morning and late afternoon (Fig. 102).

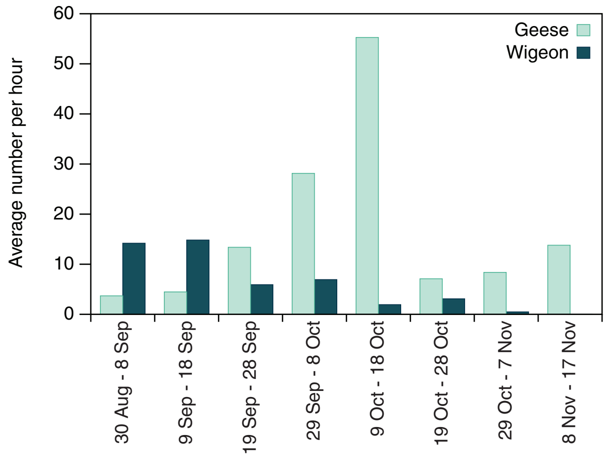


Figure 101. Autumn migration intensity of westerly migrating geese and Wigeons on the buoy-transect east of the Nysted Offshore Wind Farm broken into 10-day periods.

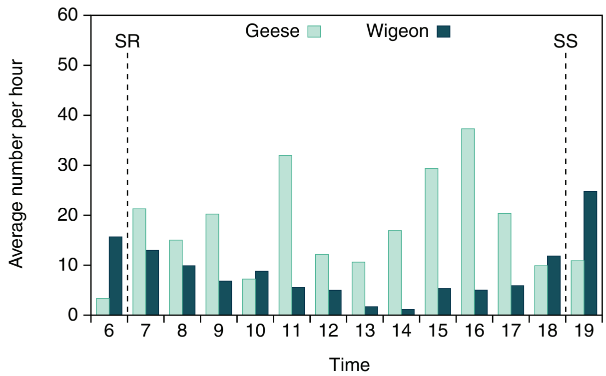


Figure 102. Autumn migration intensity of westerly migrating geese and Wigeons on the buoy-transect east of the Nysted Offshore Wind Farm broken into hourly intervals. The time represents the following periods: 6 = 6:00-6:59, SR = sunrise and SS = sunset.

Table 32. Total count numbers per season of migrating Barnacle and Brent Geese at Gedser Odde in 1988 (Christensen & Grell 1989) and at the buoy-transect east of the Nysted Offshore Wind Farm, 1999-2005 (present study). Numbers in brackets show the estimates during one migration season (autumn or spring). NC = not calculated, due to low numbers. *) Numbers mainly counted in the Rødsand Inlet during main migration period, May 2001.

	Gedser Odde autumn	Buoy-transect autumn	Buoy-transect spring
Barnacle Goose	2,398	2,353 (2,483)	31 (NC)
Brent Goose	4,735	3,450 (4,195)	9,056*

Daytime migration of geese occurred in two ways in the autumn, either as other waterbirds passing Gedser Odde in mainly a westerly direction or they were detected near the coastline of Falster heading in a southwesterly direction (Kahlert et al. 2004, 2005). During spring, the migration of Brent Geese mainly occurred north of the Rødsand Sandbar (Kahlert et al. 2002). Data from outside the Nysted Offshore Wind farm suggested that the vast majority of geese (and swans) migrated above 110 m (Blew et al. 2006).

Dabbling ducks

Historical data showed that Wigeon and Pintail were the most numerously occurring dabbling duck species at Gedser Odde during the autumn (Table 33). This pattern was confirmed also during the present study, although numbers were much smaller. If historical data were imposed into the present population estimates, both Wigeon and Pintail occurred in internationally important numbers. Markedly fewer Wigeon (and less than internationally important numbers) were estimated in the present study compared to 1988. Variable but lower reproduction since 1992 compared to 1980s (Clausager 2003) may explain the smaller "autumn-population" in recent years. The present estimate of autumn migrating Pintail numbers was close to threshold of international importance (0.9% of the biogeographical population).

Table 33. Total count numbers per season of migrating Wigeon and Pintail at Gedser Odde in 1988 (Christensen & Grell 1989) and at the buoy-transect east of the Nysted Offshore Wind Farm, 1999-2005 (present study). Numbers in brackets show the estimates during one migration season (autumn or spring). NC = not calculated, due to low numbers.

Species	Gedser Odde autumn	Buoy-transect autumn	Buoy-transect spring
Wigeon	21,057	4,333 (5,886)	122 (228)
Pintail	1,663	396 (515)	55 (NC)

The majority of Wigeon was observed in September (Fig. 101), which is somewhat surprising given that this species tend to be most abundant in Denmark in October (Olsen 1992). Wigeon is generally considered as a daytime migrant but is also known to migrate at night. The visual migration of Wigeon, which peaked at dusk indicated that some of the migration continues into the dark hours (Fig. 102). Overall, Wigeon constituted a small proportion (1%, Fig. 97A) of the entire visual migration observed at Rødsand. Wigeon occurred in a wide range of flock sizes (1-170) but mean flock size was 9.22 (95% confidence limits [8.12; 10.46], N = 279).

Although based on few observations during the autumn, Wigeon and Pintail tended to mainly migrate just south of the Rødsand Sandbar in a westerly direction, probably after they have passed Gedser Odde at close distance (Kahlert et al. 2004). Little data on flight altitude existed from boat surveys (Blew et al. 2006), which suggested that most Wigeon flew at altitudes less than 30 m.

Diving ducks

Amongst the diving ducks, it is only the Common Eider duck, which has been counted in substantial numbers both during spring and autumn in the study area. The present daytime mean estimate during the autumn was 235,000 individuals (Table 34). Desholm (2005b) also included nocturnal migration of Common Eiders and obtained a total estimate of the autumn migration of 345,000 individuals, which corresponded to 29-41% of the biogeographical population (see Kahlert et al. 2006).

The spring migration of Common Eiders has not been covered as intensively as the autumn migration. Less historical data existed (see Kahlert et al. 2000) and a relatively short period was covered in the present study. The present spring estimate from the buoy-transect was about half of the autumn estimate. However, spring migration had already commenced when the counts were initiated (see below) and hence migration before mid-March was not accounted for. In addition, the majority of Common Eiders migrated north of the Rødsand Sandbar, an area not covered by counts (Desholm et al. 2003).

Historical data suggested internationally important occurrences of Scaup *Aythya marila* (7,763 ind. corresponding to 2.5% of the present biogeographical population), which passed Gedser Odde during the autumn. The present study did not reveal any western migrating Scaups. During spring, nationally important numbers of wintering Long-tailed Ducks occur in the water south of Lolland and Falster (Kahlert et al. 2005). The presence of these birds was also associated with some local movements as well as an eastern-directed migration towards the breeding areas during the spring (March and April). In total, 1,768 were observed during spring in 2000 to 2005, which falls well short of any internationally important thresholds (theshold: 20,000 ind., see Kahlert et al. 2006).

Table 34. Total count numbers per season of migrating Common Eiders at Gedser Odde in 1988 (Christensen & Grell 1989), at the buoy-transect east of the Nysted Offshore Wind Farm, 1999-2005 (present study) and a total day- and nighttime estimate (Desholm 2005).

	Gedser Odde autumn	Buoy-transect autumn	Gedser Odde/Rødsand autumn	Buoy-transect spring
Time	Day	Day	Day + night	Day
Count	257,139	191,264	-	76,739
Mean estimate [95% conf. limits]	-	235,136 [164,895; 305,360]	345,000	119,673 [58,388; 180,958]

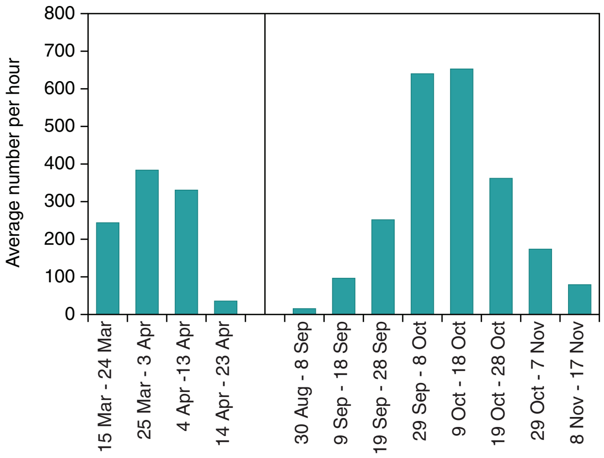


Figure 103. Autumn and spring migration intensity of westerly and easterly migrating Common Eiders on the buoy-transect east of the Nysted Offshore Wind Farm broken into 10-day periods.

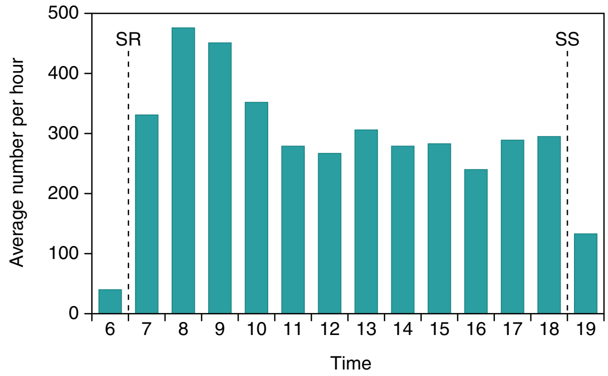


Figure 104. Autumn migration intensity of westerly migrating Common Eiders on the buoy-transect east of the Nysted Offshore Wind Farm broken into hourly intervals. The time represents the following periods: 6 = 6:00-6:59, SR = sunrise and SS = sunset.

Given the infrequent abundance of other diving duck species only Common Eider was considered in the following. The spring migration peaked from late March to the beginning of April, whereas during the autumn, the intensity of the Common Eider migration was highest between mid-September and mid-October (Fig. 103) with some annual variation (see previous reports). Common Eiders are mainly considered as daytime migrants although probably about 25% of the Common Eider migration occurs during darkness (Alerstam et al. 1974, Desholm 2005b). Common Eider dominated the entire daytime migration observed at the buoy transect especially in spring (Fig. 97). Common Eiders are highly gregarious during migration and occurred with a wide range of flock sizes (1-3,000 individuals), although during most of the time flock size was less than 100 individuals. Mean flock size was 15.92 (95% confidence limits [15.40; 16.46] N = 6,080). During the autumn, westerly orientated Common Eiders showed the highest intensity during mornings and a lower but fairly consistent intensity during the rest of the day, although this pattern may vary between days (Fig. 104).

During the autumn, Common Eiders passed Gedser Odde in a westerly direction and almost exclusively migrated south of the Rødsand Sandbar towards the wind farm area. During spring, the general migration pattern was quite different from the autumn as the majority of the waterbird migration occurred in a easterly direction north of the wind farm area towards Gedser Odde, where the birds would deflect markedly to the south to avoid crossing land, and then return to a easterly course at the tip of Gedser Odde.

Flight altitude of Common Eider over the open North Sea is generally low with a median between 0 and 5 m (Garthe & Hüppop 2004). The low flight altitude was confirmed in the Baltic Sea, where only ca. 10-20% of the Common Eiders occurred at altitudes of more than 30 m, however, dependent on wind conditions (Kahlert *et al.* 2000). Similarly, at Helgoland only 3% of all Common Eiders flew higher than 50 m, again depending on wind speed and direction (Dierschke & Daniels 2003).

Birds of prey *Falconiformes*

Birds of prey are like other terrestrial species funnelled into Gedser Odde during autumn. At the buoy-transect, it was mainly actively flying raptors that were observed such as Sparrowhawk, which was the most abundant species, but none of the species except Merlin *Falco columbarius* were counted in numbers comparable to the historical data from Gedser Odde (Table 35). During spring counts only 7 birds of prey were observed and this period was not analysed in further detail.

Table 35. Total count numbers per season of migrating birds of prey at Gedser Odde in 1988 (Christensen & Grell 1989) and at the buoy-transect east of the Nysted Offshore Wind Farm, 1999-2005 (present study). Numbers brackets show the estimates during autumn. NC = not calculated, due to low numbers.

Species	Gedser Odde autumn	Buoy-transect autumn
Red Kite *Milvus milvus*	67	9 (NC)
Sparrowhawk *Accipiter nisus*	5,917	272 (353)
Honey buzzard *Pernis apivorus*	2,702	
Buzzard *Buteo buteo*	2,154	60 (72)
Rough-legged Buzzard *Buteo lagopus*	4,109	
Osprey *Pandion haliaetus*	93	2 (NC)
Kestrel *Falco tinnunculus*	257	5 (NC)
Merlin *Falco columbarius*	80	72 (87)
All birds of prey	15,379	449 (577)

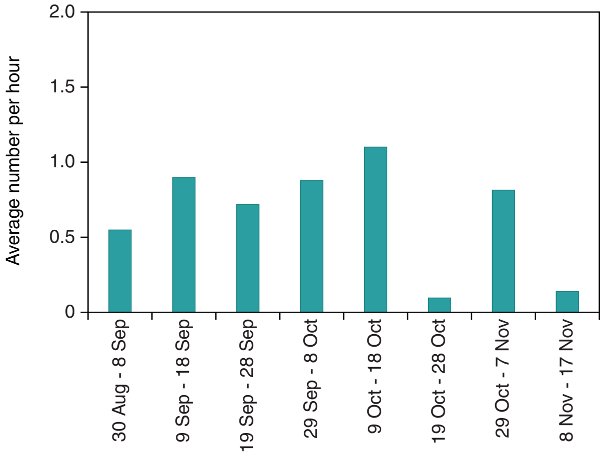


Figure 105. Autumn migration intensity of westerly migrating birds of prey on the buoy-transect east of the Nysted Offshore Wind Farm broken into 10-day periods.

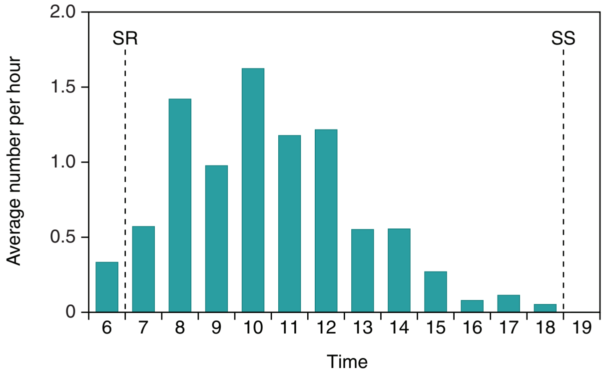


Figure 106. Autumn migration intensity of westerly migrating birds of prey on the buoy-transect east of the Nysted Offshore Wind Farm broken into hourly intervals. The time represents the following periods: 6 = 6:00-6:59, SR = sunrise and SS = sunset.

Birds of prey, mainly Buzzards *Buteo buteo* and Sparrowhawks *Accipiter nisus*, tended to occur most frequently in numbers during September until mid-October (Fig. 105). Birds of prey are all considered as daytime migrants, but constituted a small part (1‰) of the entire autumn migration at the buoy-transect. Most birds of prey (93%) were single individuals but up to 10 individuals were observed in a flock. Hence, mean flock size was low 1.08 (95% confidence limits [1.05; 1.11] N = 382). Most birds of prey were observed during morning until about noon (Fig. 106) – slightly different from previous results, when for example Sparrowhawks were mainly observed during the middle of the day (Kahlert et al. 2000).

The terrestrial bird species, including birds of prey, mainly take a southerly course, when they leave Gedser Odde during autumn (Grell 1998, Desholm et al. 2001). This was confirmed by the present estimate of the total migration of birds of prey, which constituted only 4% of the autumn numbers counted at Gedser Odde (Table 35). West of the wind farm, Hyllekrog is also a site from which there is a migration corridor of birds of prey. According to Skov et al. (1998), birds from the Hyllekrog area and the coastline further east mainly migrate in a southwesterly direction directly towards the German island of Fehmarn.

The active flying birds of prey generally fly at low altitudes (< 100 m), where they would occasionally hunt passerines at the Rødsand sandbar, and thus are more likely to be observed at the buoy-transect. Soaring raptors use thermal convection to gain height over land (normally up to 300-500 m) and their numbers were most likely underestimated at the buoy-transect. However, during the following gliding and descent, birds of prey may cover the entire range from sea-level to 500 m.

Gulls *Laridae*

Gulls occurred at the buoy-transect both during spring (4,418 individuals per season) and autumn (3,812 individuals per season.) in substantial numbers. The majority of gulls was not identified to species (autumn:

67%; spring 48%). Amongst the identified species Herring Gull constituted the largest proportion of all gulls (about 60%). Most of the unidentified gulls were probably Herring Gulls, which could not with certainty be discriminated from Great black-Backed Gull and Common Gull at some distance. Even if the number of Herring Gulls were underestimated due to unidentified individuals, numbers were far from the threshold (20,000 individuals), which would qualify the study area as internationally important.

Historical data showed that little gull occurred at Gedser Odde with 3,652 individuals in total during the autumn 1988 (Table 36). Using the present population estimate this would correspond to 3.6-5.5% of the biogeographical population (see Kahlert et al. 2006). From the more recent counts at the buoy-transect c. 250-550 individuals were estimated, which was below the current threshold (840 individuals) of international importance (see Kahlert et al. 2006).

Table 36. Total count numbers per season of migrating Little Gulls at Gedser Odde in 1988 (Christensen & Grell 1989) and at the buoy-transect east of the Nysted Offshore Wind Farm, 1999-2005 (present study). Numbers in brackets show the estimates during one migration season (autumn or spring).

Species	Gedser Odde autumn	Buoy-transect autumn	Buoy-transect spring
Little gull	3,652	184 (261)	141 (567)

Gulls tended to occur in comparable numbers at Rødsand throughout the autumn period (Fig. 107). Only Little Gull consistently moved through the study area in a westerly direction (the ratio of westerly to easterly migrating birds was 10.8. Other species such as Herring Gull, Common Gull and Great Black-backed Gull and Black-headed Gull showed ratios close to one (equal numbers with westerly and easterly orientation) or mainly easterly orientation (Black-headed Gull). During spring, the various species were mainly orientated to the east, i.e. the main migration direction during spring.

Gulls are generally day-active. From the combined radar and visual studies, regular (possibly daily) use of the Rødsand sandbars as nocturnal roosts was observed. The daytime numbers of gulls on the buoy-transect constituted about 1% of the entire bird numbers during autumn and 5% during spring. Gulls mainly occurred as solitary individuals and mean flock size was 1.17 (95% confidence limits [1.15; 1.19] N = 2,805).

During the autumn, the daytime rhythm showed the same patterns as other species, which to some extent used the study area as staging area, such as Cormorants and Sandwich Terns. Thus, migration intensity to the west was highest during mornings, while the prevailing orientation was to the east in the evening (Fig. 108), which reflected the daily movements and reversed movements from the nocturnal roost at the eastern Rødsand Sandbar to offshore foraging areas. In addition, daily movements and reversed movements of gulls also occurred from the eastern sandbars towards the mainland areas.

Flight altitudes of gulls were investigated at Gedser Odde during the base-line study (Kahlert et al. 2000b). Results from here showed that 13% of the gulls occurred at altitudes between 30 and 50 m and the rest below 30 m.

Terns *Sternidae*

Sandwich Tern was the only regularly occurring tern species on the buoy-transect during autumn (1,659 individuals per season) and spring (864 individuals per season.). The total number observed during autumn was interesting, as this converged to the threshold at 1,700 individuals, which defined internationally important occurrences (see Kahlert et al. 2006). However, numbers were most likely biased by double counts due to the flight patterns of the Sandwich Terns (see below).

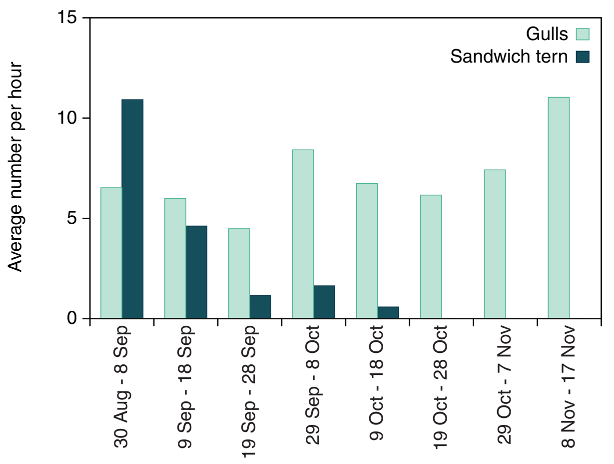


Figure 107. Autumn migration intensity of westerly migrating gulls and Sandwich Terns on the buoy-transect east of the Nysted Offshore Wind Farm broken into 10-day periods.

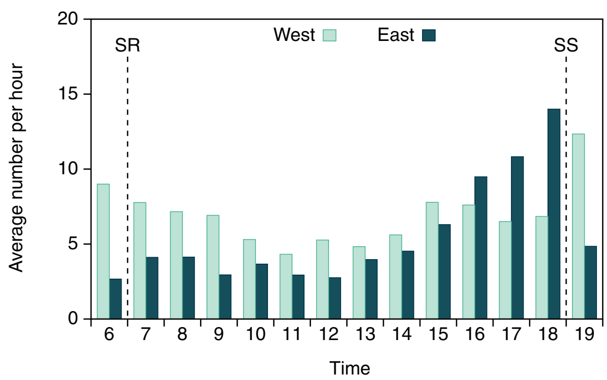


Figure 108. Autumn migration intensity of westerly and easterly migrating gulls on the buoy-transect east of the Nysted Offshore Wind Farm broken into hourly intervals. The time represents the following periods: 6 = 6:00-6:59, SR = sunrise and SS = sunset.

During autumn, large numbers of birds were already present when observation on the buoy-transect commenced late August (Fig. 107). During September, numbers dropped gradually and no Sandwich Terns were observed beyond 18 October, consistent with their migration to the wintering areas in West Africa. Sandwich Terns are generally considered as day-active and using roosts between foraging bouts and at night. Compared to the total number of bird occurrences on the buoy-transect, Sandwich Tern has little significance, comprising less than 1% of all bird occurences. Sandwich Terns were observed either solitary or in very small flocks with a mean of 1.24 (95% confidence limits [1.21; 1.28] N = 1,064), although a maximum flock size of 57 individuals may indicate some social behaviour.

There was strong evidence that Sandwich Terns stay at Rødsand for a period as the ratio of eastern to western migrating birds (0.84) was close to unity (1), i.e. almost the same number of Sandwich terns migrated in either direction. The flight pattern also tended to follow the patterns of Cormorants with large numbers of Sandwich Terns that crossed the buoy-transect in a westerly direction during the morning and mainly in an easterly direction in the evening (Fig. 109). This suggested that Sandwich Terns stay at a nocturnal roost on the eastern Rødsand sandbar from which they make foraging trips to the adjacent offshore areas, although this was not confirmed by observation. However, they were occasionally seen foraging together with the Cormorants. A daily maximum number of 383 westerly migrating individuals was obtained 31 Aug 2003, which suggested the magnitude of numbers, which could stay in the study area at a particular time.

Given the solitary behaviour and small size of the Sandwich Terns, which weakened the detection by radar, it was not possible to obtain a description of the general flight patterns, nor were any flight altitudes measured.

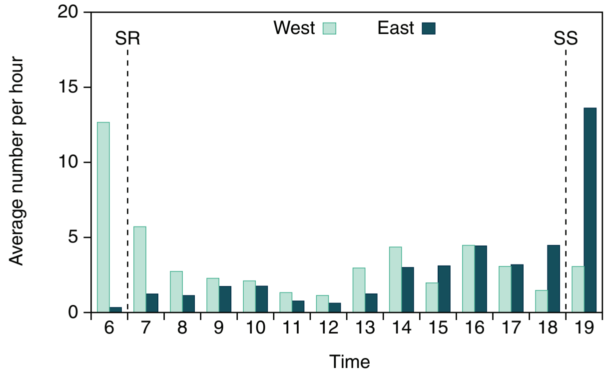


Figure 109. Autumn migration intensity of westerly and easterly migrating Sandwich Terns on the buoy-transect east of the Nysted Offshore Wind Farm broken into hourly intervals. The time represents the following periods: 6 = 6:00-6:59, SR = sunrise and SS = sunset.

Historical data showed that up to 417 Black Terns *Chlidonias niger* were counted in autumn 1988. At the buoy-transect, only one Black Tern was observed during the period 1999-2005. Several aspects could be responsible for the difference to 1988: 1) the population of Black Tern has declined from the late 1980s to present; 2) the counts at buoy-transect were carried out after the main migration period in August – a period covered in 1988 and 3) The species tends to be more frequent in Danish waters after periods of southerly winds, i.e a random element (the wind) may affect the regularity of occurrences (Olsen 1992).

Pigeons *Columbidae*

Pigeons are terrestrial birds, which would try to avoid crossing large stretches of water. For this reason, this species group is typically funnelled into the land tips, which tend to give them the shortest route across the sea. Accordingly, it is not surprising that Gedser Odde and Hyllekrog have long been known as sites with substantial migration of pigeons.

Wood Pigeon *Columba palumbus* was the only species, which has been observed in large numbers in the study area at Rødsand and the adjacent areas, and only during the autumn. Data on the autumn migration of Wood Pigeon were derived from different sources and suggested that autumn numbers may amount to 10,000-48,000 individuals (Table 37).

However, these data were all likely to be underestimated with respect to generating an estimate of the total migration volume. The studies from the observation tower at Rødsand was carried out by a combination of radar and telescope and suggested that the autumn migration of Wood Pigeon tended to occur as discrete events in which large numbers occurred in a very short period (e.g. one day). The nature of the present study with a two-days coverage each week may thus explain that large migration of Wood Pigeon was only observed in only 2 out of 7 autumns. The alternative explanation may be a large inter-annual variation in the migration route of terrestrial bird species.

Even the systematic counts at Gedser Odde in 1988 may have underestimated the overall migration volume, as observations were undertaken only visually. As Wood Pigeon occurred at high altitude (> 150 m) in the study area, many flocks were first detected by radar, and then in some cases only confirmed with difficulties after visual detection. Hence, the human observer tended not to be as efficient at detecting flocks of wood pigeon as the radar.

Table 37. Total count numbers of Wood Pigeon counted in autumn at Gedser Odde (Christensen & Grell 1989), Hyllekrog (summary in Kahlert et al. 2000) and from the observation tower at Rødsand (Kahlert et al. 2000, 2002).

Gedser 1988 (autumn total)	Hyllekrog 1984-1992 (Max. observed in one autumn)	Rødsand 1999 (one day)	Rødsand 2001 (one day)
15,850	23,670	10,000	48,050

As Wood Pigeon was not observed on the buoy-transect, phenology curves could not be generated. The two peak counts west and north of the buoy-transect occurred 15 and 17 October, respectively. Autumn migration of Wood Pigeon peaks in October in Denmark (Olsen 1992). Pigeons are generally considered as exclusively daytime migrants. Flocks during this count were mainly detected at the southwest coast of Falster and took a southwesterly course crossing the wind farm area (before it was erected; Kahlert *et al.* 2002). A smaller proportion of the flocks was detected at the tip of southeastern Lolland and had a similar orientation.

The relatively high flight altitude observed in the study area (estimated < 150 m) was confirmed in other studies. For example, over the sea 60-83% of wood pigeons were observed above 50 m (Hüppop et al. 2004).

Passerines *Passeriformes*

The passerines constitute a diverse group of many species, which occur in considerable numbers at Gedser Odde in the autumn, for example almost 200,000 individuals were recorded during daytime in 1988 (Table 38). Most abundant were Chaffinces/Brambling *Fringilla coelebs/montifringilla* (97,000) and swallows (50,000). At the buoy-transect, passerines comprised 4% of all autumn migrating birds (Fig. 97A). The length of the transect combined with the size of the passerines meant that passerines were difficult to identify to the species level – only 29% were identified to genus or species. Most abundant amongst the identified birds were swallows (Table 38) of which 81% was observed in just one day (17 Sep. 2001). Population estimates for passerines may vary considerably across species. For the most abundant species, these estimates amount to several million individuals. For example, the estimated number of swallows in Sweden, Finland and eastern Denmark was 1.2 mill individuals (Desholm in press). None of the passerine observations at the bouy-transect suggested numbers which would approach internationally important numbers. During spring, only 282 individuals were observed, and hence spring migration of passerines at low altitude (< 100 m) was much less intense than during autumn. In the autumn the migration of passerines show an inconsistent pattern with several peaks (Fig. 110). Only the mid-September peak could be ascribed to a particular genus, namely swallows.

Passerines are both diurnal and nocturnal migrants. Typical nocturnal migrants are for example thrushes *Turdidae* and warblers *Sylviidae*, whereas e.g. swallow *Hirundininidae*, swifts *Apodidae*, larks *Alaudidae*, pipits and wagtails *Motacillidae* together with finches *Fringillidae* and crows *Corviidae* mainly or exclusively migrate during daytime (see review in Kahlert et al. 2005). The flocks sizes of passerines observed at the buoy-transect varied considerably (range: 1-2,000 individuals). However, 90% of flocks comprised 10 individuals or less and mean flock size was 2.56 (95% confidence limits [2.46; 2.68] N = 2,190). At the buoy-transect, the number of migrating passerines peaked in the middle of the day (Fig. 111).

Table 38. Total count numbers per season of migrating passerines at Gedser Odde in 1988 (Christensen & Grell 1989) and at the buoy-transect east of the Nysted Offshore Wind Farm, 1999-2005 (present study). Numbers in brackets show the estimates during one migration season (autumn or spring).

	Gedser Odde autumn	Buoy-transect autumn	Buoy-transect Spring
Swallow	50,000	3,737 (4,517)	-
Passerine total	185,118	14,492 (19,359)	282 (515)

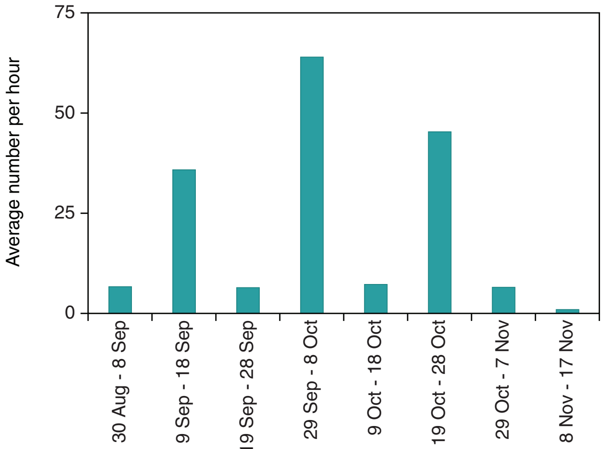


Figure 110. Autumn migration intensity of westerly migrating passerines on the buoy-transect east of the Nysted Offshore Wind Farm broken into 10-day periods.

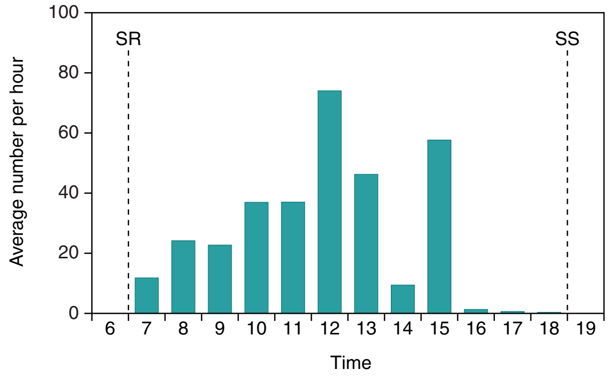


Figure 111. Autumn migration intensity of westerly migrating passerines on the buoy-transect east of the Nysted Offshore Wind Farm broken into hourly intervals. The time represents the following periods: 6 = 6:00-6:59, SR = sunrise and SS = sunset.

The present radar study has shown that autumn migration of terrestrial birds from Gedser Odde, which involves passerines, is mainly orientated in southerly directions (Desholm et al. 2001). Hence, only a smaller proportion (10%) of the passerines would migrate along the Rødsand sandbar and cross the buoy-transect, using the figures in Table 38. However, a more diffuse broad-fronted migration may occur from the western part of Falster and the southeastern part of Lolland passing the eastern part of the study area (Desholm et al. 2001).

The passerine spring migration is concentrated at the German island of Fehmarn (see e.g. Koop 2004). This main migration route at low altitude (<100 m) was, however, likely to follow the socalled "fugleflugtslinie" – literally bird migration route between Fehmarn and the Rødby area on Lolland east of Hyllekrog, where the distance across the Baltic Sea is shortest. This may explain the low numbers of passerines observed at the buoy-transect during spring.

Radar data from an anchored ship at the Nysted Offshore Wind Farm suggested that the visual passerine migration occurred mainly below 30 m during daytime (Blew et al. 2006). Passerines may however, show a wide range of flight altitudes up to several hundred metres.

Other species

Amongst other species or species group not mentioned above, Christensen & Grell (1989) mentioned a number of remarkable occurrences at Gedser Odde in 1988 (Table 39), although none of these occurred in internationally important numbers, using the present population estimates (see Kahlert et al. 2006). Also none of the species were confirmed to occur in comparable numbers in the present study (Table 39). Common Crane *Grus grus* for the obvious reason that this is a terrestrial species, which would take a southerly course from Gedser Odde, and thus less likely to be observed at buoy-transect. The occurrences of Bewick's Swans *Cygnus columbianus* and bar-tailed godwit *Limosa limosa* in 1988 seem to have been accidental, as they were hardly ever observed at the buoy-transect during the period 1999-2005.

Number of divers tended to be higher at Rødsand in spring than during autumn, possibly because migration in spring occurs closer to the coastline. Thus, at Gedser Odde divers tended to take a southwesterly course in the autumn (M. Desholm, pers. comm.), thereby lowering the probability of this species group to be detected from the observation tower. The same may apply for the skuas. The occurrence of Pomarine Skua may be dependent on the lemming cycle in the Arctic. Mass occurrences as in 1988 were therefore likely to be highly infrequent.

Table 39. Numbers per season of other selected species migrating at Gedser Odde in 1988 (Christensen & Grell 1989) and at the buoy-transect east of the Nysted Offshore Wind Farm, 1999-2005 (present study). Numbers in brackets show the estimates during one migration season (autumn or spring). NC = estimate not calculated due to low numbers.

Species	Gedser Odde autumn	Buoy-transect autumn	Buoy-transect spring
Divers	1,071	54 (NC)	238 (443)
Bewick's swan	247	0	0
Common crane	303	0	18 (NC)
Bar-tailed godwit	674	4 (NC)	0
Pomarine skua	144	NC (54)	0
Arctic skua	155		2 (NC)

4.2.2 Wind farm effects on migration

4.2.2.1 Lateral distribution during construction

Probability of crossing the wind farm area

In this section, the overall lateral distribution of bird flocks was investigated after they have passed the wind farm. Thus, during spring birds were mainly migrating in easterly directions (mainly Common Eiders), while the study area covered the eastern part of the wind farm and areas north, south and east of this. First, an overall model, which predicted that birds would pass the eastern gate, was applied on data. This model incorporated two of the project phases (base-line and construction, Fig. 112), crosswind situations (northerly and southerly) and time (day and night). The main construction phase only covered spring 2003.

The analysis showed that the probability that birds passed the eastern gate of the wind farm was significantly less during the construction phase compared to the results from the base-line study (Table 40). Already during the base-line study, the proportional numbers, which crossed the flight trajectory across the eastern gate, was relatively small (21% of all tracks). This declined to 11% during construction, and hence in relative terms, approximately every second flock that crossed the eastern gate during the base-line study failed to enter the wind farm area during the construction phase. There was some inter-annual variation in the probability of crossing flocks during the base-line (25% in 2000 and 16% in 2001) (see Kahlert et al. 2006), which showed that the relative loss of flocks varied from more than half (56%) to less than one third (31%). In addition, there were some effects of time of the day and crosswinds (Table 40).

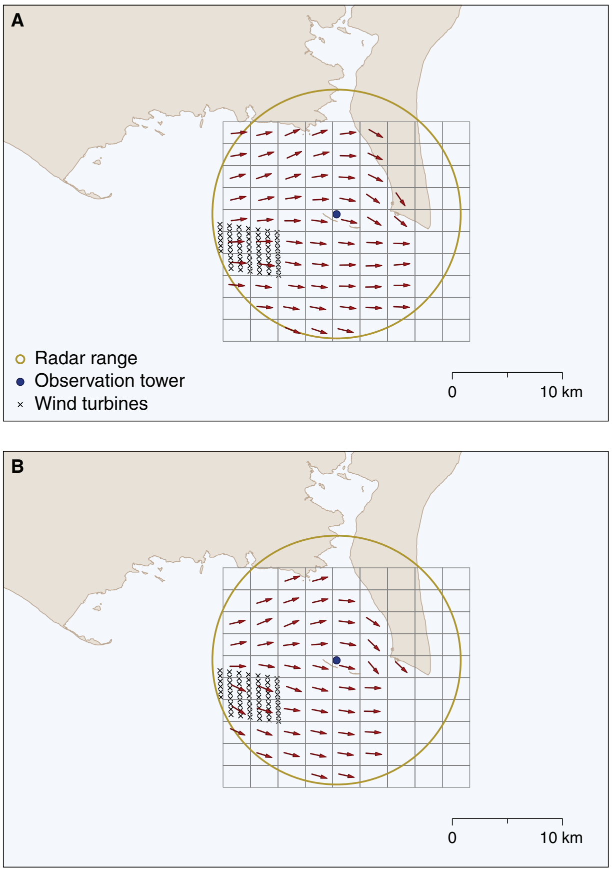


Figure 112. Mean orientation of migrating birds (arrows) used in the analysis of the probability that bird flocks flying in an easterly direction in the study area will pass the north of, south of or through the Nysted Offshore Wind Farm (eastern gate) in spring during a) the base-line study (2001, 2002) and b) the construction phase (2003).

Table 40. Significance of Maximum Likelihood Estimates in a logistic regression model, predicting the probability that bird flocks cross the eastern gate of the wind farm as a function of phase (base-line/operation), wind direction (northerly/southerly), time (day/night) and first order interactions between factors. The most parsimonious model was chosen, using Akaike´s information Index. Model Goodness-of-Fit tests were carried out according to Hosmer & Lemeshow (SAS 1999), showing deviation (D) or compliance (C) between model and data at the alpha-level of 0.05.

Variable (DF)	All data Wald X^2
Phase (1)	48.00 ***
Phase*time (1)	9.24 **
Phase*wind (1)	5.03 *
Time (1)	2.40 NS
Wind (1)	12.62 ***
Day*wind (1)	2.02 NS
Goodness-of-Fit (5)	0.10 (C)
Sample size	2,732

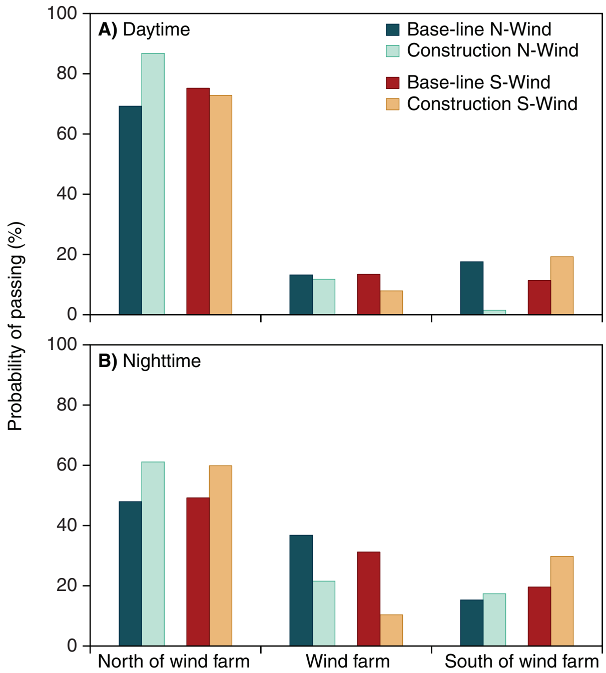


Figure 113. Probability that bird flocks flying in an easterly direction in the study area will pass the north of, south of and through the wind farm area (eastern gate) in spring during the base-line study (2001, 2002) and the construction phase (2003). Data are presented for a) daytime and b) nighttime under different cross-wind regimes.

Overall, comparable proportions of the birds passed the eastern gate during day and night (Time, Table 40). However, the relative reduction in the likelihood of birds passing the eastern gate between base-line and construction was highly dependent on the time of the day (phase*time, Table 40). Thus, during daytime the decline in probability of birds passing the eastern gate was not as great (11 and 41%) as during nighttime (41% and 67%), (Fig. 113). Hence, overall approximately one third of flocks that passed the eastern gate during the base-line study avoided the wind farm during daytime in the construction phase compared to more than half during nigttime.

Birds had a higher probability of passing the eastern gate during northerly crosswinds (21%) than during southerly crosswinds (16%, wind, Table 40), most likely because the area north of the wind farm was the most important trajectory, and hence a northerly crosswind would displace the migration route further to the south and to the same latitude as the wind farm. Nevertheless, the relative loss of flocks observed between base-line and construction at the eastern gate was significantly higher during periods of southerly crosswinds (half of the flocks) compared to northerly crosswinds (one quarter of flocks), (phase*wind, Table 40). Given these results, it was not surprising that the most remarkable avoidance response was observed during periods of southerly winds at nighttime. Thus, 2 out of 3 flocks (67%), which crossed the eastern gate during the base-line study, did not appear here under these conditions during the construction phase (Fig. 113B).

Birds clearly chose other migration routes than through the wind farm area during the construction phase compared to those during the base-line study. During daytime, when the avoidance of the wind farm area was not as pronounced as at night, there was no clear pattern in the displacement, as both the trajectories north and south of the wind farm gained importance dependent on the prevailing wind conditions (Fig. 113A). At night, the migration route north of the wind farm gained further importance during construction, so that more than 60% of the flocks were observed using this trajectory (Fig. 113B).

Migration intensity at the wind farm

In this section, the local migration intensity was investigated by visual observations and radar during base-line and construction (Fig. 114). Due to the prevailing orientation of the migration to the east and north in spring, the buoy-transect together with the eastern and northern gates of the wind farm were placed after birds have passed the wind farm area, and thus the number of flocks, which migrated out of the wind farm, was counted.

During daytime, the overall visual migration intensity was halved on the buoy-transect during the construction phase compared to the base-line level (Fig. 115). All nine selected species contributed to this reduction.

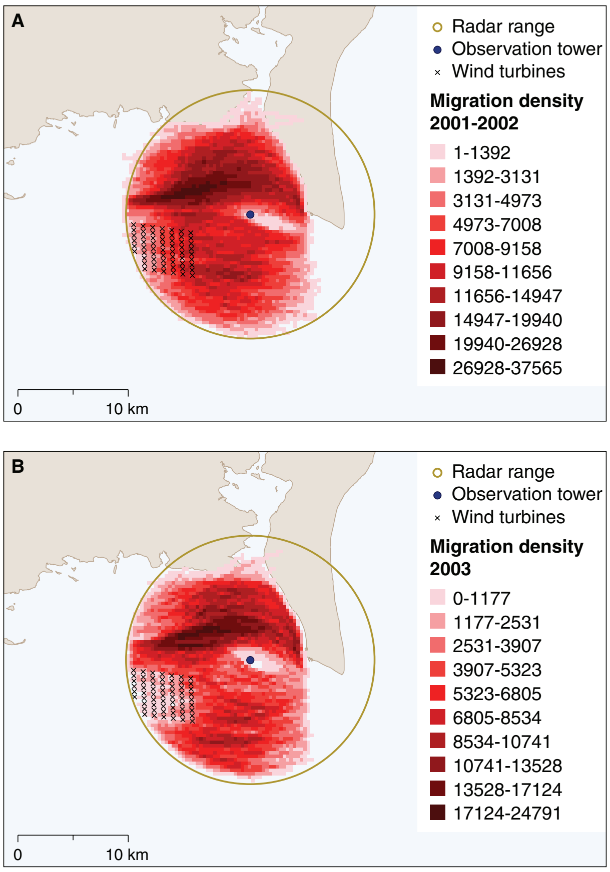


Figure 114. Spatial migration density of waterbird flocks migrating in the study area during spring. The density is indicated by the total length of tracks in metres within each grid cell. Maps are presented for a) the base-line study (2001, 2002) and b) the construction phase (2003).

At the eastern gate, substantially more migration occurred during periods of tailwind, however, this effect was most remarkable during the base-line study (Fig. 116A). During the construction phase, migration intensity dropped significantly during periods of tailwind irrespectible of the time of the day, while a less pronounced reduction during periods of headwinds was not significant (Fig. 116B).

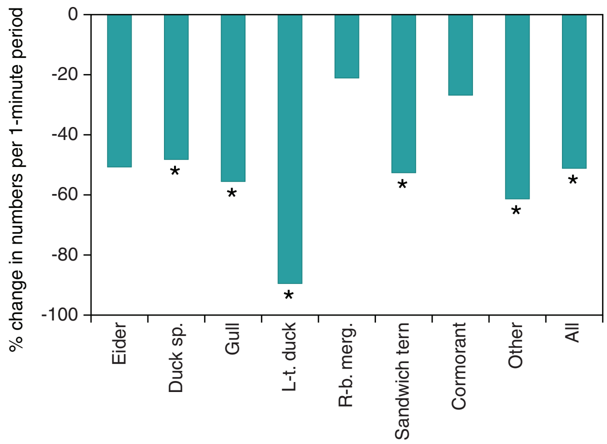


Figure 115. Proportional change in the average numbers of birds between the base-line study and the construction phase for nine selected species categories. Significant changes for P < 0.05 was labelled with asterisks (Kolmogorov-Smirnov Test).

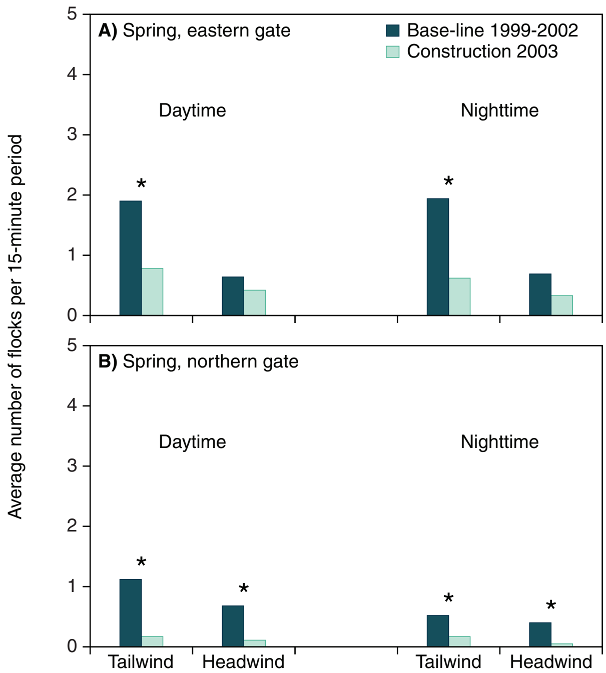


Figure 116. Average number of flocks per 15-minute period crossing the eastern (a) and northern (b) gate of the Nysted Offshore Wind Farm during spring, broken into periods of head- and tailwinds, day- and nighttime and project phases (base-line/construction). Significant differences between base-line and operation for P < 0.05 are labelled with asterisks (Kolmogorov-Smirnov Test).

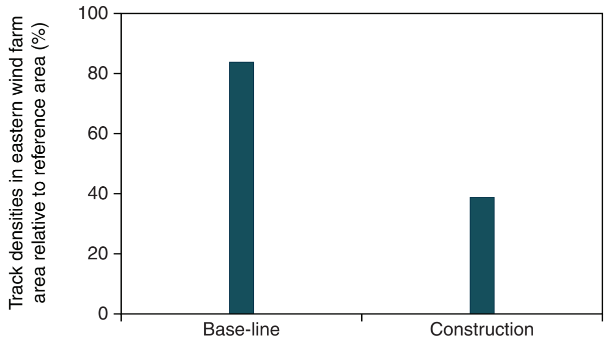


Figure 117. Track densities in eastern wind farm area relative to reference area (%) compared between the base-line study (2001, 2002) and the construction phase (2003).

At the northern gate, consistent and significant reductions in migration intensity were observed during the construction phase both during periods of tail- and headwinds and day- and nighttime.

It was further investigated whether the reduced migration intensity at the gates also resulted in a general reduction in migration intensity in the wind farm area during construction. During the base-line study, track densities in the wind farm area constituted on the average 84% of track densities in the reference area compared to 39% during the construction phase, i.e track densities (a measure of migration intensity) was overall reduced by 54% in the wind farm area (Fig. 117).

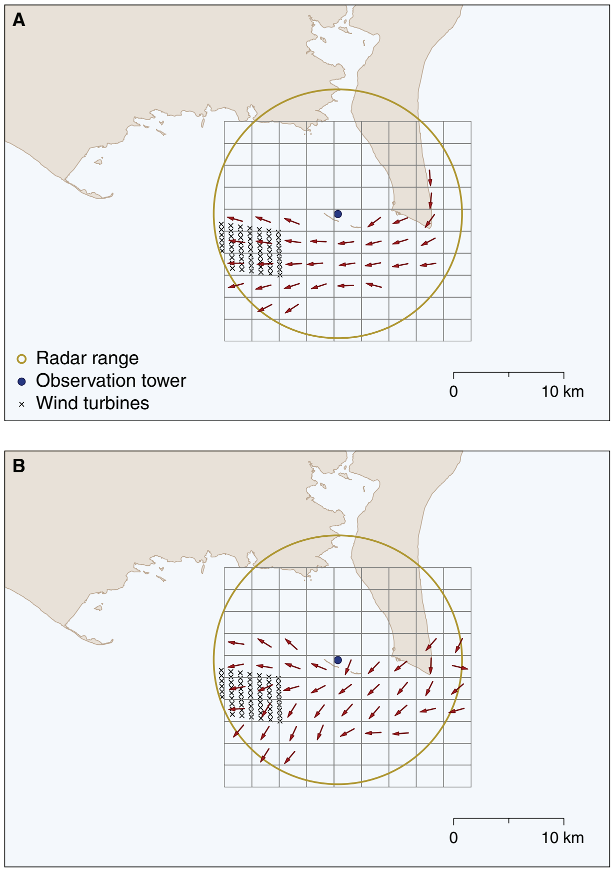


Figure 118. Mean orientation of western migrating tracks (arrows) used in the analysis of response distance to the Nysted Offshore Wind Farm in autumn during a) the base-line study (2000-2002) and b) the operational phase (2003-2005).

4.2.2.2 Lateral distribution during autumn, operation phase

Lateral response distance at the wind farm

In this section, overall lateral responses of bird flocks as they approached the wind farm were tested to determine the response distance, at which avoidance occurred. In the area between the eastern gate and a north-south line 6 km east of this, mainly waterbird flocks migrated in westerly directions towards the wind farm. The flight trajectories of these flocks were analysed before and after construction of the wind farm (Fig. 118). In the following it is relevant to know that 225° corresponds to an orientation to the southwest, 270° to due west and 315° to northwest.

In the light of the drawbacks associated with using mean orientation in order to determine the response distance at lateral deflection (to the north or south), the standard deviation (s.d.) of the orientation was used. The rationale behind the use of this parameter was discussed in Kahlert *et al.* (2005). The changes in the mean orientation were only meaningful to incorporate in the analysis in situations, when birds showed a systematic deflection either to north or south.

First, an analysis of variance was carried out on the s.d. (standard deviation) of the orientation of birds, in which the flocks were grouped into project phases (base-line/operation), crosswind (northerly/southerly), time (day/night) distance to wind farm (100, 200, 300, 400, 500 1,000, 1,500, 2,000, 2,500, 3,000, 3,500, 4,000 and 5,000 m).

The overall analysis of the s.d. of the orientation showed that this measure of deflection was significantly higher during the operational phase (average: 22.5°) compared to the base-line (average: 13.6°) (phase, Table 41). Furthermore, the size of this difference was dependent on the distance to the wind farm (phase*distance, Table 41). During the base-line study, the s.d. was consistently low (range 11.2-14.9°), (Fig. 119). Conversely, the s.d. ranged from low to high during the operational phase (range 14.1-31.0°) in such a manner that s.d. was comparable (1.6-3.3°) between baseline and operational phase at long distances (3.5-5 km) from the wind farm and showed a markedly greater difference (14.2-16.2°) compared to at a close distance to the wind farm (less than 1 km), (Fig. 119). This reflected a wider range of directions adopted by birds, as they approached the wind farm (see also Fig. 15 in Kahlert *et al.* 2005) compared to the relatively uniform orientation during the base-line and at long distance during the operational phase. Hence, it can be concluded that birds deflected laterally as they approached the wind farm.

Table 41. Analysis of variance on the deflection (the standard deviation of the orientation) of bird flocks at the Nysted Offshore Wind Farm (WF). The statistical model used for the analysis focused on testing the deflection of birds as they approached the wind farm (distance) during the base-line and the operation of the wind farm (phase). Furthermore, the model tested whether a potential difference in deflection between phases was dependent on the distance to the wind farm (phase*distance) and whether this effect was dependent on crosswind (northerly/southerly), response pattern (avoidance of WF / crossing WF) and time (day/night).

Variable (DF)	F-value
Phase (1)	423.02 ***
Distance to WF (12)	26.18 ***
Phase*Distance (12)	12.42 ***
Phase*Distance*Response (26)	4.71 ***
Phase*Distance*Time (26)	1.17 NS
Phase*Distance*Wind (26)	2.63 ***
Explanatory power of model (R^2)	0.69
Sample size	598

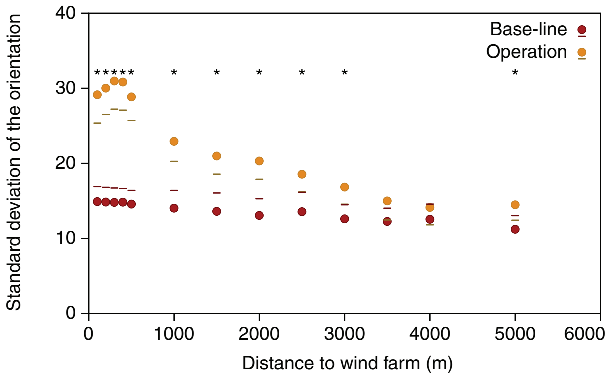


Figure 119. Orientation of tracks of autumn migrating waterbird flocks, which approached the Nysted Offshore Wind Farm, presented as the mean of annual standard deviation values (dots) with upper 95% confidence limit for the base-line period (2000-2002) and lower 95% confidence limit for the operational phase (2003-2005) (bars) for each distance class out from the eastern gate. Significant differences between base-line and operation (for P < 0.05) are labelled with asterisks.

There were also effects of response type and crosswinds on the phase*distance interaction (Table 41). Not surprisingly, birds showed greater deflection when they avoided the wind farm (phase difference: 10.0°) compared to those that maintained their heading and crossed the eastern gate of the wind farm (phase difference: 7.9°). In northerly crosswinds deflection was greater of the orientation of the birds (phase difference: 12.6°) compared to southerly winds 9.6°), possibly because birds were more prone to deflect to the south in northerly crosswinds. To the south there were also no barriers, which restricted their deflection, in contrast to the north where even the Rødsand Sandbar has been shown to be a barrier to migrating waterbirds. There was no significant difference in the overall deflection pattern between daytime and nighttime (Table 41), however see below for modification of this conclusion.

In order to systematically determine the distance at which the lateral deflection of birds started as they approached the wind farm during the operational phase, the difference in s.d. between the base-line and the operational period was tested at each distance. This analyses showed that at close distance there was a sequence of significant differences between the base-line and operational phase (0.1-3.0 km), whereas at longer distances (3.5-5.0 km) the deflection were generally comparable between the base-line period and the operational phase (although significantly different at 5.0 km), (Fig. 119). Furthermore, the response towards the wind farm was graded as the significant deflection tended to fall in two steps: a first and relatively slight deflection at distances between 1.0 and 3.0 and a more radical deflection at 0.5 km or closer.

In a similar way, the variation in the response distance under different conditions was explored with respect to response pattern, crosswind and time (see Kahlert et al. 2006). A series of pair-wise t-tests at each distance gave several P-values between 0.05 and 0.10, i.e. a clear tendency which was almost significant at the usual alpha level of 0.05. In each of the project phases the sample size was only two or three, and this was likely to be responsible for the relatively insensitive statistical tests. For this reason, the alpha-level was elevated to 0.10. In addition, by doing multiple t-tests there was a risk (10%) of getting a significant result by chance. Therefore, one insignificant result in a sequence of significant results was ignored and vice versa. In this way, quite consistent patterns were revealed (see Kahlert et al. 2006). The response distances during various conditions are shown in Table 42. The distance at which the first deflection occurred tended to be longer during daytime (1.5-3.5 km) than nighttime (0.5 in three cases).

Under certain conditions it was possible to detect a systematic change in the flight course, using the mean of the orientation as parameter (Table 42). During daytime in the operational phase, birds generally changed their orientation in a more southwesterly direction compared to the base-line period. During nighttime there was one case of systematic deflection in a northwesterly direction. It was also remarkable that during periods of southerly winds in which birds avoided the wind farm (both day and night), a systematic difference in the mean orientation was observed already when birds entered the first transect at 5 km. This suggested that birds may deflect gradually at a longer distance than originally thought. However, it could neither be confirmed nor excluded that data from the operational phase were biased by species that had other natural orientations (e.g. southwesterly migrating geese or northwesterly migrating staging birds heading for the Rødsand Inlet).

Table 42. Response distance of autumn migrating birds, approaching the Nysted Offshore Wind Farm in westerly directions during different condtions of time (day/night), crosswinds (northerly/southerly) and response pattern (avoidance or crossing of the eastern gate). General deflection was derived from the standard deviation of the orientation of tracks while systematic deflection was extracted from the mean orientation.

			Response distance (km)	
Time	**Wind**	**Response**	**General deflection**	**Systematic deflection**
Day	North	Avoid	0.1-3.5	-
		Cross	0.1-0.2 and 1.0-3.0	1.5-2.5 (Southwest)
	South	Avoid	0.1-1.5	0.2-5.0 (Southwest)
		Cross	0.1-2.5	0.1-0.5 (Southwest)
Night	North	Avoid	0.1-0.5	-
		Cross	0.1-0.5	-
	South	Avoid	0.1-3.5	0.3-5.0 (Northwest)
		Cross	0.3-0.5	-

Table 43. Significance of Maximum Likelihood Estimates in three logistic regression models, predicting the probability that bird flocks cross the eastern gate of the wind farm as a function of phase (base-line/operation), the distance in metres to the observation tower, wind direction (northerly/southerly), species (Common Eider/geese/other ducks/not identified) and first order interactions between factors. The most parsimonious model was chosen, using Akaike´s information Index. Model Goodness-of-Fit tests were carried out according to Hosmer & Lemeshow (SAS 1999), showing deviation (D) or compliance (C) between model and data at the alpha-level of 0.05.

Variable (DF)	**All data Wald X^2**	**Daytime – Common Eider Wald X^2**	**Daytime – geese Wald X^2**
Phase (1)	83.97 ***	110.42***	4.18*
Phase*distance (1)	31.35 ***	Not fitted	Not fitted
Phase*time	30.76***	Not fitted	Not fitted
Phase*wind (1)	2.48 NS	Not fitted	Not fitted
Distance (1)	45.37***	Not fitted	0.91 NS
Wind (1)	27.00 ***	33.37***	0.65 NS
Time (1)	40.80 ***	Not fitted	Not fitted
Distance*wind (1)	63.58 ***	35.02***	0.62 NS
Time*wind (1)	4.48 *	Not fitted	Not fitted
Goodness-of-Fit (6-8)	22.05 (D)	8.53 (C)	6.41 (C)
Sample size	3,869	430	42

A species specific analysis on Common Eiders was tried. Results tended to go in the same direction as the overall data set, however not with the same consistency, most likely as a result of smaller initial flock samples and the restricted area in which species identification could be undertaken.

Probability of crossing the wind farm area

In this section, the overall lateral responses shown by bird flocks as they approached the wind farm were tested to determine what proportions would (i) cross the eastern gate of the wind farm or alternatively pass (ii) north or (iii) south of the wind farm. Data were exclusively compiled during the autumn, and the majority of the western migrating birds identified to species, which approach the wind farm, were Common Eider or geese.

First, an overall model, which predicted the likelihood that birds would pass the eastern gate of the wind farm, was applied to the complete dataset. This model incorporated two project phases (baseline and operation), (Fig. 120), crosswind situations (northerly and southerly), time (day and night) and the distance to the observation tower, when passing the buoy transect. The last measure corresponded to the spatial distribution of the migration route taken by waterbirds along a north-south longitudinal axis, as they approached the wind farm.

The model showed that the significant state change from the base-line to the operation phase was associated with a highly significant decline in the probability that birds would cross the eastern gate (Table 43). During the base-line 40% of the flocks passed the eastern gate compared to 9% during operation (Fig. 121). This meant that almost 8 out 10 flocks that crossed the eastern gate during the base-line study avoided the wind farm during the operational phase. While there

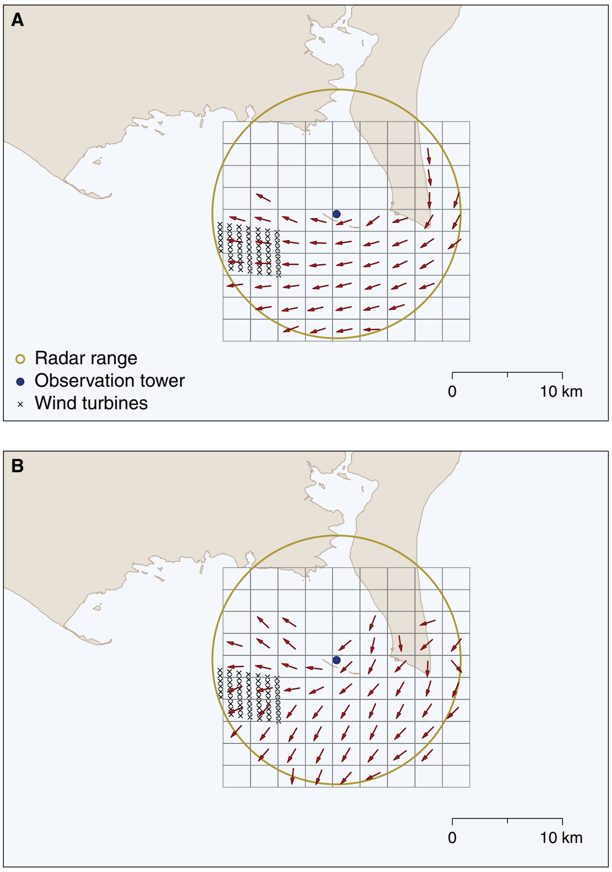


Figure 120. Mean orientation of migrating birds (arrows) used in the analysis of the probability that bird flocks flying in a westerly direction in the study area will pass the north of, south of or through the Nysted Offshore Wind Farm (eastern gate) in autumn during a) the base-line study (2000-2002) and b) the operational phase (2003-2005).

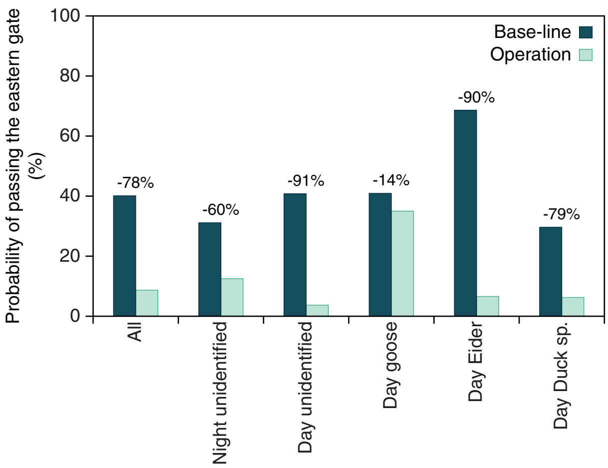


Figure 121. Probability that bird flocks flying in a westerly direction towards the Nysted Offshore Wind Farm will cross the eastern gate in autumn during the base-line study (2000-2002) and the operational phase (2003-2005). Data are presented for different all flocks and different categories species (Eider/geese/-unidentified) and time (day/night).

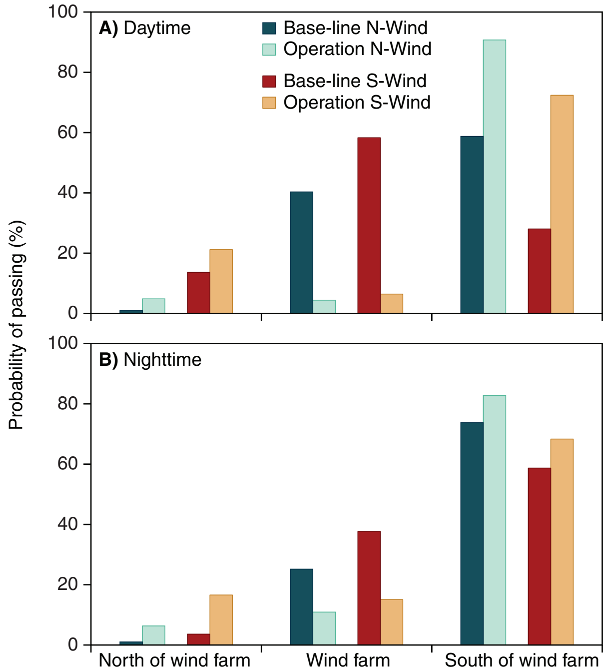


Figure 122. Probability that bird flocks flying in a westerly direction in the study area will pass the north of, south of and through the wind farm area (eastern gate) in spring during the base-line study (2000-2002) and the operational phase (2003-2005). Data are presented for a) daytime and b) nighttime under different crosswind regimes (northerly/southerly).

were some inter-annual variation in the base-line data (range: 24-48%), the year-specific operation data showed very little variation (Range 8-9%). Hence, there were no indications that birds habituated to the wind farm, if anything, they showed a consistent avoidance response throughout the operation years. A number of other factors also influenced the probability that birds would pass the eastern gate (Table 43). However, the clearest effect on the probability was obtained by the transition from base-line to operation (highest Wald X^2-values in Table 43). The effect of the erection of the wind farm was affected by several factors.

Birds that migrated in a westerly direction at the same latitude as the wind farm had a higher probability of crossing the eastern gate of the wind farm, and this corresponded to a short and long distance to the tower (see effects of this factor in Kahlert et al. (2006), shown across all years). An approach at the same latitude as the wind farm (for example at a distance of 4,000 m) resulted in a large difference in probability between the base-line (high probability) and the operational phase (low probability) (phase*distance in Table 43). By contrast, there was virtually no difference at 9,000 m, corresponding to a course which took birds well south of the wind farm. Thus, probabilities converged to 0 both during base-line and operation at this latitude. In other words, birds that migrated at this southerly latitude exhibited a low probability of crossing the wind farm area during the base-line and this low probability of crossing the eastern gate was unchanged during the operation phase.

In previous reports, it was shown that the migration route of waterbirds was highly affected by crosswinds. Migration routes were generally situated further to the north during periods of southerly winds compared to winds from northerly directions. As southerly winds displaced birds to the same latitude as the wind farm, this increased the overall probability that they would cross the eastern gate (see previous section for description of latitudinal effects). This wind effect was consistent across the transition from the base-line period to the operational phase (phase*wind, Table 43). During the operational phase 7% of the flocks crossed the eastern gate during periods of northerly winds compared to 11% during southerly winds (see variation in Fig. 122).

In the initial EIA, the potential difference in flight behaviour and collision risk was flagged up with respect to time effects, as the difference in time (day/night) also reflects a change in visibility. In this respect, the *a priori* prediction that birds in reduced visibility (at night) would show a higher probability of crossing the eastern gate was confirmed. During the operation phase, 4% crossed the eastern gate during daytime compared to 13% at night, and in relation to base-line levels this meant that 6 out of 10 flocks, which crossed the eastern gate of the wind farm during the base-line study did not do so at night during the operational phase compared to 9 out of 10 during daytime.

By day, some of the flocks detected by radar were identified to species or species group: Common Eider, geese, duck sp. and flocks not identified to species. A preliminary analysis of the daytime data showed that there was a species-specific effect on the probability of crossing the eastern gate. Common Eiders avoided the wind farm during the operation phase, while this effect was significant but less pronounced amongst geese (Fig. 121, Table 43). The results of the goose data suggested less avoidance amongst this species group, but see the discussion below.

It was evident that the migration routes taken by waterbirds were displaced after the construction of the wind farm. Previous analyses showed that the deflection occurred gradually and that long distance reverse migration (> 5 km) did not occur (Kahlert *et al.* 2005). Given that the major response was that of gradual deflection, it is important to determine whether migrating birds were displaced to the south or north of the wind farm. By day, an *a priori* prediction would be that birds would mainly deflect to the south, because daytime migration mainly involves Common Eiders, which winter to the SW and WSW of the study area. In addition, the base-line orientation of migrating birds was WSW (Fig. 96) and the majority of migration took place south of the mid-latitude of the wind farm area (see Fig. 123). Hence, the most appropriate change of heading for an Common Eider duck approaching the wind farm from the east would be to adjust the flight course further to the south and circumvent the wind farm along its southern edge.

By day, birds primarily showed course deflections to the south (Fig. 122A and supported in Table 42). During the base-line study in periods of southerly crosswinds, ca 60% of the flocks took a course south of the wind farm area. This percentage increased to more than 90% during the operational phase. In northerly winds, the wind farm area constituted the most important migration corridor holding ca 60% of the flocks during the base-line. This changed dramatically during operation of the wind farm as the main migration route was displaced to south of the wind farm.

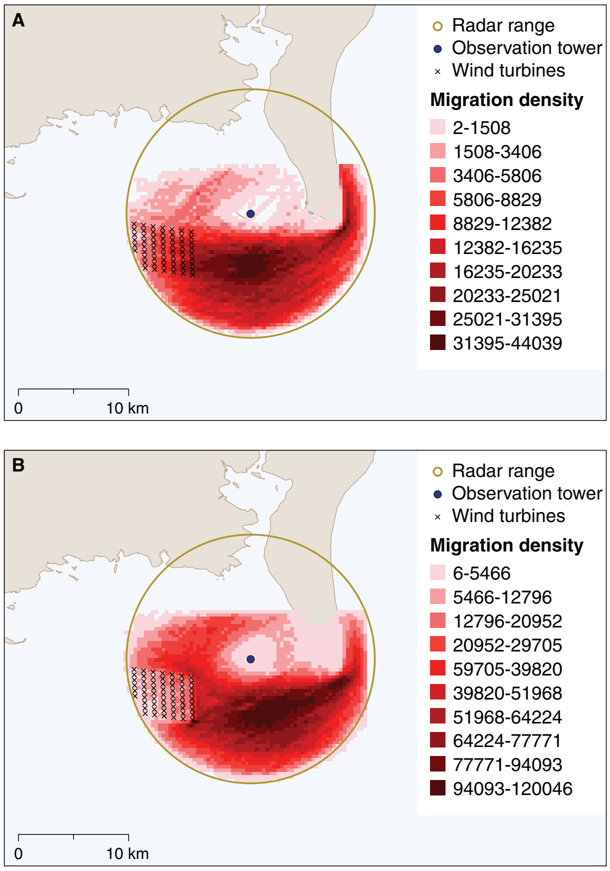


Figure 123. Spatial migration density of waterbird flocks migrating in the study area during autumn. The density is indicated by the total length of tracks in metres within each grid cell. Maps are presented for A) the base-line study (2000-2002) and B) the operational phase (2003-2005).

At night, birds showed more or less equal deflection rates to the north and to the south (Fig. 122B). Irrespective of the crosswind regime, the most important migration corridor was situated south of the wind farm area both during the base-line and the operation phase. While the trajectory north of the wind farm was generally of least importance, it gained some significance during periods of southerly crosswinds and assumed greater importance than the wind farm corridor during the operational phase.

Migration intensity at the wind farm

In this section, the local migration intensity was compared inside and outside of the wind farm during base-line and operation (Fig. 123). Given the clear avoidance response of birds as they approached the wind farm, an overall reduction in migration intensity within the wind farm area would be expected. Conversely, as there was a clear response to the wind farm at distances less than 1 km from the wind farm, only minor effects (or no effects at all) were expected amongst the migration intensity of birds monitored visually along the buoy-transect.

By day, the overall visual migration intensity was about 20% higher at the buoy-transect during the operation phase compared to the "natural" occurrences pre-construction, although the difference was not significant (Fig. 124). The relative change in the visual daytime migration intensity of various species groups showed substantial variation during operation of the wind farm. However, none of the species showed significantly reduced migration intensity, although reductions approached c. 30% amongst passerines. In this particular case, the difference between base-line and operation could mainly be ascribed to an observation of c. 3,000 swallows on a single day during the base-line study. As a one-off event, this did not affect the overall pattern of no significant change between base-line and operation. Cormorants, gulls and dabbling ducks showed substantially more intense flight activity at the buoy-transect during operation (up to c. 70%), although the significance level for dabbling ducks was not as high as for the other species. The intensified migration in Common Eiders was more moderate (ca 25%), yet significant. Hence, the results suggested that the importance of the area east of the wind farm was maintained for the most numerously occurring species during daytime. Cormorants and gulls, which were predicted to be attracted by the wind farm, increased their migration intensity substantially, and it was confirmed anecdotally by the maintenance and NERI staff that they roosted on the turbine foundations. On several occasions, it was observed on the radar monitor how bird signals "departed" from the super-structures in the wind farm area.

In order to explore how the migration intensity in the wind farm area was affected by avoidance and attraction, systematic counts were carried out at the eastern and northern gate of the wind farm, using radar.

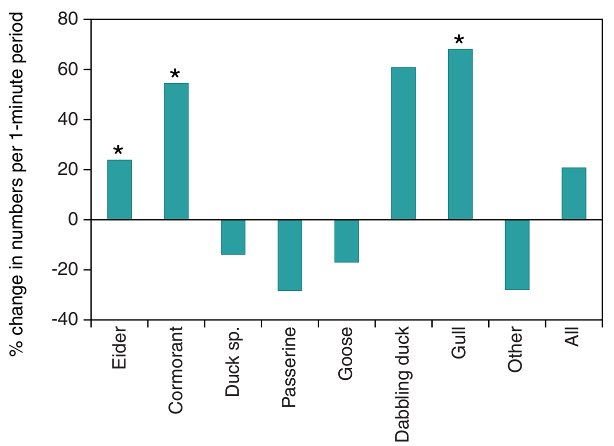


Figure 124. Proportional change in the average numbers of birds between the base-line study and the operational phase for nine selected species categories. Significant changes for P < 0.05 was labelled with asterisks (Kolmogorov-Smirnov Test).

These counts showed that by day, migration during periods of tailwinds was the most important at the eastern gate during the base-line study, and that the number of crossings dropped dramatically post-construction (Fig. 125A). As we know from the visual counts at the buoy-transect, the daytime migration was dominated by Common Eiders, and they were also known to avoid the wind farm. Hence, a reduction in migration intensity at the eastern gate was expected during the favourable tailwinds at daytime. Migration intensity was reduced during periods of headwinds. Nevertheless, a significant reduction in migration intensity during these wind conditions was also observed during the operational phase. We already concluded that, at night, the avoidance response was less evident than by day. In terms of migration intensity the results tended to support this pattern, as the reduction in migration intensity observed at night was not significant during the operational phase.

At the northern gate, migration resulted mainly from birds coming from mainland areas. Generally, large inter-annual variation was observed during the base-line study (see Kahlert et al. 2006). It was remarkable that the results from 2002 (last base-line year) showed as low a migration intensity as was observed during the operational phase. This was mainly due to the fact that the study was terminated mid-September before the onset of the main migration period of many species. To some extent this was balanced by exceptional high migration intensity in 1999 (also the case at the eastern gate), when the study was postponed to commence in late September, and hence primarily covered the main migration period of the most important species.

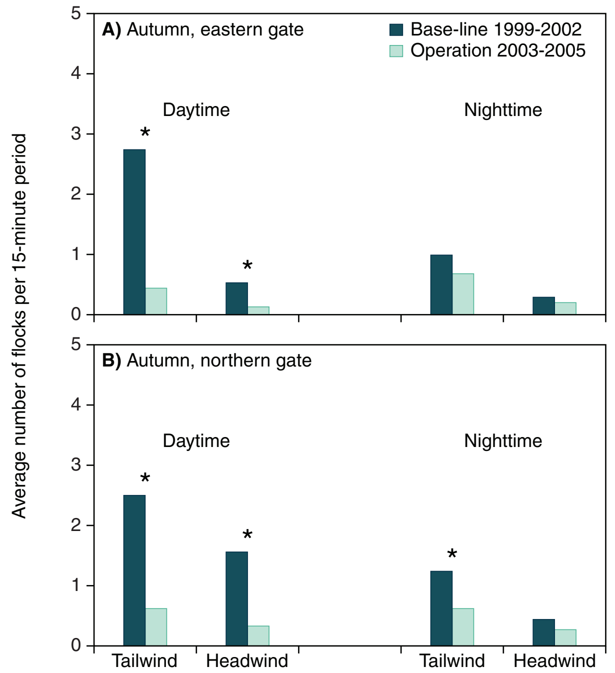


Figure 125. Average number of flocks per 15-minute period crossing the eastern (A) and northern (B) gate of the Nysted Offshore Wind Farm during autumn, broken into periods of head- and tailwinds, day- and nighttime and project phases (base-line/operation). Significant differences between base-line and operation for P < 0.05 are labelled with asterisks (Kolmogorov-Smirnov Test).

During the base-line study, migration intensity at the northern gate (Fig. 125B) was comparable to the results from the eastern gate, except that daytime migration during periods of headwinds was more intense at the northern gate. No species identification was possible due to the distance from the observation tower, and the large migration intensity could mainly be attributed to results from 1999 (see Kahlert et al. 2006). It could be speculated whether the headwind migrating radar tracks represented staging birds moving locally in the area. During the operational phase, a similar pattern of significant reductions in migration intensity was also observed at the northern gate, except during periods of headwinds at night (Fig. 125B).

Results from both the eastern and northern gate showed significant reductions in migration intensity during the operational phase, so it was predicted that the overall migration intensity in the wind farm area would also be reduced. This was tested by comparing an area in the eastern part of the wind farm and a corresponding reference area in the approach area to the wind farm (see Fig. 21). During the base-line study, track densities in the eastern wind farm area constituted 60% of level in the reference area on annual basis (Fig. 126). This suggested that a substantial proportion of the westerly migrating flocks was lost in the wind farm area even during the base-line as a result of reduced detection rate and a unfavourable flight angle compared to the closer reference area, in which birds showed a sharp radar reflection as a result of presenting the radar beam with a larger surface area (see also Horns Rev studies). However, during the operational phase, the track densities was significantly less (by 57%) than the base-line level, ($t = 7.64$, $DF = 4$, $P < 0.0016$). Part this reduction may derive from the so-called shadow effect caused by individual turbines, (see chapter 2.4.2).

Hence, it can be concluded that although some species tended to be attracted to the wind farm, birds mainly avoided it to the extent that the overall migration intensity in the eastern part of the wind farm was significantly reduced.

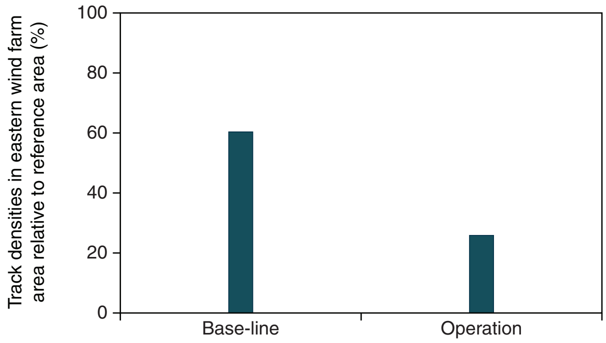


Figure 126. Track densities in eastern wind farm area relative to reference area (%) compared between the base-line study (2000-2002) and the operational phase (2003-2005).

4.2.2.3 Lateral distribution during spring migration, operation phase

Probability of passing the wind farm

In this section, the overall lateral distribution of bird flocks was investigated after they have passed the wind farm. Thus, during spring birds are mainly migrating in easterly directions (mainly Common Eiders), while the study area covered the eastern part of the wind farm and areas north, south and east of this. First, an overall model, which predicted the likelihood of birds crossing the eastern gate, was applied on all data. This model incoporated two of the project phases (base-line and operation, Fig. 127), crosswind situations (northerly and southerly) and time (day and night).

The probability that birds crossed the eastern gate declined significantly during operation of the wind farm – overall from 21% of the flocks during the base-line to 8%, which was highly significant (Table 44). In other words, 2 out 3 flocks that crossed the eastern gate during the base-line, avoided the wind farm during the operational phase. The base-line percentage varied between 16 and 25%, while the range during operation was 6 to 11% (see Kahlert et al. 2006). Even the smallest annual difference between base-line and operation and the comparison with least statistical power (2001 vs. 2004) confirmed the significant avoidance of the east-

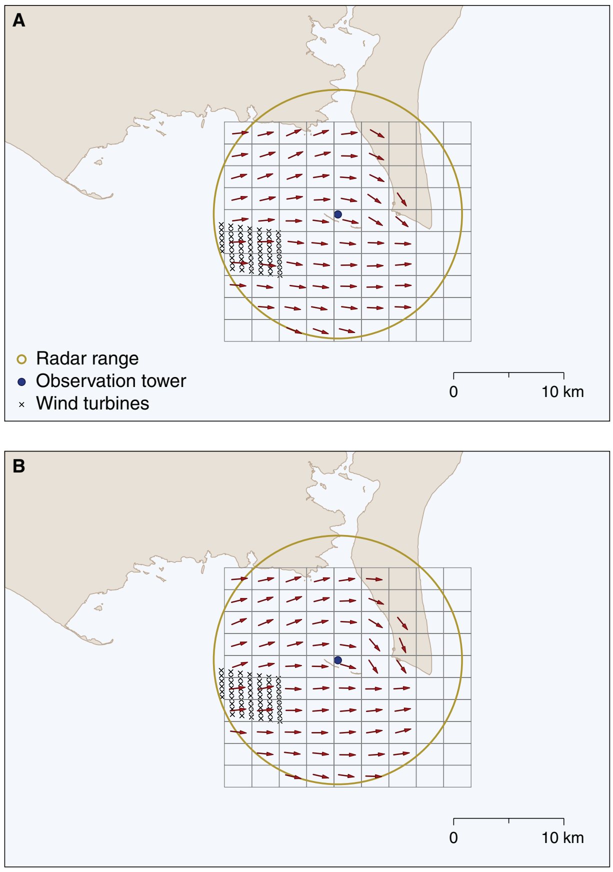


Figure 127. Mean orientation of migrating birds (arrows) used in the analysis of the probability that bird flocks flying in an easterly direction in the study area will pass the north of, south of or through the Nysted Offshore Wind Farm (eastern gate) in spring during a) the base-line study (2001-2002) and b) the operational phase (2003-2005).

Table 44. Significance of Maximum Likelihood Estimates in a logistic regression model, predicting the probability that bird flocks cross the eastern gate of the wind farm as a function of phase (base-line/operation), the distance in metres to the observation tower, wind direction (northerly/southerly), and first and second order interactions between factors. The most parsimonious model was chosen, using Akaike´s information Index. Model Goodness-of-Fit tests were carried out according to Hosmer & Lemeshow (SAS 1999), showing deviation (D) or compliance (C) between model and data at the alpha-level of 0.05.

Variable (DF)	**All data Wald X^2**
Phase (1)	113.00 ***
Phase*time (1)	2.88 NS
Phase*time*wind (1)	3.35 NS
Phase*wind (1)	Not fitted
Time (1)	20.23 ***
Wind (1)	5.94 *
Time*wind (1)	7.83 **
Goodness-of-Fit (5)	0.43 (C)
Sample size	4,514

ern gate during operation (χ^2 = 26.12, DF = 1, P < 0.0001 in a year-specific model). As for the autumn, the most significant factor, which contributed to explain the variation in the probability that birds would cross the eastern gate, was the project phases, which did not interact with other factors (Table 44).

There was a significant effect of crosswind on the probability that birds would cross the eastern gate. Hence, at southerly wind the probability was reduced to 11% compared to 16% northerly winds (Table 44).

The time of the day (day/night) greatly affected the probability of birds crossing the eastern edge (Table 44). Similar to the autumn operation phase, the probability that birds would cross the eastern gate was higher during the night than during the day and this pattern was consistent both during the base-line and operation phase. The magnitude of the time effect was dependent on the wind (time*wind, Table 44) insofar that the probability of crossing the eastern gate was comparable during daytime at both crosswind situations (Fig. 128A) compared nighttime, when the probability of crossings was lower during southerly crosswinds (Fig. 128B).

The spring analysis reflected how birds displaced after they have passed wind farm. Although, the results showed some significant relocation of the migration routes away from the wind farm area, the relocation patterns were more complex than during autumn.

The most significant avoidance effects were observed during the night (Fig. 128B). Both the area north and south of the wind farm gained some importance.

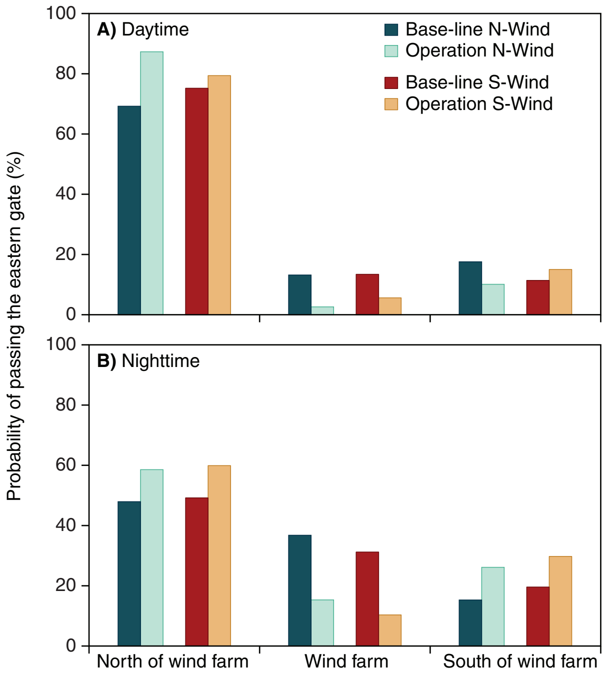


Figure 128. Probability that bird flocks flying in a westerly direction in the study area will pass the north of, south of and through the wind farm area (eastern gate) in spring during the base-line study (2000-2002) and the operational phase (2003-2005). Data are presented for a) daytime and b) nighttime under different crosswind regimes (northerly/southerly).

During daytime, only in situations with northerly winds a clear change in migration routes was detected. Both the trajectory crossing the eastern gate of the wind farm and the south of it lost importance, while the trajectory north of the wind farm became more important to the extent that more than 90% of the flocks migrated here during operation. Conversely, no major changes in migration routes (north, south or across wind farm) were found during daytime and southerly winds. Already during the base-line period, the trajectory at the eastern gate had little importance, and a further but minor reduction in migration at this place during the operational phase led to an increase both north and south of the wind farm.

Migration intensity at the wind farm

In this section, the local migration intensity on buoy-transect and at the eastern and northern gates was investigated before and after construction of the wind farm (Fig. 129), using telescope and radar. Due to the prevailing orientation of the migration to the east and north in spring, the transect and gates were placed after birds have passed the wind farm, and thus the number of flocks, which migrated out of the wind farm, was counted. Furthermore, it was investigated whether changes at the gates was associated with a general reduction in migration intensity in the wind farm area.

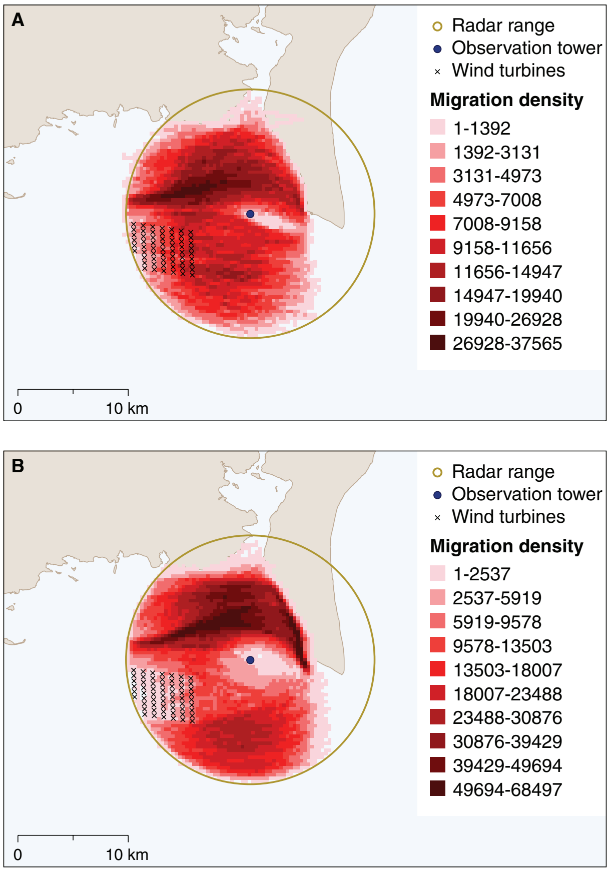


Figure 129. Spatial migration density of waterbird flocks migrating in the study area during spring. The density is indicated by the total length of tracks in metres within each grid cell. Maps are presented for A) the base-line study (2001-2002) and B) the operational phase (2004-2005).

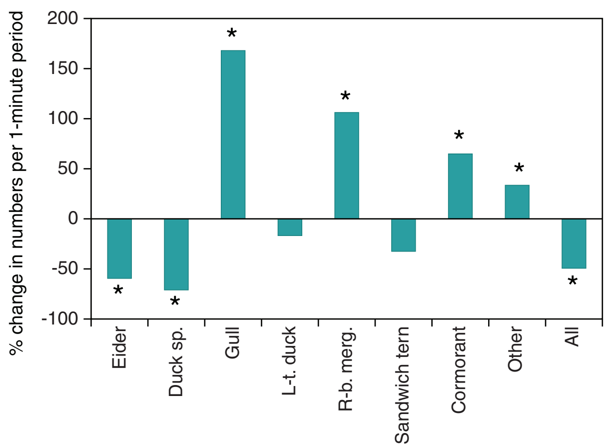


Figure 130. Proportional change in the average numbers of birds between the base-line study and the operational phase for nine selected species categories. Significant changes for P < 0.05 was labelled with asterisks (Kolmogorov-Smirnov Test).

Overall, the daytime migration intensity on the buoy-transect was reduced significantly by 50%. However, there were remarkable differences between the selected species (Fig. 130). While the migration intensity of ducks was reduced by more than 50%, fish-eating (Cormorant, Red-breasted Merganser and Sandwich

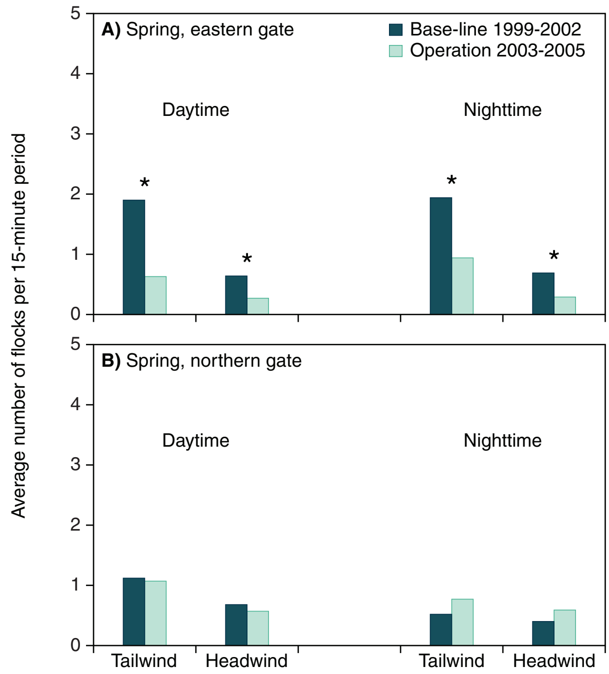


Figure 131. Average number of flocks per 15-minute period crossing the eastern (A) and northern (B) gate of the Nysted Offshore Wind Farm during spring, broken into periods of head- and tailwinds, day- and nighttime and project phases (base-line/construction). Significant differences between base-line and operation for P < 0.05 are labelled with asterisks (Kolmogorov-Smirnov Test).

Tern) and omnivorous species (gulls) increased significantly or remained at the same migration intensity during operation compared to the base-line study (Fig. 130).

Similar to the autumn migration period there was a remarkable difference between periods of tailwind and headwind at the eastern gate insofar that most flocks were observed during periods of tailwind (Fig. 131A). There were significant declines in the migration intensity during the operational phase under all wind and time conditions, although the relative change was not so pronounced during periods of headwinds. These results suggested that the overall avoidance of the eastern migrating birds (mostly waterbirds) towards the wind farm shown by other data was associated by a general decline in migration intensity on the "back-side" of the wind farm.

Conversely, there was no change in the migration intensity between the base-line and operational period at the northern gate and also little difference between tail- and headwind periods (Fig. 131B). The north-bound migration was not very intense in spring at least not according to the visual observation on the buoy-transect except some occasionally intense and broad-fronted migration of mainly passerines at high altitude (Blew et al. 2006). Therefore a likely explanation is that flocks coming out on the "back-side" of the wind farm at the northern gate was birds that migrated above the wind farm both during the base-line and the operational phase and thus had no reason to show an avoidance response.

In addition, the area in and around the wind farm was most important with respect to staging waterbirds during spring. This involves for example Long-tailed Duck, Common Eider and Herring Gull, which were all observed in considerable numbers during the base-line study and also together with Cormorant inside the wind farm during operation. Hence, some of the migration at the northern gate could be local staging waterbirds.

Given that migration intensity declined at the eastern gate during the operational phase, this may be associated with a general reduction in migration intensity in the wind farm area. This was confirmed by a comparison between the eastern wind farm area and a reference area east of it (see Fig. 21). Even when taking into account the impaired detection of flocks by radar at long range, track densities (a measure of migration intensity) was in relative terms reduced by 57% in the eastern wind farm area during operation of the wind farm compared to the base-line study (Fig. 132).

4.2.3 Collision risk

4.2.3.1 Measuring avian collisions

In total, 178,005 minutes of TADS-operation was conducted during the study period, representing a total of 123.6 days out of a study period of 180 days (equals 259,200 minutes), resulting in an operation efficiency (OE) throughout the entire study period of:

$$OE = \frac{178{,}005}{259{,}200} \times 100\% = 68.7\% \qquad \text{Equation}$$

Monitoring was conducted in approximately equal proportions of the two viewing modes with a little bias towards the 45º view (Table 45).

Wind conditions during the study period affected the choice of viewing mode to a very high degree, since the preferred vertical view required a wind direction from the opposite side of the turbine tower to the placement of the camera. Otherwise the turbine blades would continuously sweep through the field of view of the camera and facilitate a false triggering. In the autumn periods, the optimal wind for the vertical viewing mode was from westerly directions (180°-360°) as the camera was mounted on the eastern side of the turbine tower (90°). In 52.2% of the study autumn period winds were from westerly directions and consequently it came from easterly directions in the remaining 47.8% (Fig. 133). In the spring periods, the optimal wind for the vertical viewing mode was from easterly directions (0°-180°) as the camera was mounted on the western side of the turbine tower (270°). In 23.6% of the study spring period winds were from easterly directions and consequently it came from westerly directions in the remaining 76.4% (Fig. 134).

Of these 17 automatically triggered sequences (Table 46), only one bird/bat was recorded as colliding with the rotating turbine blades as it was observed (in the 45º viewing mode) falling down from the sky without beating its wings. The fact that the bird did not use its wings suggests that it was a bird falling after colliding with the turbine blades and not a bird showing avoiding action by flying downwards.

Table 45. The operation time (when the camera is running), monitoring time (when the camera was able to detect birds) and the number of recorded thermal video sequences separated in accordance to the two different viewing modes. The two viewing modes are listed as they were prioritised during operation of the TADS.

	Operation time (minutes)	Monitoring time (minutes)	Number of sequences
Vertical view	85,752	65,163	3494
45 degree view	92,253	80,989	2013
Total	178,005	146,152	5507

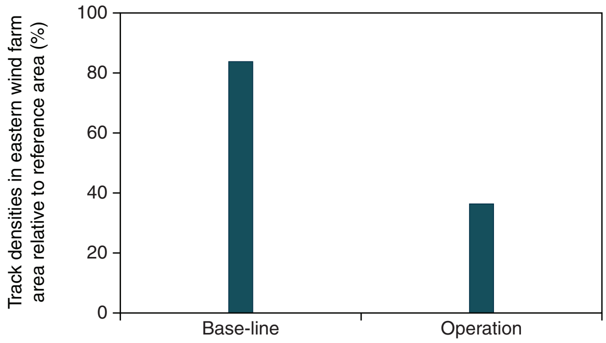


Figure 132. Track densities in eastern wind farm area relative to reference area (%) compared between the base-line study (2001-2002) and the operational phase (2004-2005).

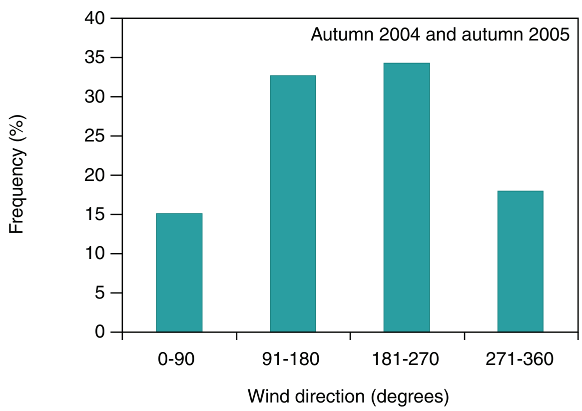


Figure 133. Frequency distribution of the wind direction divided in to four sectors (0-90° = north-east, 91-180° = east-south, 181-270° = south-west, 271-360° = west-north) and experienced in the study area during autumn 2004 and autumn 2005.

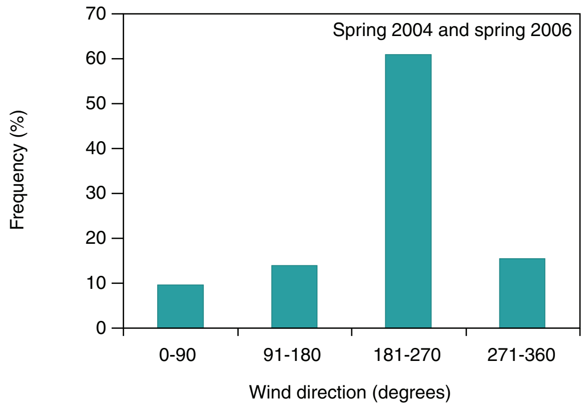


Figure 134. Frequency distribution of the wind direction divided in to four sectors (0-90° = north-east, 91-180° = east-south, 181-270° = south-west, 271-360° = west-north) and experienced in the study area during spring 2004 and spring 2006.

Table 46. The species composition of the 17 thermal video sequences trigged automatically by animals during the 146,152 minutes of collision monitoring using one TADS mounted on a single turbine. Monitoring time is given as a total for the vertical and 45º viewing modes.

	Bird	Bat	Moth	Bird/bat	Monitoring time (hours)
Spring 2004	3				412.5
Autumn 2004	6				1001.2
Autumn 2005		2	1	2	631.3
Spring 2006	3				399.8

The remaining 5490 non-animal sequences can be characterised as false triggered sequences, and were the result of changing temperature patterns in the background of the camera view. Such temperature changes in the field of view were, in order of frequency, caused by drifting clouds, sun heating of the atmosphere especially just after sunrise by the blades of the turbines turning into the field of view because of changing wind conditions, or due to other reasons (e.g. the sun entering the field of view; Desholm 2005a, Desholm 2005b).

However, such false triggered sequences were easily identified as being non-animal sequences, since a series of similar (showing similar picture in the first frame) sequences were saved during a restricted period of time which could be processed and removed within a few minutes in a single operation, and these periods were then excluded from the monitoring time. In order to estimate the monitoring efficiency, such unusable periods, which comprised many false-triggered sequences, were excluded from the operation time. Of the total operation time, 31,853 minutes (17.9%) could be characterised as unusable where the trigger software was constrained in operating properly. Thereby, the monitoring efficiency (ME) amounted to:

$$ME = \frac{178{,}005 - 31{,}853}{259{,}200} \times 100\% = 56.4\% \qquad \text{Equation}$$

4.2.3.2 Collision model parameterisation

Near rotor-blade avoidance response

During the TADS-operation period of 123.6 days, no waterbirds, which were the target species in this study, were detected as approaching the rotor-blades at short distance when the vertical viewing mode was used. One passerine was observed flying towards the rotor-blades and eventually performed a 180° horizontal turn and returned in the direction it came from. At a longer distance from the turbines (100-200 m) when using the horizontal viewing mode and manual recording, five out of 198 flocks (2.5%) of the waterbirds (probably Common Eiders) performed horizontal and/or vertical evasive manoeuvres to individual turbines or to the whole wind farm.

Flight speed and altitude

Mean air speed for Common Eiders was estimated to 17.34 m/sec (SD = 2.4; n = 352) for all flocks detected by radar in the study area during 1999-2004 and visually determined to species.

The flight altitude was estimated on the basis of 152 hours of horizontal TADS-recordings conducted during autumn 2004 (43 hours), autumn 2005 (71 hours), and spring 2006 (38 hours). In spring 2004, no estimations of flight altitude of Common Eiders were performed. In total, 44 flocks of waterfowl were recorded inside the wind farm and 149 flocks outside.

The mean (±SD; N) flight altitude was 14.6 m (±13.2; 44) and 27.4 m (±22.8; 149) for flocks of waterbirds flying inside and outside the wind farm, respectively. Fig. 135 shows the frequency distribution of flight altitudes for waterbird (probably Common Eiders) flocks inside and outside the wind farm. Only one flock was observed flying higher than the upper reach of the rotor-blades (110 m) and the percentage of flocks flying below the rotor-blades were 88.6% and 55.7% for flocks inside and outside the wind farm, respectively.

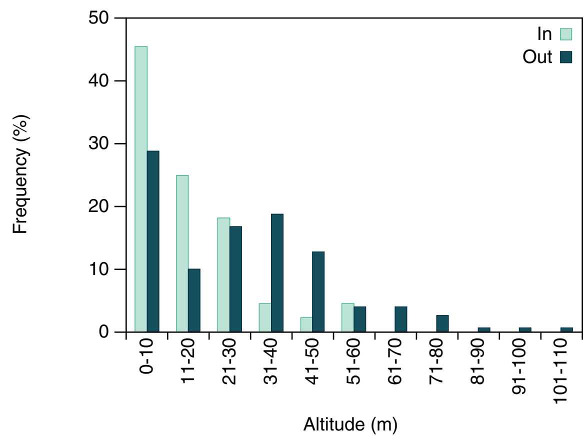


Figure 135. Frequency distribution of the flight altitude for flocks of migrating waterbirds passing the view of the TADS during autumn 2004, autumn 2005 and spring 2006. “In” means flocks flying within the wind farm and “Out” flocks flying just outside the wind farm to the south.

In order to get a factor in the decrease in coverage with increasing altitude inside the wind farm, a correction factor was calculated for each 10 m altitude interval for the flocks flying inside the wind farm. However, since no observations was made above 60 m inside the wind farm, a comparison between inside and outside the wind farm was based on the data from the 0-60 m interval only. The Common Eiders were flying lower inside the wind farm compared to outside (Kolmogorov-Smirnov two-sample two-tailed test, D = 0.2316, $n_{in(corrected)} = 51$, $n_{out} = 149$, d.f. = 2, $p < 0.05$) with a higher frequency of low-flying (<30 m) flocks inside the wind farm compared to outside (Fig. 136). The mean percentage of waterbird flocks flying below 30 m (below rotor-blade height) was 84.19% (Fig. 136).

A tendency to increasing flight altitude with increasing tail-wind component was discovered (Fig. 137), but the explanatory power was relatively low. This could, in part, be due to the very few data collected in periods with head winds, periods which are known to result in low migration volume of Common Eiders (Pettersson 2005), and thus, periods that have not been prioritized in the data collection protocol.

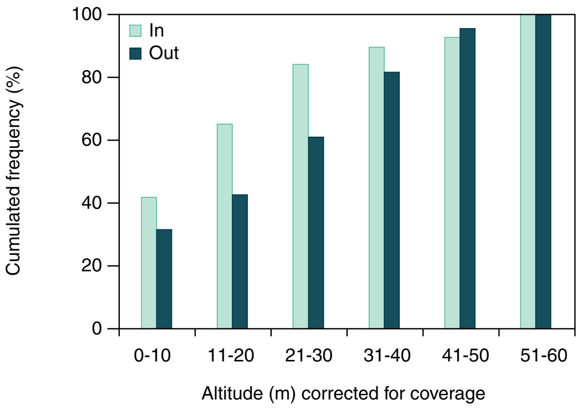


Figure 136. Cumulated frequency distribution of the corrected (for flocks inside the wind farm) flight altitude for flocks of migrating waterbirds passing the view of the TADS during autumn 2004, autumn 2005 and spring 2006. "In" means flocks flying within the wind farm and "Out" flocks flying just outside the wind farm to the south.

Only five out of the 149 flocks of waterbirds migrating outside the wind farm were detected during darkness, and hence, a proper day vs. night comparison of flight altitudes could not be carried out. All data from outside the wind farm were consequently pooled in to a single data set. In order to explain the lack of birds during the night-time from TADS-recordings below 110 m (the altitude interval covered by the TADS in horizontal viewing mode), a comparison was made between the number of waterbird flocks recorded by radar and the number recorded by TADS during a period (17-19 October 2005) of high migration intensity when simultaneous monitoring was conducted by both TADS and radar. During day-time, the TADS recorded 96% of the flocks recorded by the radar (N = 50). At night, the TADS recorded 0% of the flocks recorded by the radar (N = 26). Only flocks passing within the field of view and range of the TADS was used in this analysis. Consequently, it is concluded that the waterbirds are flying above turbine height (>110m) during the night and that the night-time collision risk therefore is close to zero. As a consequence of this we only run the collision prediction model for the waterbirds migrating during day-time.

Flock size and species composition

From the horizontal TADS-recordings (from both inside and outside the wind farm) 38 flocks of larger gulls (i.e. Herring Gull) and 187 flocks of waterfowl (probably Common Eiders) could be assessed for flock size. The average (±SD) flock size were 30.9 (±21.8) and 1.1 (±0.3) individuals for Common Eider and larger gulls, respectively.

The frequency distribution of the waterfowl flock sizes (Fig. 138) was skewed towards smaller flocks with values for skewness and kurtosis of 1.3 and 2.0, respectively. Again the number of flocks detected in darkness was not sufficient for a proper statistical analysis between day and night. For Cormorants and passerines, the other two species/group of species which were observed during the horizontal recordings, the number of flocks was insufficient for any statistical analyses of their flock sizes.

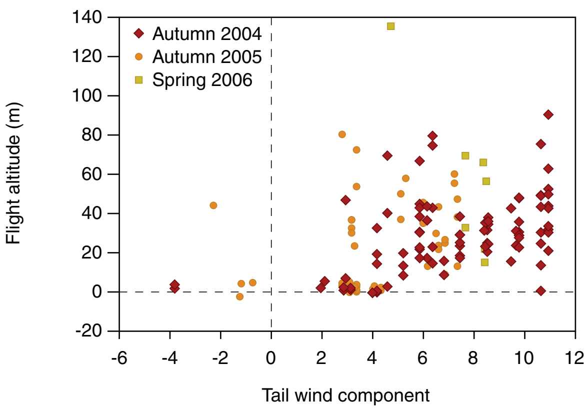


Figure 137. Relationship between the tail wind component and flight altitude. Positive tail wind component means tail wind whereas negative component values means head winds.

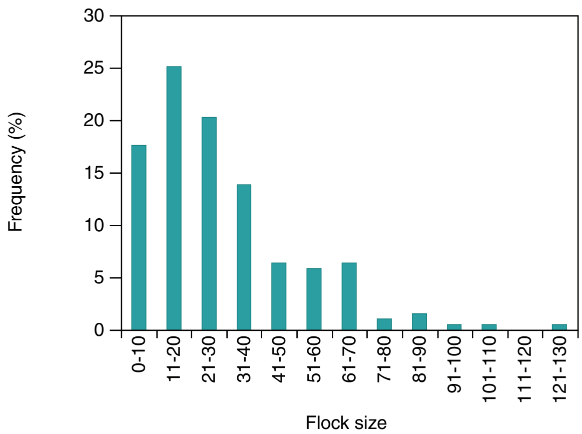


Figure 138. Frequency distribution of the flock size of waterbirds (mainly Common Eiders) as observed by the TADS recordings (n = 187).

4.2.3.3 Collision model

Parameterisation of model input values

In the following, procedures for parameterisation of the model input-data for the stochastic predictive collision model (SPCM; see Fig. 15) will be outlined. For a description of the abbreviations used for transitions rates and in-crossing numbers, see chapter 2.6.3.

The estimated autumn migration volume of 235,136 individuals (n_1) for Common Eiders in the study area is adopted from Table 34. It is obvious that the estimated number of collisions will be directly correlated with n_1, and hence, no variation is built in to this input parameter. Any variation in n_1 will not influence the proportion of the birds passing the study area.

Values presented in this paragraph are derived from the post-construction radar study at Nysted. The overall proportion of flocks crossing the eastern row of turbines decreased significantly from 40.4% (n = 1,406) during pre-construction (2000-2002) to 8.9% (n = 779) during initial operation (2003; χ^2 = 239.9, P < 0.001; Desholm & Kahlert 2005). The average (±SD) proportion of flocks entering the wind farm (r_1) during the post-construction autumn seasons of 2003-2005 was 11.55 (±7.93). The resulting frequency distribution (Fig. 139) is judged to be normal distributed (Kurtosis: -0.099; Skewness: 0.70), and hence, r_1 is re-sampled at each model event from at normal distribution with the above described average and SD-values.

Overall, the average (±SD) wind direction was 168.9° (±118.67°) and was judged to be normal distributed (Kurtosis: -1.26; Skewness: 0.46), and thus, the built in feature of the software Stella was used to draw a wind direction from a normal distribution with the above described parameters for each model run. The wind direction was then transformed in to a horizontal risk distance (HRD) in accordance to equation M05 and Fig. 140.

In Fig. 141, the frequency distribution of the distance to nearest turbine for flocks passing through the first row of the wind farm is shown. The mean (±SD) distance to nearest wind turbine was 156.0 m (±64.1) and the frequency distribution was judged to be normal distributed (Kurtosis: -0.41; Skewness: -0.68).

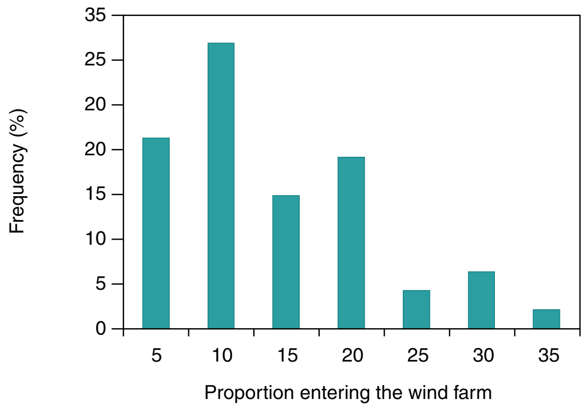


Figure 139. Frequency distribution of the proportion of the flocks of waterbird entering the wind farm through the eastern gate. Data comes from the post-construction radar studies.

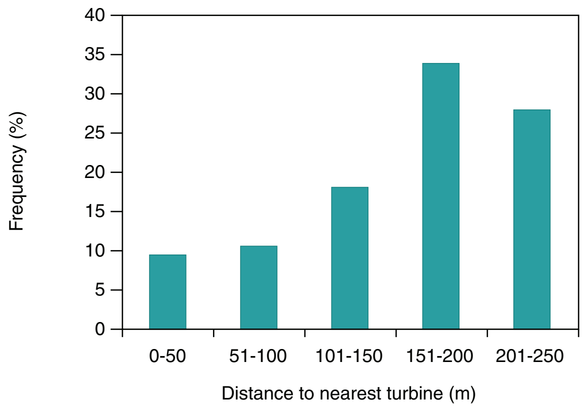


Figure 141. Frequency distribution of the distance to nearest turbine for flocks of waterbirds entering the wind farm through the eastern row of turbines. Data comes from the post-construction radar studies.

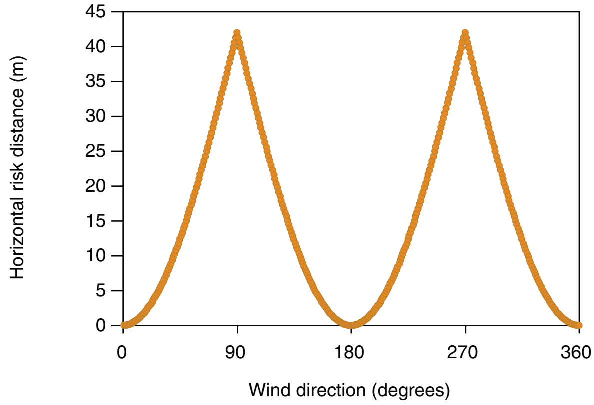


Figure 140. The relationship between the wind direction and the horizontal risk distance (see text for further detail).

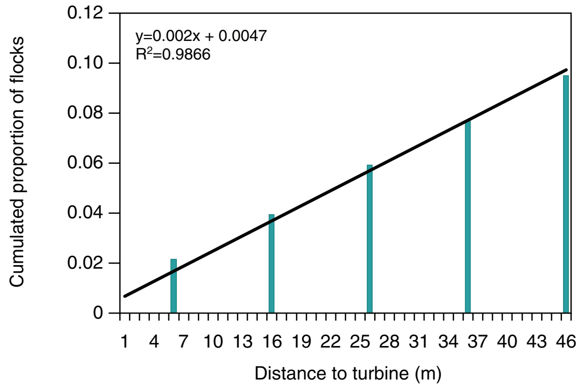


Figure 142. The same data as presented in figure 141, but here the distance to nearest turbine for flocks of waterbirds are presented as a cumulated frequency distribution.

Each re-sampled horizontal risk distance is then used together with the known distribution of distance between flocks of birds and the nearest turbine (Fig. 141) to calculate the proportion (r_2) of waterfowl flocks flying within the HRD in the given wind situation in accordance to y = 0.002x + 0.0047 (Fig. 142). This equation describes the relationship between the cumulative proportions of waterbird flocks migrating at different distances to the nearest turbine.

TADS measurements of the migration altitude of Common Eiders migrating inside the wind farm was corrected for coverage (see above), and 0.1581 was used as input value for the proportion (r_3) of waterbird flocks migrating above 30 m (Fig. 136).

The proportion (r_4) of birds trying to pass the area swept by the rotor-blades without performing any evasive actions was significantly constrained by the general large proportion of birds which avoided flying in the collision risk zone of the blades. Therefore, it is not possible to estimate an r_4-value based on the data collected for this report. However, Winkelman (1992) reported that 92% of the birds approached the rotor without any hesitation at day time. This figure was adopted as the r_4-value. It must be stressed here that this value has not been collected for Common Eiders, but is the only available estimate at present.

The probability of passing safely the rotor-blades by chance (c) was adopted from Tucker (1996) where different values are presented for head (0.665) and tail (0.809) wind situations. So the re-sampled wind directions from earlier in the model are used to determine whether the head or tail wind value of c should be used for the given iteration.

On average, each flock entering the wind farm from the east pre-construction passed 5.9 (SD = 2.5) north-south orientated rows of turbines. The majority of all trajectories (48.7%) passed 8 rows whereas the remaining flocks were more or less evenly distributed with between 1 to 7 row passages (Fig. 143). For the present model a rounded mean of 6 rows were adopted as can be seen in Figure 15 and their inclusion in the model framework follow the description in the Method paragraph.

Running the model

Using the model framework and input values described above in this stochastic predictive collision model (Fig. 15) for the Nysted offshore wind farm resulted in an average (±SD) number of 44.4 (±51.1) migrating Common Eiders colliding during one autumn season (Table 47, Fig. 144 and Fig. 145). The estimated 95% confidence limits (CL) are ±3.2, and consequently, this means that we are 95% confident that the mean lies between 41.2 and 47.6 Common Eiders colliding with the turbines in the Nysted offshore wind farm. Hence, the general risk of collision for waterbirds passing the study area at Nysted is estimated to lie between 0.018% and 0.020% (($n_{collision}$ ± CL)*100%).

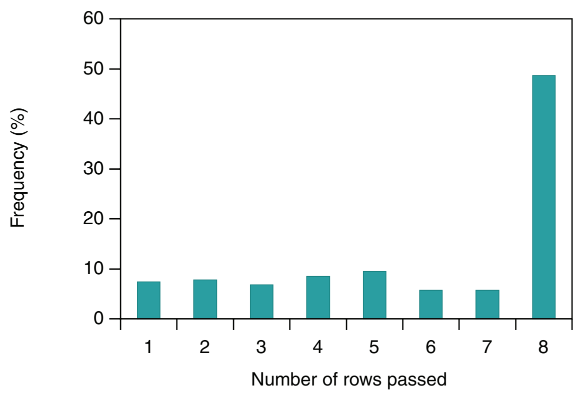


Figure 143. Frequency distribution of the number of north-south orientated rows of turbines passed by the autumn migrating flocks of waterbirds passing the wind farm area in the pre-construction period (2000-2002; Redrawn after Desholm 2005b).

Table 47. Input and output values for the 1000 iterations of the stochastic predictive collision model (Fig. 15). Numbers in superscript refer to the reference: 1) Tucker 1996, 2) Winkelman 1992.

	Parameters	Average value (SD)	Re-sampling method
Model input	n_1	235,136	Fixed number
	C	0.665/0.809	Head wind / tail wind[1]
	r_1	0.1155 (0.0793)	Normal distribution
	r_2	0.0267-0.0887	Variable due to wind
	r_3	0.1581	Fixed value
	r_4	0.92	Fixed value[2]
	n_m	6	Fixed number
Model output	$n_{collision}$ (wind farm)	44.4 (51.1)	Stochastic modelling
	Probability of collision (%)	0.018 – 0.020	$n_{collision}$ ±SD used

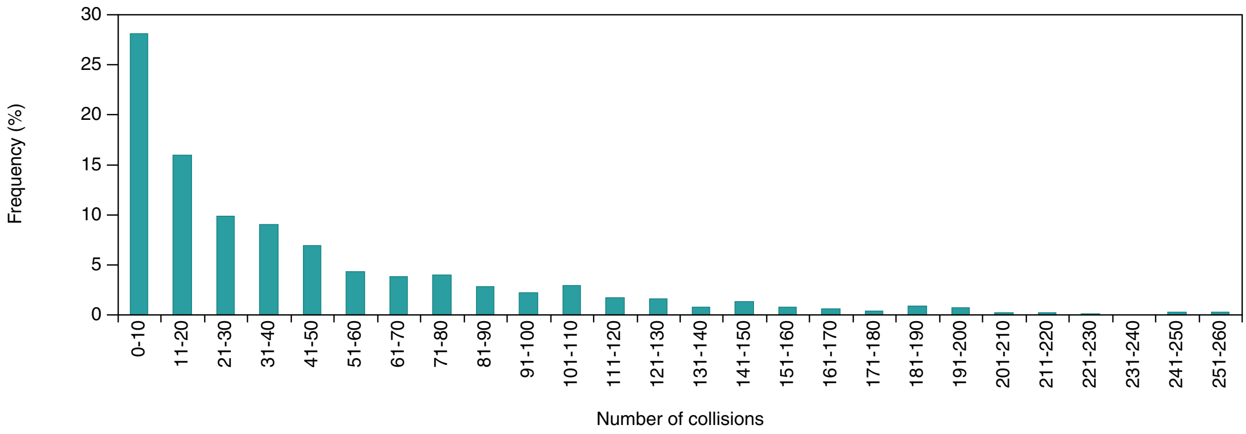


Figure 144. Frequency distribution showing the number of estimated collisions after 1000 iterations of the stochastic collision model.

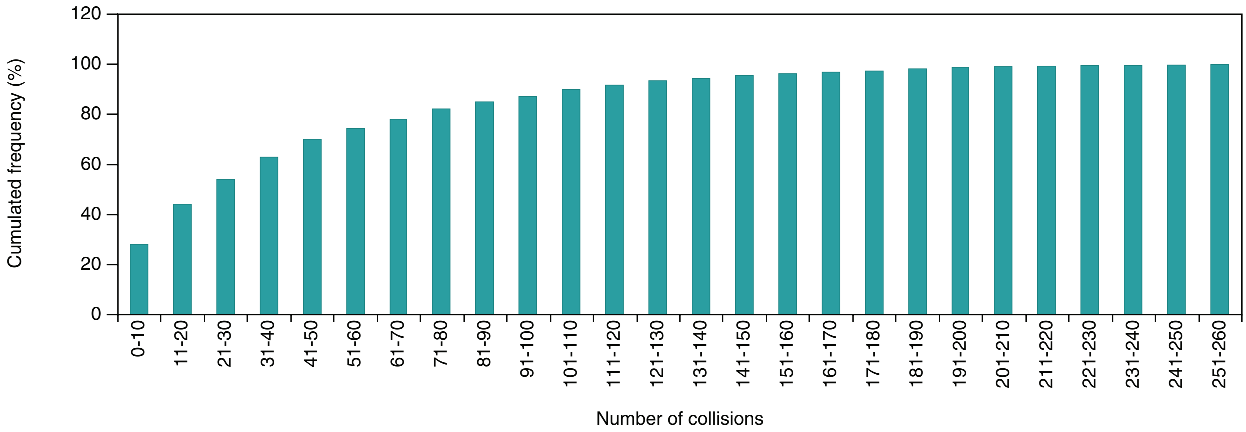


Figure 145. The same data as presented in Fig. 144, but here the number of estimated collisions are presented as a cumulated frequency distribution.

4.3 Migratory bird studies at Horns Rev

Christensen, T.K., Jens Peder Hounisen, Ole Therkildsen

4.3.1 Species specific phenology at Horns Rev

A total of 82,727 birds were recorded by the systematic visual observations on the four transects during 2003-2005. The numbers of individuals recorded of the different species or species groups, ranged between 2 and 63,446 individuals. Diving ducks, almost exclusively Common Scoter, gulls and terns constituted the most numerously occurring group of species (Table 48). Waders constituted the group with most recorded species, with especially high numbers migrating in spring. Knot *Calidris canutus* and Golden Plover *Pluvialis apricaria* constituted the dominant species amongst the radar observations. Such high numbers of shorebirds were not recorded during visual transect observations.

The descriptions of species occurrence and behaviour in relation to the Horns Rev wind farm, is generally based on the visual transect observations, but also include the radar recordings where species identification was obtained, as well as some occasional observations made of specific behavioural reactions of bird approaching the wind farm, that could not always be recorded during the more standardised observation procedures. During radar observations in 2003-2005, a total of 1,190 tracks were assigned to species or species group, embracing a suite of 29 different species.

During 2005, the species composition of visually observed birds recorded during transect counts was comparable with the species composition recorded in 2003 and 2004. In all years, Common Scoter, gulls and terns were the numerically dominant species. Taking the different seasonal coverage into account in comparing numbers recorded during all three study years, the numbers recorded in separate years did not show marked differences. Only Common Scoter showed a small, but declining trend in numbers recorded during visual transect observations.

In the following paragraphs the most numerously occurring species, and species of special interest, recorded at Horns Rev, are considered with regards to general occurrence, flight intensity, flock size or flight behaviour relevant to wind farm issues. Data are included both from the visual observations and from species specific observations obtained during radar operation. A few observations of other bird species, i.e., raptors and passerine birds, were made during transect observations, but these observations were considered very sporadic. A more accurate picture of the occurrence of these species, although not numerically, could be obtained from miscellaneous observations made from the transformer station throughout the study (see Christensen et al. 2006).

Table 48. The number of species and numbers of individuals in different species groups recorded during visual transect observations at Horns Rev wind farm 2003-2005.

	Visual transects	
	Number of species	Number of individuals[1]
Divers	2	117
Gannet	1	557
Grebes	1	11
Petrels	3	6
Cormorants	2	186
Egrets	1	1
Swans	1	27
Geese	2	275
Diving ducks	4	63,446
Dabbling ducks	3	50
Mergansers	2	11
Raptors	4	6
Shorebirds	6	120
Skuas	3	150
Gulls	8	7,914
Terns	3	8,747
Alcids	3	82
Passerines[2]	5	1,021
Total	54	82,727

[1] The number of individuals includes both those birds identified to species and those only identified to species group. A detailed list of species recorded during visual transect observation is given in Christensen et al. (2006).
[2] The number of Passerines species recorded during transect observation is not representative for the occurrence in the area. A more representative list of the occurrence of passerine species is given in Christensen et al. (2006) showing miscellaneous observations made during the present study.

Divers Gavia arctica/stellata

A total of 117 divers was recorded during visual transect observations during 2003-2005. Most divers were recorded in March and November (Fig. 146), reflecting the known occurrence with highest number of staging divers in the area during winter (see Christensen et al. 2003, Petersen et al. 2004). The relatively low numbers of divers recorded during peak spring migration in April and May, is probably a result of too few days of observation relative to the length of the migrating season, in combination with the irregular occurrence of very intensive diver migration in the Horns Rev area (cf. Jacobsen et al. in prep.). The peak staging period of divers at Horns Rev in February, as evidenced by maximum numbers recorded during aerial surveys (Petersen et al. 2005), was not covered in any of the three study years.

The mean migration activity of divers recorded on the four transects around and inside the wind farm during spring and autumn periods, expressed as the mean number of birds per 15 minutes, is shown in Fig. 147. Mean migration activity showed a consistent pattern being highest east of the wind farm, lower in the area north of the wind farm, and lowest at the edge and within the wind farm. Divers were only recorded flying into the wind farm in the autumn of 2005, when a total of 3 birds made four crossings of the two transects located at the edge and inside the wind farm. In all years the activity level of divers was comparable between spring and autumn, and activity was higher in the morning hours, when on average 56% of the divers were recorded during the first two hours after sunrise.

Divers were mainly observed as solitary individuals or as two individuals together, with a mean flock size ranging between 1.04 and 1.39 in both spring and autumn (Table 49). Divers occurring in larger flocks in the area were only recorded during radar observations in April 2005, when seven flocks of 3, 4, 5, 7, 10, 12 and 13 individuals, respectively, were observed. As divers form loose flocks during migration, these flocks probably reflect the occurrence of migrating divers staging in the Horns Rev area at this time. That all seven flocks were flying in a southerly direction suggested that these flocks represented birds making local movements to compensate nocturnal drift by a northward current.

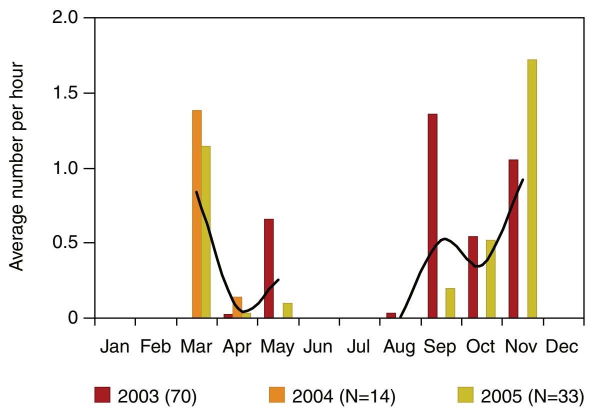


Figure 146. The seasonal occurrence of divers shown as the average number recorded per hour of observation recorded during spring and autumn periods in 2003, 2004 and 2005.

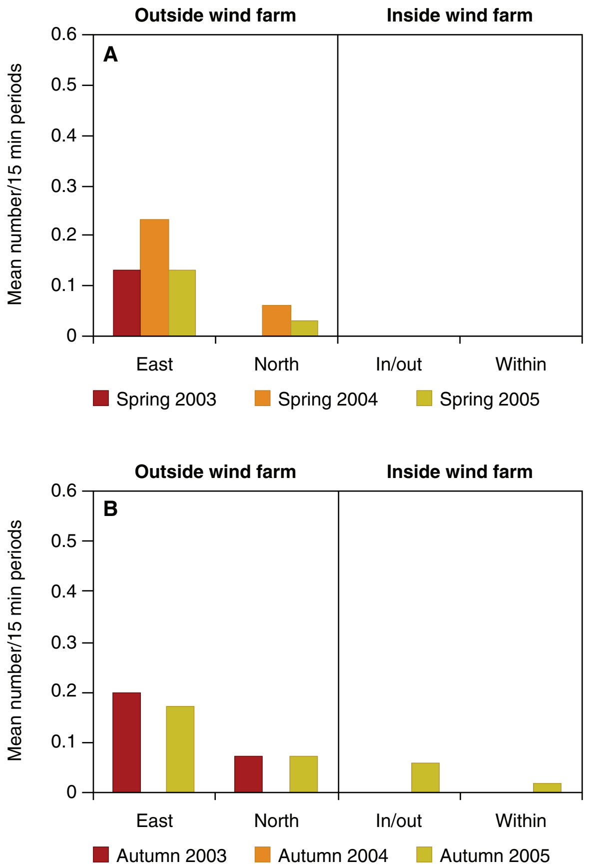


Figure 147. Migration intensity (mean number of birds per 15-minute period) of divers crossing the four transects located east and north of the wind farm, along the eastern row of turbines (In/Out) and within the wind farm (Within) in 2003, 2004 and 2005 during spring and autumn periods.

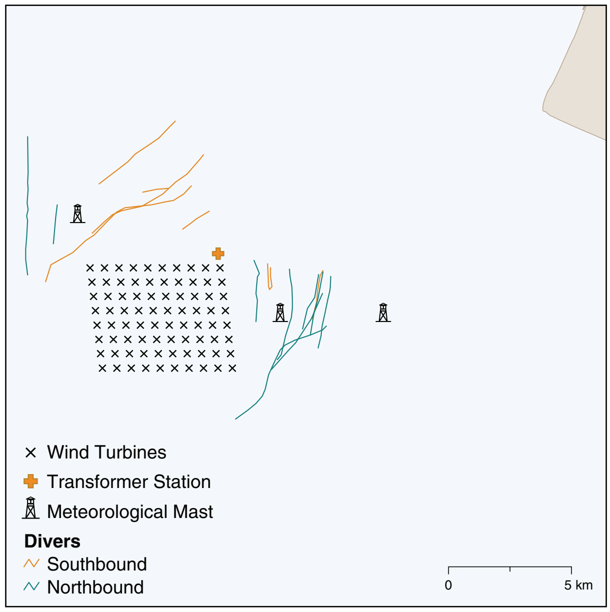


Figure 148. Radar tracks of 16 individuals/flocks of divers migrating southwards and northwards at Horns Rev during spring 2003-2005.

A total of 16 tracks/flocks of divers, comprising 61 individuals, were recorded by radar during 2003-2005. None of the tracks of divers were recorded to cross into the wind farm (Fig. 148). Likewise, all divers that approached the wind farm from the north when crossing the transect north of the wind farm and which were visually followed, consistently deflected westward and passed around the wind farm. Besides the 3 divers observed inside the wind farm during transect observations, only two individuals were recorded flying close to the wind farm, actually passing in between the transformer station and the wind farm. One diver recorded by radar was flying southward towards the meteorological mast just east of the wind farm. At a distance of ca. 1 km north of the meteorological mast this bird made a U-turn and flew back north (see Fig. 148).

Table 49. Mean flock size recorded during spring and autumn 2003-2005 and total number of flocks (N). Data were log-transformed.

	Spring				Autumn			
	2003	2004	2005	N	2003	2004	2005	N
Divers	1.39	1.21	1.15	32	1.07	-	1.04	62
Gannet	1.16	1.18	1.23	267	1.13	-	1.15	190
Common Scoter	4.63	4.11	5.94	3,566	4.49	-	3.38	398
Herring Gull	1.13	1.18	1.21	563	1.07	-	1.10	1,666
Great Black-backed Gull	1.13	1.18	1.15	238	1.08	-	1.04	1,270
Black-headed Gull	2.51	1.32	1.26	25	2.45	-	-	34
Common Gull	1.19	1.30	1.84	252	1.18	-	1.05	159
Little Gull	1.84	1.89	9.21	167	1.75	-	2.16	243
Kittiwake	1.17	1.29	1.29	261	1.11	-	1.19	823
Arctic/Common Tern	2.04	2.15	4.33	492	1.73	-	1.76	326
Sandwich Tern	1.27	1.65	1.51	2,367	1.28	-	2.40	974

Gannet *Sula bassanas*

A total of 561 Gannets were recorded during visual transect observations in 2003-2005. Most Gannets were recorded during late spring and late summer (Fig. 149). Comparing years, some marked variation in the occurrence of Gannets is evident, especially in August and September. This variation is probably influenced by prevailing weather conditions, especially wind force and wind direction, which may displace Gannets differently in the North Sea, and hence, affect numbers occurring at Horns Rev. The occurrence of Gannets may, however, also be affected by variable food availability and by the breeding success within the colonies of northwest Europe, from which the birds originate.

The mean migration activity of Gannets recorded on the four transects around and inside the wind farm during spring and autumn periods 2003-2005, expressed as the mean number of birds per 15 minutes, is shown Fig. 150. Mean migration activity was generally highest east of the wind farm, lower in the area north of the wind farm, and lowest at the edge of the wind farm. Except for the very high number recorded during autumn 2004, the level of migratory activity was slightly higher during spring than during autumn. Only 10 out of the 561 individuals have been recorded crossing the two transects located at the edge and inside the wind farm during all study years. Gannets normally occurred as solitary individuals or in loose flocks, and showed a flock size ranging between 1.1 and 1.3 birds in both spring and autumn (Table 49). Most Gannets were recorded during morning hours (49%) and fewest at evening (19%).

A total of 126 tracks/flocks of Gannets, comprising 268 individuals, were recorded by radar during 2003-2005. Gannets were recorded in all observation periods, except in March and October. The majority of Gannets were migrating towards north, both during spring (84 of 95 tracks) and autumn (27 of 31 tracks). No tracks of Gannets were recorded flying into the wind farm, and Gannets generally kept clear of the wind farm. In a few cases southbound individual birds came in very close to the wind farm, and these birds clearly made marked turns in the flight trajectory that probably reflected avoidance reactions towards the wind farm or towards individual turbines (Fig. 151).

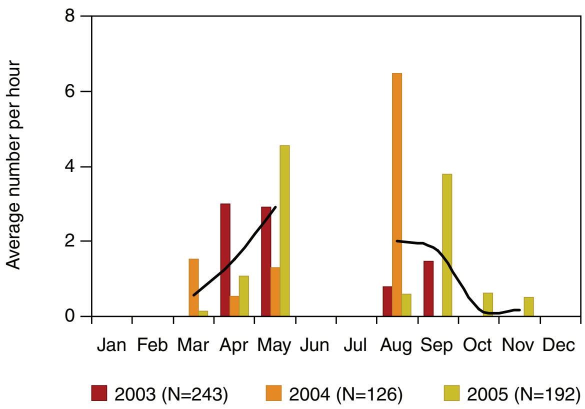


Figure 149. The seasonal occurrence of Gannets shown as the average number recorded per hour of observation during spring and autumn periods in 2003, 2004 and 2005.

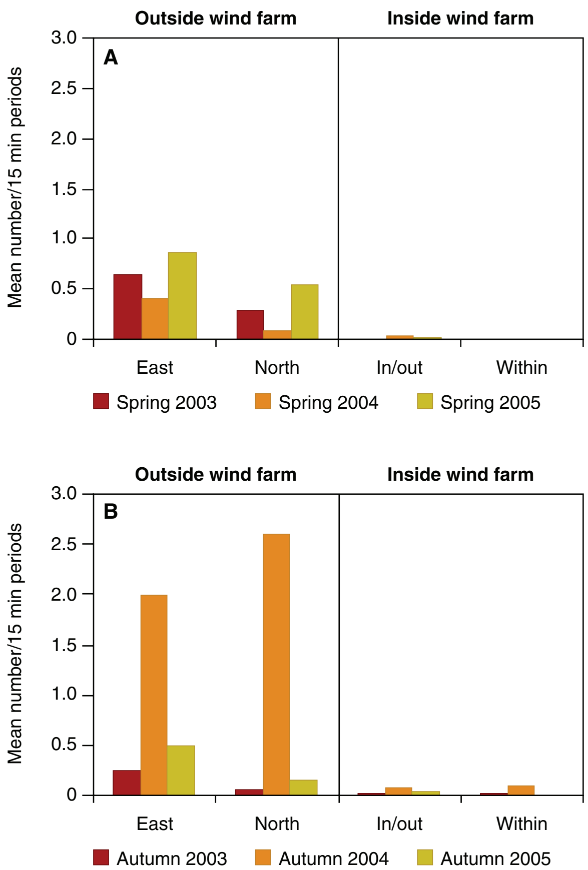


Figure 150. Migration intensity (mean number of birds per 15-minute period) of Gannets crossing the four transects located east and north of the wind farm, along the eastern row of turbines (In/Out) and within the wind farm (Within) in 2003, 2004 and 2005 during spring and autumn periods.

Common Scoter *Melanitta nigra*

A total of 63,301 Common Scoters were recorded during visual transect observations during 2003-2005. Most Common Scoters were observed in April and May, but some difference in occurrence existed between years. Compared to the high numbers recorded in spring during 2003 and 2004, numbers were much lower in 2005, and exceptionally small in April and May, where the numbers peaked in both 2003 and 2004 (Fig. 152). This difference in the occurrence of Common Scoter was only evident during spring, and was in all probability affected by a change in distribution. In 2003 and 2004, Common Scoters were observed in high numbers exploiting the area just north and north-west of the wind farm, whereas in the spring of 2005, the birds had moved further westwards and were only recorded in small numbers close to the wind farm (cf. aerial surveys see Fig. 34). In contrast to the high and variable numbers recorded during spring, the Common Scoter was consistently observed in very low numbers during autumn periods.

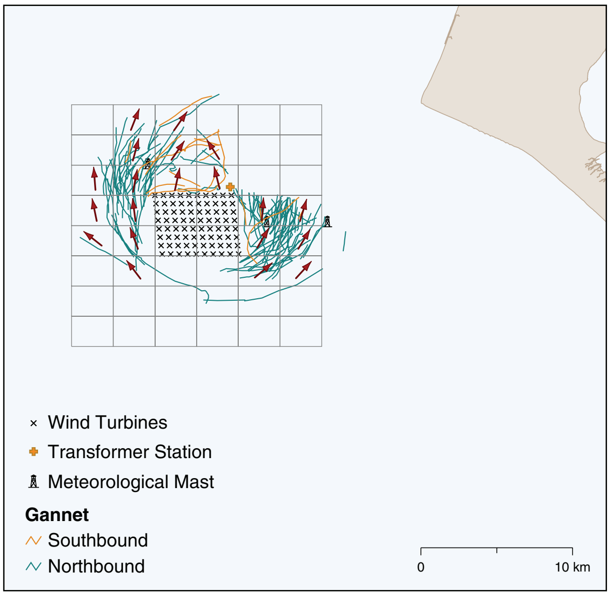


Figure 151. Radar tracks of 126 individuals/flocks of Gannets migrating southwards and northwards at Horns Rev during spring 2003-2005.

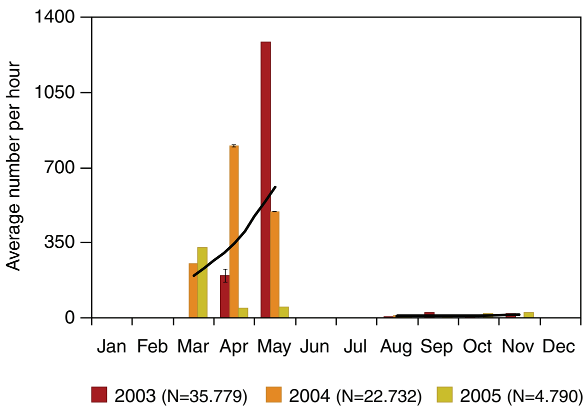


Figure 152. The seasonal occurrence of Common Scoter shown as the average number recorded per hour of observation recorded during spring and autumn periods in 2003, 2004 and 2005.

The mean migration activity of Common Scoters recorded on the four transects around and inside the wind farm during spring and autumn periods, expressed as the mean number of birds per 15 minutes, is shown in Fig. 153. Mean migration intensity was generally highest east of the wind farm, lower north of the wind farm, and lowest at the edge and within the wind farm. In spring 2004, migration activity was extremely high north of the wind farm, which reflects the flying activity when the high numbers of birds exploiting this area were making local movements to and from a north-eastern direction. The diurnal pattern of activity showed that most were recorded during morning hours (70%), and fewest were recorded during evening hours (7%). The average flock size ranged between 3.38 and 5.94 individuals (Table 49). However, during a few occasions with extremely intense migration, no attempts were made to record flock size.

During 2003-2005, a total of 916 (1.45% of all recorded Common Scoters) individuals were recorded to pass the two transects at the edge and inside the wind farm. Although representing a very low number of birds, the relative frequency of Common Scoters recorded on these transects increased from 0.03% in 2003 to 2.9% in 2004 to 5.3% in 2005, indicating that some reduced reaction towards the wind farm may have occurred.

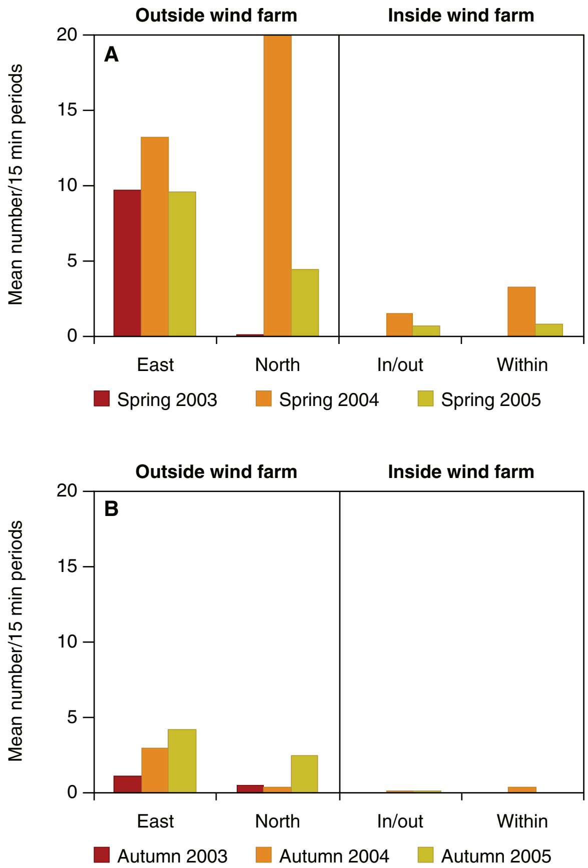


Figure 153. Migration intensity (mean number of birds per 15-minute period) of Common Scoter crossing the four transects located east and north of the wind farm, along the eastern row of turbines (In/Out) and within the wind farm (Within) in 2003, 2004 and 2005 during spring and autumn periods.

Any assessments of the potential reduced reactions of Common Scoters to the wind farm, in terms of a measure of the total change in number of birds flying within the wind farm area, should account for the increasing number of birds recorded in and around the wind farm over the three study years. Using only data from the period of peak occurrence in spring, the number of Common Scoters recorded flying inside the wind farm increased from 1 individual in 2003 to 635 in 2004 and decreased to 248 in 2005. In terms of relative number, the occurrence inside the wind farm in spring, as a proportion of the whole, increased from an average of 0.003% in 2003 to 2.87% in 2004 and 5.9% in 2005, although some seasonal variation existed (Fig. 154). Correlation of the occurrence inside the wind farm with occurrences on each transect showed the strongest correlation with the occurrence on the transect north of the wind farm (r^2 = 0.80, $F_{1,6}$ = 24.75, p = 0.0025), suggesting that the occurrence inside may actually just reflect occurrence by chance and not that the Common Scoter have got used to the presence of the wind farm.

All recorded radar tracks of southbound and northbound Common Scoters are shown in Fig. 155. Common Scoters were 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 a common roosting and foraging area just north of the wind farm, which was used by a high number of birds during April and May 2003 and 2004, whereas fewer birds were present in this area 2005 (cf. Petersen et al. 2005).

A total of 288 tracks/flocks of Common Scoters, comprising at least 2,379 individuals, were recorded by radar during 2003-2005. The majority of tracks were recorded during April and May, and most showing a northward direction. Of all recorded tracks, 33 passed into the wind farm (Fig. 155). The pattern of movements of Common Scoters around the wind farm reflects that most birds pass around the wind farm, and reflects the movements to and from the staging area north of the wind farm.

Gulls *Laridae*

A total of 7,914 gulls were recorded during visual transect observations in 2005. Of these, 83% was assigned to species level. A slight majority (63%) was recorded during autumn, but the seasonal occurrence varied between species. Of the identified birds, the most numerously occurring species was Herring Gull (N=1,851), Little Gull (N=1,196), Great Black-backed Gull (N=1,160) and Kittiwake (N=1,002). Except for the one individual of Sabine's Gull *Larus sabini* that was observed in 2003, all identified species were recorded within the wind farm. The percentage recorded inside the wind farm varied markedly between species, being highest in Herring Gull (35.3%), Lesser Black-backed Gull (37.9%), Great Black-backed Gull (37.6%), Common Gull (37.7%) and Kittiwake (30.6%), and lowest in Little Gull (4.8%).

The seasonal occurrence of the most numerously occurring gull species recorded at Horns Rev during 2003, 2004 and 2005 are shown in Fig. 156A-E.

In the spring of 2005, Little Gull was observed in very high numbers during the late evening hours of 20 April. The number of Little Gulls flying in a northerly direction at the east side of the wind farm was estimated to 1,800 to 2,000 birds. In relation to the total flyway population of 60,000-90.000 birds from which these birds originate, this record covers a significant part of the population. During the following days, Little Gulls were observed in lower, but relatively high numbers during transect counts. During these days, the birds showed a less determined directional movement than during the evening of the 20 April.

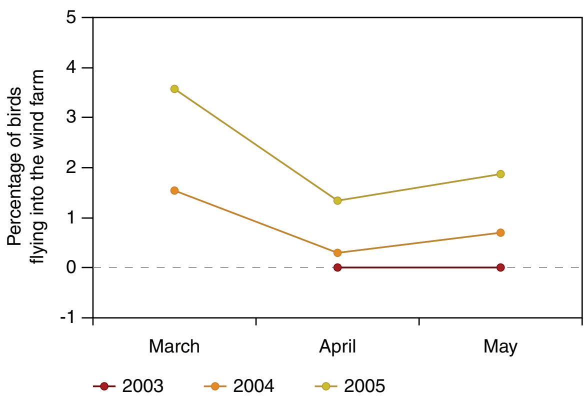


Figure 154. The percentage of Common Scoter recorded by visual transect observations inside the wind farm (crossing the two transects located along turbines rows) during spring in 2003, 2004 and 2005.

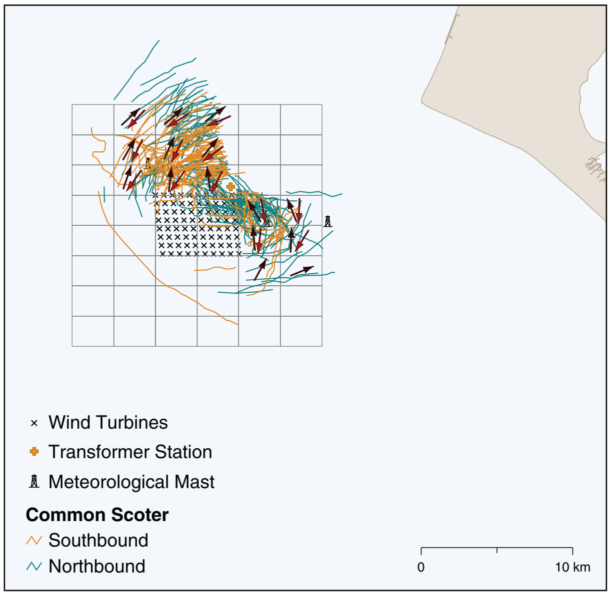


Figure 155. Radar tracks of 288 individuals/flocks of Common Scoter migrating southwards (N = 126) and northwards (N = 162) at Horns Rev during 2003-2005.

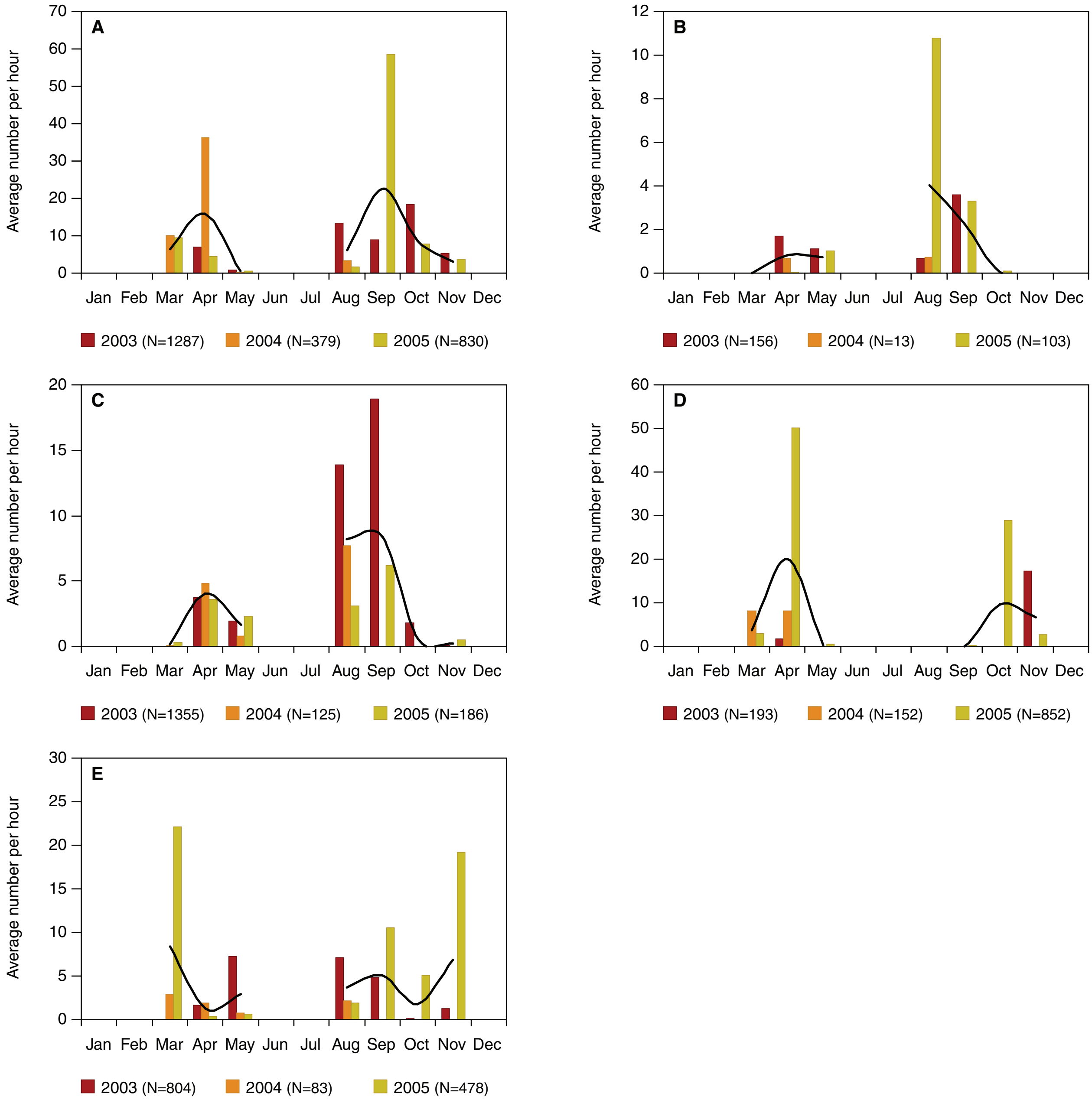


Figure 156. The seasonal occurrence of gulls shown as the average number recorded per hour of observation recorded during spring and autumn periods in 2003, 2004 and 2005. A) Herring Gull, B) Lesser Black-backed Gull, C) Great Black-backed Gull, D) Little Gull and E) Kittiwake.

Table 50. Mean number of birds recorded per 15-minute visual observation during spring and autumn 2003-2005. All birds are observed during counts on the four transects located east and north of the wind farm, along the eastern row of turbine (In/Out) and crossing the wind farm (Within), see Fig. 7. Unidentified terns are included as Common/Arctic Terns. The data set was log-transformed before the means were calculated.

		Spring				Autumn			
		2003	**2004**	**2005**	**N**	**2003**	**2004**	**2005**	**N**
Herring Gull	East-transect	0.32	1.51	0.68	223	1.13	-	1.54	684
	North-transect	0.43	1.71	0.24	246	0.71	-	2.08	451
	In/Out	0.53	0.75	0.16	134	1.71	-	1.48	448
	Within	0.05	1.41	0.15	94	0.41	-	1.51	196
Great Black-backed	East-transect	0.41	0.29	0.36	109	1.09	-	0.38	439
Gull	North-transect	0.31	0.31	0.28	88	0.86	-	0.51	352
	In/Out	0.27	0.04	0.13	41	2.25	-	0.33	378
	Within	0.16	0.12	0.31	48	0.56	-	0.14	130
Little Gull	East-transect	0.17	0.25	0.93	345	0.24	-	0.96	180
	North-transect	0.09	0.54	0.55	361	0.23	-	0.64	254
	In/Out	0.11	0.03	0.02	23	0.01	-	0.04	4
	Within	0.01	0.03	0.03	4	0.11	-	0.06	26
Kittiwake	East-transect	0.57	0.24	0.63	92	0.48	-	1.36	257
	North-transect	0.62	0.42	0.34	201	0.65	-	0.90	319
	In/Out	0.33	0.12	0.26	68	0.72	-	1.01	219
	Within	0.23	0.14	0.17	45	0.23	-	0.44	68
Arctic/Common	East-transect	0.50	0.88	1.25	414	0.66	-	0.92	381
Tern	North-transect	0.32	0.14	1.81	1,370	0.19	-	0.33	82
	In/Out	0.64	0.08	1.18	772	0.45	-	0.23	117
	Within	0.03	-	1.24	682	0.12	-	0.01	29
Sandwich Tern	East-transect	1.66	0.74	1.24	654	0.58	-	1.04	313
	North-transect	2.36	1.20	0.86	1,074	0.52	-	1.42	938
	In/Out	6.91	1.00	0.82	1,198	1.02	-	0.37	355
	Within	1.60	0.57	0.31	526	0.24	-	0.46	86

Mean migration activity of gulls recorded on the four transects around and inside the wind farm during spring and autumn 2003-2005 is shown in Table 50. The migration activity of the large gulls, Herring Gull and Great Black-backed Gull, did not show a consistent pattern in relation to the different transects (areas around and within the wind farm). For both species, migration intensity was only slightly higher outside than inside the wind farm. Herring Gull seemed to have a peak occurrence in autumn, but no seasonal variation is evident for Great Black-backed Gull. Of the smaller gull species, Kittiwake showed a migration pattern that resembled Herring Gull, while Little Gull, was showing extremely low occurrence within the wind farm and no marked seasonal variation.

Gulls were mainly observed as solitary individuals or as a few birds together. Mean flock size was for most species ranging between 1,04 and 1.84 birds together (Table 49). Only Little Gull occurred in larger flocks, especially in the spring of 2005, when mean flock size was 9.2 birds. There was no morning or evening peak in the occurrence of most gull species, with an almost consistent occurrence of 25% in the morning hours, 50% during daytime and 25% during evening hours.

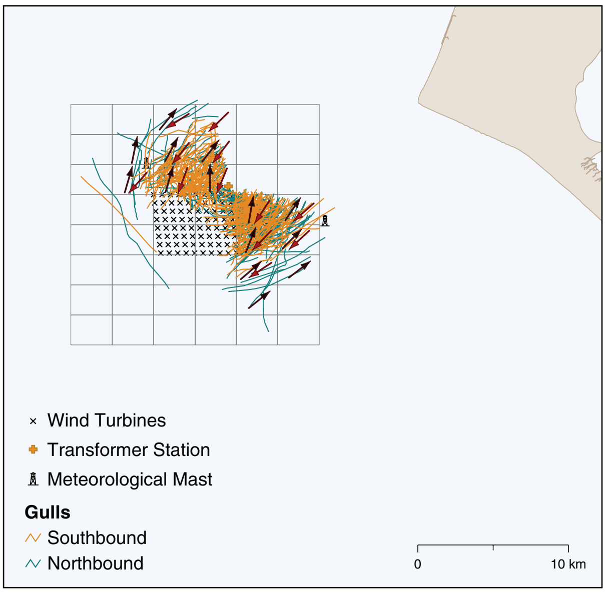


Figure 157. Radar tracks of all 461 individuals/flocks of Gulls migrating southwards (N = 259) and northwards (N = 202) at Horns Rev during 2003-2005.

Taking into account the duration of period length, gulls were probably occurring in comparative intensities throughout all daylight hours.

A total of 461 tracks of gulls, comprising at least 1,254 individuals, were recorded by radar during 2003-2005. Gulls were recorded in all observation periods, and a total of 259 flocks were flying in a southerly direction. Most tracks were obtained in spring (N = 257), and species identification were made in 82% of the records. The majority of tracks were obtained on Great Black-backed Gull (N = 202), Herring Gull (N = 79) and Lesser Black-backed Gull (N = 41). A total of 109 of tracks of gulls were recorded flying into or inside the wind farm (Fig. 157)

Terns *Sterna spp.*

A total of 8,747 terns were recorded during visual transect observation 2003-2005. Of these, 6,969 (80%) was assigned to species, 2,243 as Common/Arctic Tern and 4,726 as Sandwich Tern, respectively. Most terns were recorded in spring, i.e., 80% of the Common/Arctic Tern and 82% of the Sandwich Terns. Since the occurrence of the unidentified terns matched the occurrence of Arctic/Common Terns, these groups were lumped together. The occurrence of terns at Horns Rev clearly reflects the periods of spring and autumn migration. As evident from Fig. 158. the number of terns show a marked variation between spring and autumn and between years, which probably relate to coincidental timing of concentrated tern migration and observations at Horns Rev.

Migrating activity of terns recorded on the four transects around and inside the wind farm during spring and autumn 2003-2005 is shown in Table 50. For both Common/Arctic Tern and Sandwich Tern, no consistent pattern in occurrence outside and inside the wind farm was apparent, although the highest values of migration intensity of both species generally were found outside the wind farm. In spring, the mean flock size was slightly higher for the Common/Arctic Tern, ranging between 2.04-4.33, than for the Sandwich Tern, ranging between 0.57-1.60, but was comparable for the two species in autumn (Sandwich Tern: 1.28-2.40; Common/Arctic Tern: 1.73-1.76) (Table 49). Most terns were recorded during daylight hours (74% and 80% of the Common/Arctic terns and Sandwich Terns, respectively), with lowest numbers occurring at dawn and dusk (8%-15 for both species).

The pattern of tern migration in relation to the wind farm was generally comparable between the three study years, although marked differences in migration activity was found. The marked activity of Sandwich Terns crossing the eastern row of turbines (In/out in Table 50) in spring 2003, have no obvious explanation, and may be an artefact from recording a few terns making foraging along this line of turbines. In 2003, Common/Arctic Terns were recorded to repeatedly fly in and out of the wind farm, returning approximately 200-300 meters beyond the first row of turbines, and a similar, but less conspicuous behaviour at the edge of the wind farm, has been recorded on several occasions in Sandwich Terns.

A total of 144 tracks/flocks of terns were recorded by radar during 2003-2005. All records were made during April, May and August, and a total of 83 flocks were flying southward and 61 flocks northwards. Of all tracks recorded during 2003-2005, 44 were recorded inside the wind farm (Fig. 159).

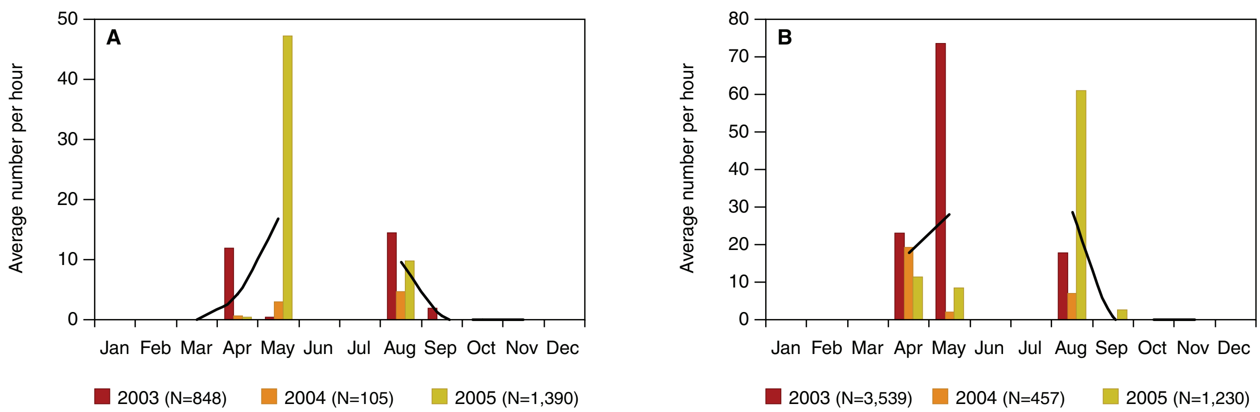


Figure 158. The seasonal occurrence of terns shown as the average number recorded per hour of observation recorded during spring and autumn periods in 2003, 2004 and 2005. A) Common /Arctic Tern, B) Sandwich Tern.

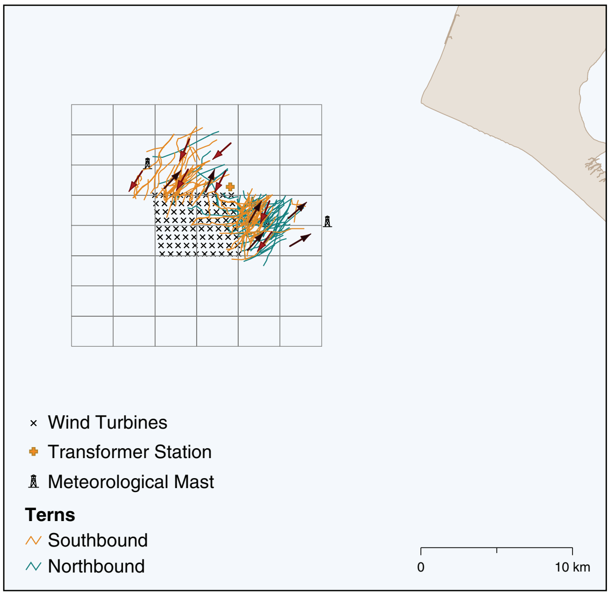


Figure 159. Radar tracks of all 144 individuals/flocks of terns flying around and within the Horns Rev wind farm during 2003-2005.

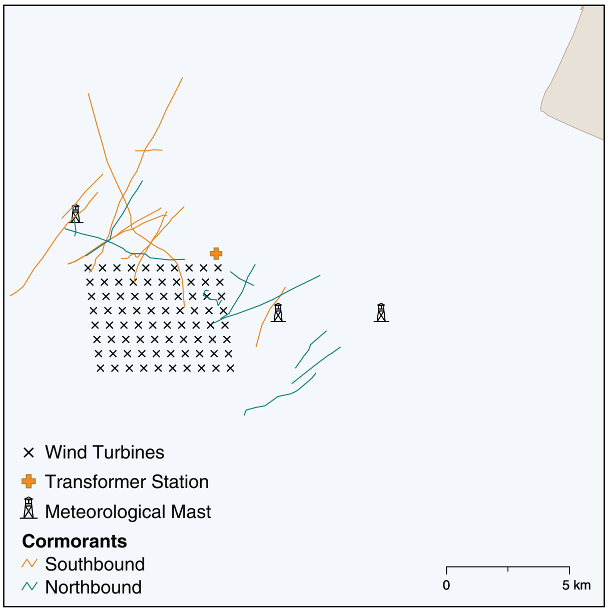


Figure 160. Radar tracks of all 19 individuals/flocks of Cormorants flying around and within the Horns Rev wind farm during 2003-2005.

Other species

Cormorants

During visual transect observation 185 Cormorants and 1 Shag *Phalacrocorax aristotelis* were recorded during 2003-2005. Most Cormorants were observed flying east of the wind farm (73%), while 14% were recorded inside the wind farm. The one individual Shag was recorded inside the wind farm. In total, two to three Shags were seen perching or resting on the turbines and meteorological masts, and to forage close to wind turbines inside the wind farm and around the transformer station during spring 2004. Cormorants were also observed to perch and rest on the meteorological mast east of the wind farm, and on the wind turbines.

During radar observation a total of 19 tracks of Cormorants and 1 track of Shag was recorded. Of the Cormorants tracks, a total of 3 tracks entered the wind farm, while 2 tracks were of Cormorants flying out of the wind farm. The one track of Shag represented a bird flying in between two easternmost rows of turbines (Fig. 160), were it was recorded foraging as well.

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

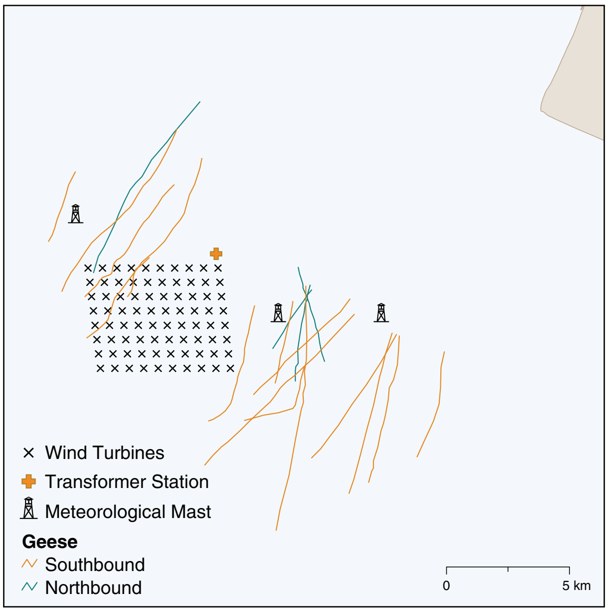


Figure 161. Radar tracks of all 19 individuals/flocks of geese flying around and within the Horns Rev wind farm during 2003-2005.

Geese

During visual transect observations 275 geese were recorded during 2003-2005. Of these 123 were identified as Greylag Goose *Anser anser*, and 142 as Brent Goose *Branta bernicla*, whereas 10 were not identified. Most geese were recorded east of the wind farm (N = 222), and no geese were recorded inside the wind farm. There was a marked difference in occurrence between years, with 261 individuals recorded in 2003, none in 2004 and 14 in 2005.

A total of 19 flocks of geese, comprising 8 flocks of Greylag Goose and 11 flocks of unknown species, were recorded by radar during 2003-2005. The majority of flocks were heading southwards (N = 15), and a total of 4 flocks were recorded inside the wind farm (3 flocks of Greylag Goose) (Fig. 161).

Observation of one flock of 53 Greylag Goose entering the wind farm from the north showed that this flock constantly increased flight altitude from before entering the wind farm and when flying within the wind farm, ultimately flying in rotor height. Within the wind farm, the birds had a less determined flight direction resulting in a disrupted flock structure.

Ducks

During visual transect observation a total of 4 species of diving ducks, comprising 207 individuals were recorded during 2003-2005. Of these, the most numerously occurring species, the Velvet Scoter *Melanitta fusca* (N = 193), were the only species that clearly is associated with open offshore areas. The other species were Tufted Duck *Aythya fuligula* (N = 3), Goosander *Mergus merganser* (N = 4) and Red-breasted merganser *Mergus serrator* (N = 7). The relatively high number of Velvet Scoter *Melanitta fusca* is a result of this species occurring in combination with the numerously occurring Common Scoter.

During visual transect observation only 3 species of dabbling ducks were recorded and all in very low numbers: Pintail *Anas acuta* (N = 6), Wigeon *Anas penelope* (N = 8) and Teal *Anas crecca* (N = 15). In addition, 21 unidentified ducks were recorded.

Waders

During all visual transect observations a relatively high numbers of species were recorded during 2003-2005, but all in small numbers (total N = 120). A total of 6 species were identified: Golden Plover *Pluvialis apricaria* (N = 11), Greenshank *Tringa nebularia* (N = 1), Redshank *Tringa totanus* (N = 2), Oystercatcher *Haematopus ostralegus* (N = 19), Curlew *Numenius arquata* (N = 13), Ruff *Philomachus pugnax* (N = 2), whereas a total of 72 individual shorebirds in 9 flocks were not identified to species. Of these, only 3 Curlew, 1 Oystercatcher and 31 unidentified shorebirds were recorded inside the wind farm.

The suite of waders species recorded by radar were fully comparable to those recorded during visual observations, including Oystercatcher (N = 5), Golden Plover (N = 1,034), Curlew/Whrimbrel *Numenius arquata/N. phaeopus* (N = 9), Curlew (N = 5), Bar-tailed Godwit *Limosa lapponica* (N = 15), Knot *Calidris canutus* (N = 2,230) and 734 unidentified shorebirds. The high numbers of Knots and Golden Plovers recorded was only obtained due to the use of radar that detected the substantial migration of these species during the afternoons of 13 May in both 2004 and 2005. This migration occurred at altitudes high above the wind turbines, and would have gone undetected if not picked up by the radar. During these two days of wader migration, a total of 65 flocks were recorded while migrating towards north-northwest. In 2004, 12 of 32 flocks were identified visually as Knot, including 2,150 individuals, while 3 flocks was noted as Golden Plover including 1,034 individuals. In 2005 only 2 of 36 flocks were identified, which proved to be Knots (N = 80). The remaining flocks were not observed visually, but assessed from flight speed (cf. Fig. 165), flight direction, time of day and by echo appearance on the radar, these were assessed to represent waders and most probably Knots. – Of all 87 tracks of waders recorded during 2003-2005 (Fig. 162), 71 were recorded during northward migration at the two days with Knot and Golden Plover migration in May. Only 10 tracks were recorded during autumn (August/September), and these were all heading towards south.

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 monitor. Given this it was assumed that most unidentified flocks represented Knots. The flight altitude of one flock was estimated to be c. 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. 162 including two separate flocks of Curlew recorded on 25 March and 11 May, respectively.

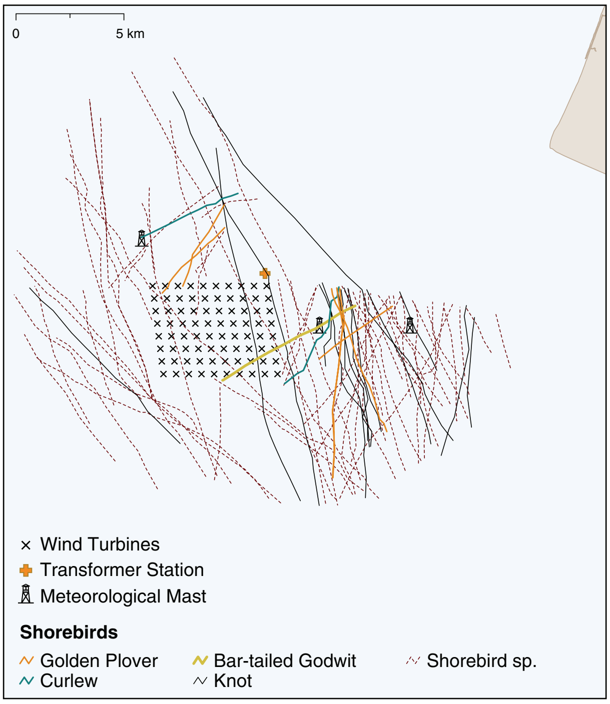


Figure 162. Radar tracks of Golden Plover (N = 6), Curlew (N = 2), Bar-tailed Godwit (N = 1), Knot (N = 14) and unidentified shorebirds (N = 58, probably Knots) migrating northwards at Horns Rev during 2003-2005. Only 9 tracks were recorded heading south, and these were all recorded during autumn.

The behaviour of waders flying towards the wind farm was noted for four flocks of shorebirds: Golden Plover (N = 11), Curlew (N = 4), Whimbrel (N = 1) and Oystercatcher (N = 15). The flocks of Golden Plover and Oystercatcher passed above the turbines, while the one Whimbrel entered the wind farm at the height of the rotors and flew southward through the wind farm. The one flock of Curlews stalled just before the wind farm and increased altitude before passing above the wind farm, markedly increasing wing beat frequency.

Skuas

During visual transect observations 150 skuas were recorded during 2003-2005. Of these 141 were identified as Arctic Skua *Stercorarius parasiticus*, 2 as Pomarine Skua *Stercorarius pomarinus*, 2 as Great Skua *Stercorarius skua* and 5 as unidentified skuas. Considering all skuas, most birds were recorded east (N = 71) and north (N = 43) of the wind farm, and with 36 individuals recorded inside the wind farm. The seasonal occurrence of Arctic Skua (Fig. 163) matches the migration period of Common/Arctic Tern, which are the preferred victims of the parasitizing foraging behaviour performed by skuas. Most skuas were recorded in spring 2003 when the highest numbers of Common/Arctic terns were also recorded. Likewise, most skuas (50%) were recorded during daytime.

The behaviour of foraging skuas observed during all years showed that the parasitic chases of terns with the aim of stealing the fish caught by terns, on some occasions were performed at the altitudes of the turbine rotors. Most observations of foraging skuas were made outside the wind farm, but a few took place in between the turbines.

Alcids

During visual transect observation 82 alcids were recorded during 2003-2005. Of these 4 was identified as Razorbill *Alca torda*, 15 as Guillemot *Uria aalge* and 3 as Black Guillemot *Cepphus grylle*. The vast majority of alcids was observed east (N = 60) and north (N = 19) of the wind farm, with only 3 individuals recorded flying inside the wind farm. Alcids were observed during March-May and September-November. No tracks of alcids were recorded by radar.

Pigeons and doves

No pigeons and doves were recorded during visual transect observation. However, 7 flocks of Wood Pigeon *Columba palumbus*, comprising 1,145 individuals, were recorded by radar on two consecutive days in October 2003. These flock were picked up by the radar when approaching from the north, and was visually identified when passing the wind farm area (Fig. 164).

The migration altitude for all flocks of Wood Pigeons was generally much higher than the wind turbines, and the flocks may actually have passed the Horns Rev area undetected if not recorded by radar. In only one flock, some increase in altitude was observed when approaching the wind farm, suggesting that this flock initially was flying in rotor altitude. Generally, it was the observers impression that these flocks of Wood Pigeon used both the wind farm, especially the transformer station, and the meteorological masts as a heading point.

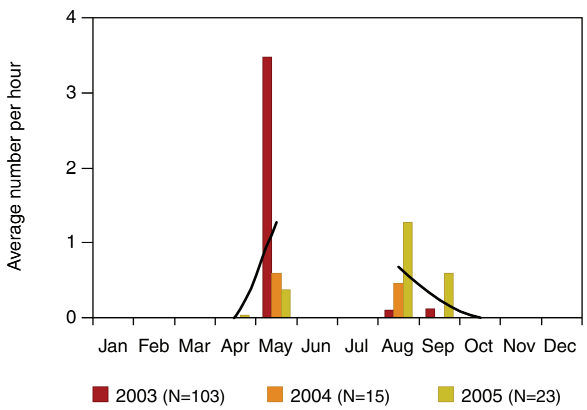


Figure 163. The seasonal occurrence of Arctic Skua shown as the average number recorded per hour of observation recorded during spring and autumn periods in 2003, 2004 and 2005.

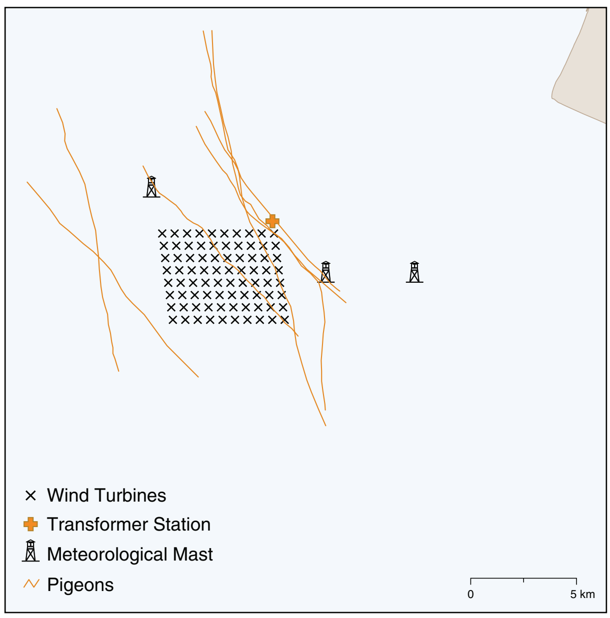


Figure 164. Radar tracks of seven flocks of Wood Pigeon migrating southwards at Horns Rev during October 2003.

4.3.1.1 Flight speed

Flight speed measures were obtained on a total of 3,311 tracks of birds during 2003-2005. Of these 513 (15.5%) were identified to species or species group. In Fig. 165 the frequency distribution of flight speed of unidentified bird is presented graphically including the measures of identified species (divers N = 11, Common Scoter N = 103, Gannet N = 70, Gulls N = 134, Terns N = 38, shorebirds sp. N = 17, Knot N = 16 and Golden Plover N = 10).

The distribution of unknown species shows 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. Although there is a marked overlap in flight speed, the identified species display a division between slowly flying gulls, terns, species with an intermediate and variable flight speed, Knot, Gannet and Curlew, and faster flying Common Scoter and divers.

The variable flight speed recorded, especially in waders, and the large overall range of measured flight speeds (c. 8-116 km/hour) probably reflect that birds fly at different speeds in relation both to variable behaviours, i.e., foraging vs. directional migration, and in relation to variable wind conditions, i.e., head and tail wind. In the present study, no data were recorded on bird behaviour in relation to flight speed measurements, but head and tail wind data were available for 3,263 tracks. The mean flight speed during head and tail winds for selected species and for unknown species is shown in Fig. 166. It is evident that flight speed of Gannet and Common Scoter, gulls and terns, did not differ markedly with respect to head or tail winds. Cormorants, geese and waders tend, however, to fly faster in tail wind conditions than in head wind. This sensitivity to wind conditions may explain the larger variation in average flight speed of waders species in Fig. 165.

4.3.1.2 Turbines as resting platforms

From the 306 observation periods of the two transects at the edge and within the wind farm, a total of 2,448 observations of single turbines were made with respect to recording the presence of resting or perching birds on the turbine basic platforms, c. 8 m above sea level. In total 56 records of resting birds were made including 63 individuals. Of these records, 22 (39%) were made during the observation period 31 August - 1 September 2004, at which time all turbines were inactive, and most nacelles were dismounted due to renovation of the turbine generators.

The most frequently recorded species were Great Black-backed Gull (20 records of 22 individuals), Cormorant (14 records of 18 individuals) and Herring Gull (8 records of 8 individuals). The remaining records were of Lesser Black-backed Gull (N = 1), Sparrow Hawk (N = 3), Shag (N = 3), unidentified gulls (6 records of 7 individuals) and White Wagtail *Montacilla alba* (N = 1). In the following, only cormorants and gulls are analysed, and all observations of gulls were pooled to improve sample size. To avoid a bias from the observations period in autumn 2004 where the wind farm on a whole was not active, the records from this period were treated separately in the following analyses.

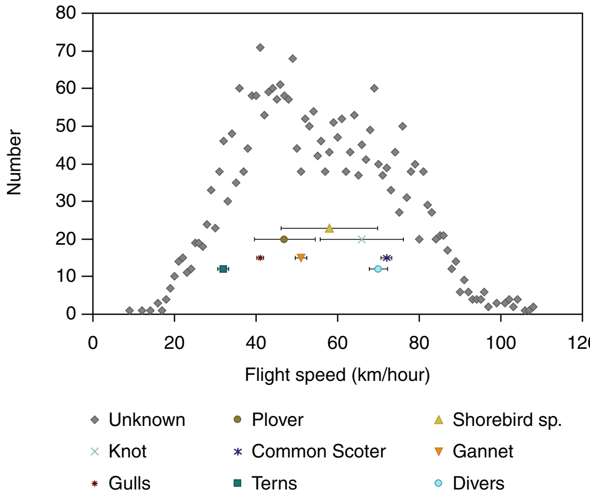


Figure 165. The frequency distribution of flight speed measurements of unidentified species recorded during 2003-2005. Mean flight speed (±SE) of identified species is shown separately.

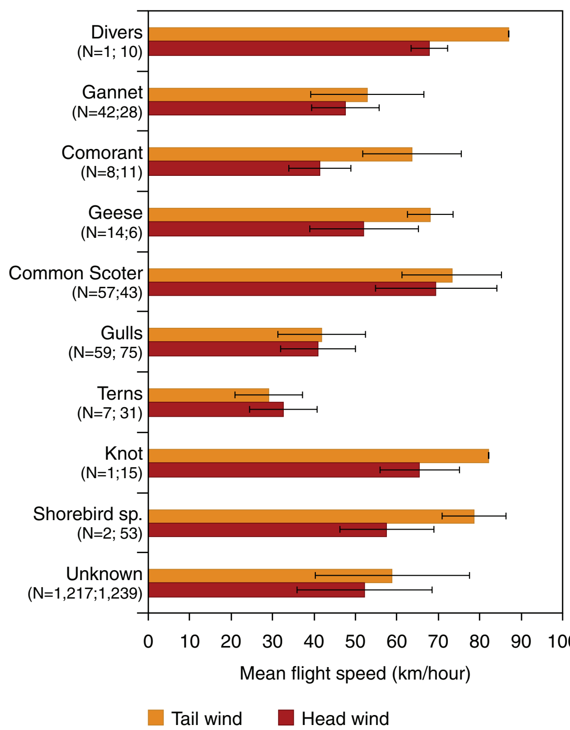


Figure 166. The mean flight speed (± SE) of bird tracks of species or species groups in relation to flying into the wind (head wind) and with the wind (tail wind), recorded during 2003-2005. The number of speed measurements for tail and head winds is shown.

Only 2 and 1 record were made of resting Cormorants on turbines in the two transects at the edge and within the wind farm, respectively, and all records were made on turbines at the edge of the wind farm. Including records of Shag, the numbers increased to 4 and 2, respectively, and again, all records were made on turbines at the edge of the wind farm. For both Cormorant and Shag all records were made on active turbines. During the period when the wind farm was not in operation, a total of 11 records of resting Cormorants were made. Of these, only 2 records were made on turbines within the wind farm.

The number of records of gulls on turbines on the two transects at the edge and within the wind farm was 18 and 6, respectively. Of these, 22 were made on turbines located at the edge of the wind farm, whereas only 2 records were made on turbines within the wind farm. A total of 11 records were on operating turbines and 13 records on not-operating turbines. Of the two records of gulls resting on turbines within the wind farm during normal operation, one was on an operating turbine and one was on an not-operating turbine. During the period when the wind farm was not in operation, a total of 11 records of resting gulls were made. Of these, 8 records were made on turbines within the wind farm.

4.3.1.3 Turbine activity and bird passing

An adequate number of individual birds recorded for the analyses of the effects of turbine activity on the probability of birds flying into the wind farm, was available for Common Scoter (N = 234), Arctic Skua (N = 25), Herring Gull (N = 257), Great Black-backed Gull (N = 149), Kittiwake (N = 129), Common/Arctic Tern (N = 639) and Sandwich Tern (N = 1,055). For these species, the seasonal occurrence was assessed in order only to include periods where the species were present in the area.

The percentages of 15 minute periods with observations of birds flying into the wind farm by crossing the transect located at the eastern row of turbines, in relation to the activity of turbines are shown in Table 51. Common Scoter, Arctic Skua, Great Black-backed Gull and Sandwich Tern were generally observed to fly into the wind farm more frequently when they entered the wind farm between two turbines of which one or both were not active. That more birds flew in between inactive turbines were, however, only significant for Great Black-backed Gull and Sandwich Tern.

4.3.2 Radar recording of bird migration and behaviour at Horns Rev

4.3.2.1 Overall migration patterns

During 2003-2005 a total of 7,770 tracks of birds or flocks of birds were recorded. Of these 4,086 were of southbound movements and 3,684 of northbound movements. The number of bird tracks recorded during spring and autumn 2003-2005 is shown in Table 52.

Table 52. Number of bird tracks recorded by radar during spring and autumn periods during the three study years 2003-2005.

	2003	2004	2005	Total
Spring	no recordings	1,893	2,060	3,953
Autumn	1,259	643	1,915	3,817
Total	1,259	2,536	3,975	7,770

Most tracks of birds/bird flocks were recorded north and east of the wind farm, while much fewer tracks were recorded west and south of the wind farm and within the wind farm. In the area covered by the radar, there were no clear or discernible routes of bird migration, either during northward and southward movements. The fact that fewer tracks were recorded within and beyond the wind farm is to a large extent caused by the presence of the individual wind turbines shadowing the radar, and from the decrease in detectability of birds by the radar at progressively longer distances. In consequence, it was chosen not to analyse the data quantitatively, e.g., calculating densities of tracks, but to assess data qualitatively. Likewise, it was chosen not to make a separation between spring and autumn periods, since the aim of the study was to assess bird behaviour in relation to the wind farm, which was expected to be similar regardless of time of season.

Table 51. The percentage of time units with occurrence of birds flying into the wind farm between two turbines in relation to the activity of turbines.

	Turbine activity					Observation period	
Species	2 active	1 active	0 active	χ^2	p	Number of 15 min. time units	Months
Common Scoter	4.9 %	8.5 %	13.3 %	5.26	0.072	693	3-5
Arctic Skua	1.7 %	2.2 %	4.2 %	3.07	0.215	1,001	5, 8-9
Herring Gull	9.7 %	11.4 %	11.8 %	1.17	0.555	1,442	3-5, 8-11
Great Black-backed Gull	6.8 %	13.2 %	8.7 %	9.16	0.010	1,155	4-5, 8-9
Kittiwake	5.6 %	4.9 %	7.9 %	1.64	0.441	1,442	3-5, 8-11
Common/Arctic Tern	5.8 %	4.4 %	6.3 %	0.748	0.688	1,155	4-5, 8-9
Sandwich Tern	24.1 %	35.2 %	30.0 %	7.83	0.012	488	4-5, 8

The total number of southbound and northbound bird tracks during spring and autumn is shown in Fig. 167A,B, respectively. As data is 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.

As can be seen from the average orientation of bird migration or movements around the wind farm area, a general deflection towards the wind farm is evident, both during southbound and northbound bird movements (Fig. 167A,B). Considering northbound migration, it is evident that birds pass around rather than fly through the wind farm. It is also evident that most birds have made the adjusting deflection in flight orientation already at distances of more than 4 kilometres, and, even though relatively few northbound bird tracks are recorded south of the wind farm, the majority of those that show deflection, deflect west around the wind farm. A similar pattern of westward deflection around the wind farm is also observable for southbound tracks north of wind farm. That deflection in orientation in the area north of the wind farm seems not to occur at similar long distances to the wind farm may be a result of inclusion of a substantial number of tracks of Common Scoter flying to the roosting and foraging site just north of the wind farm from coastal areas north of Blåvands Huk. The south-westerly orientation in bird orientation north and east of the wind farm is, however, expected, as bird movements in this area may reflect the continuation of southbound bird migration along the coastline north of Blåvands Huk.

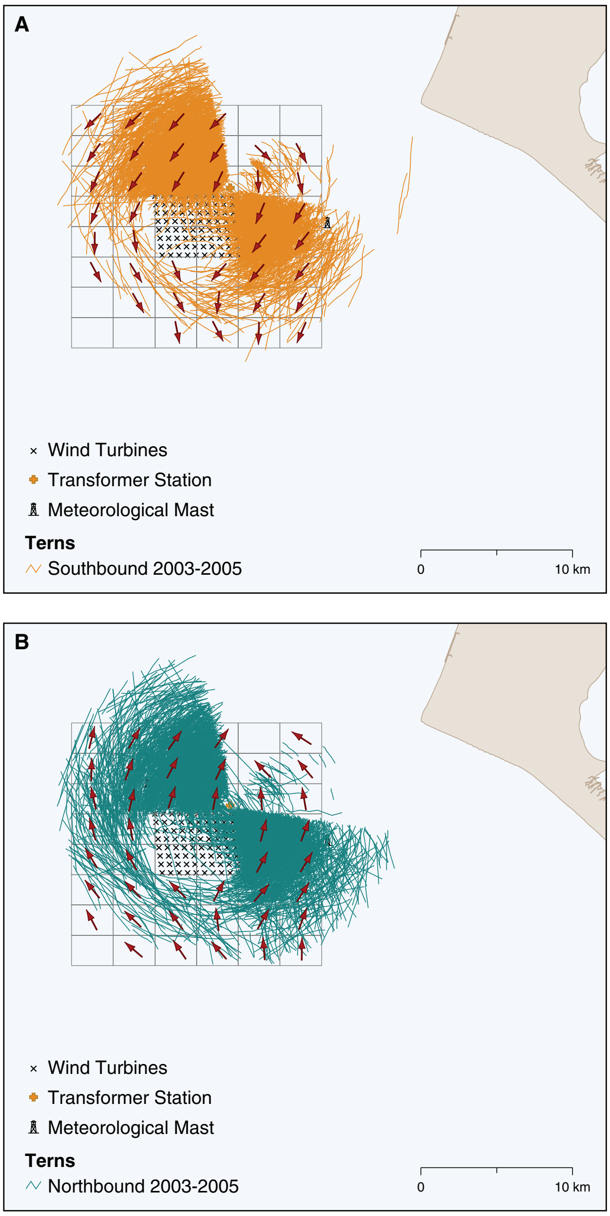


Figure 167. Radar tracks of birds/bird flocks migrating southwards (A) and northwards (B) at Horns Rev during 2003-2005. Arrows shows the average orientation in the flight direction of bird within each grid cell. The vertical position of migrating birds is not known.

4.3.2.2 Lateral changes in migration routes

A total of 3,276 southbound bird tracks, including 2,108 tracks recorded north of the wind farm and 1,168 east of the wind farm during 2003-2005, were selected for analyses of lateral deflection (see methods) of migrating waterbirds (Fig. 168).

Deflection north of the wind farm

Of the tracks recorded north of the wind farm, the flight orientation varied between 99º and 268º, when calculated in the different distance intervals used in this analysis (see Fig. 22). On average the overall orientation of migrating birds was 204º. A slight, but significant difference in mean orientation was found between years (ANOVA: $F_{2,3041} = 13.82$, $P < 0.0001$, $R^2 = 0.01$; N = 3,044 track segments), relating to a slightly differing orientation in 2003 (210º) compared to 2004

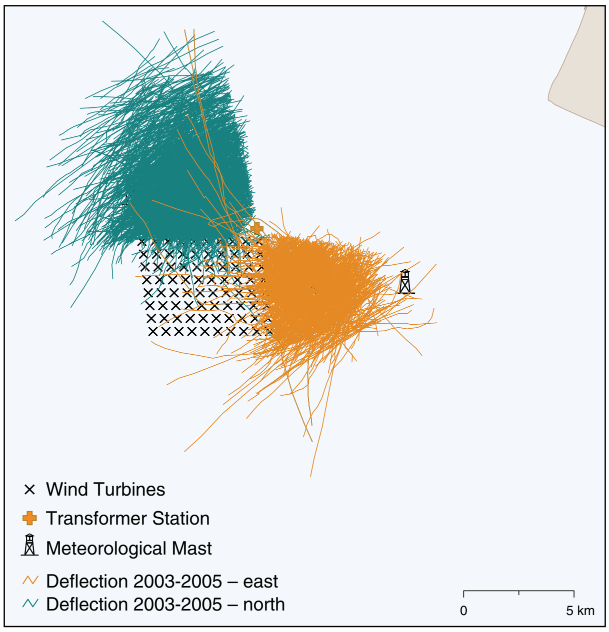


Figure 168. Tracks selected for analyses of lateral deflection in flight orientation. A total of 2,108 and 1,168 tracks were selected north and east of the wind farm, respectively.

(201º) and 2005 (203º). However, the overall average orientation of birds flying towards the wind farm showed a consistent change from a south-westerly direction when far from the wind farm to a more southerly orientation at close distances to the wind farm (Fig. 169A). Assessed from the high standard deviations of the means of bird orientation at distances of 200 to 500 m from the wind farm (Fig. 169B), migrating birds probably reacted to the presence of wind farm/wind turbines at this distance by deflecting from directional migration, thereby increasing standard deviation (birds may turn both towards east and towards west to circumvent the wind farm, or just fly in circles for a short time). That the orientation of bird migration at distances closer than 500 meter from the wind farm shows an almost southerly orientation suggests that birds generally tend to pass the wind farm by flying in between turbine rows while heading south.

Based on data collected during all three study years, the general pattern of migrating birds changing their orientation from a south-westerly orientation to a more southerly orientation when flying in close to the wind farm, strongly indicates that migrating birds react to the presence of the wind farm. However, the reactions of migrating birds, in terms of flight orientation, were significantly affected, not only by distance (ANOVA: F_{14} = 18.93, P < 0.0001), but also by wind direction (easterly or westerly crosswinds) (ANOVA: F_1 = 57.49, P < 0.0001), time of day (day or night) (ANOVA: F_1 = 95.33, P < 0.0001) and by the interaction between distance to the wind farm and time of day (ANOVA: F_{14} = 3.27, P < 0.0001).

As evident from Fig. 169A,B, migrating birds flying towards the wind farm showed marked changes in their orientation at distances of between 200-500 meters from the northern row of turbines. Thus, to assess bird migration in relation to the wind farm in more details, analyses were performed separately on track segments recorded at distances of more than 400 m from the wind farm and closer than 400 m from the wind farm. At distances closer than 400 m from the wind farm, the mean orientation of migration (193º ±1.2 SE) was significantly related to distance to the wind farm, time of day and wind direction (Table 53). At distances of more than 400 m from the wind farm the orientation of migration averaged 208° ±0.6 SE, and was significantly related to distance to the wind farm, time of day, wind direction and the interaction between distance and day (Table 53).

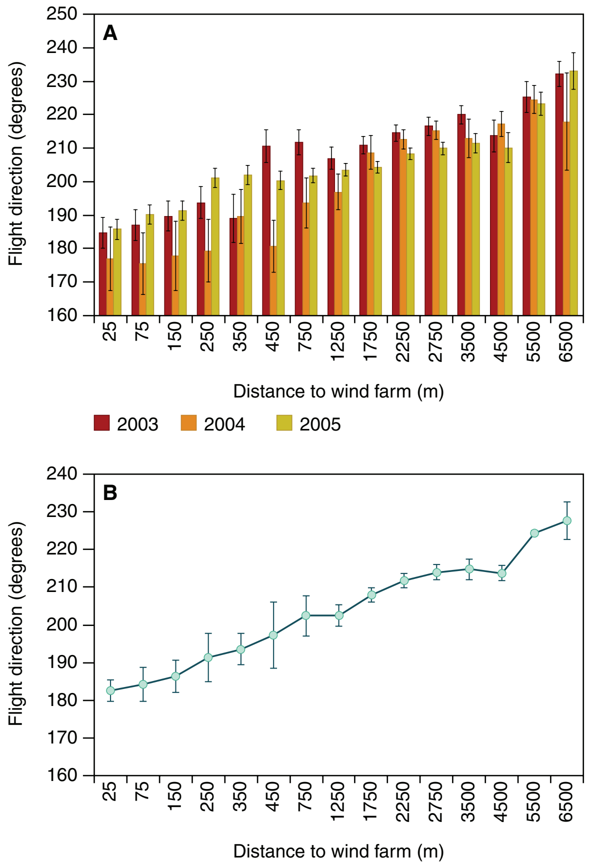


Figure 169. Mean orientation (± SE)in relation to distance (axis shows means of distance intervals) to the wind farm of southbound tracks of migrating birds recorded by radar north of the wind farm shown for A) separate years: 2003 (N = 474), 2004 (N = 709) and 2005 (N = 925), and B) as the average and standard deviation between years.

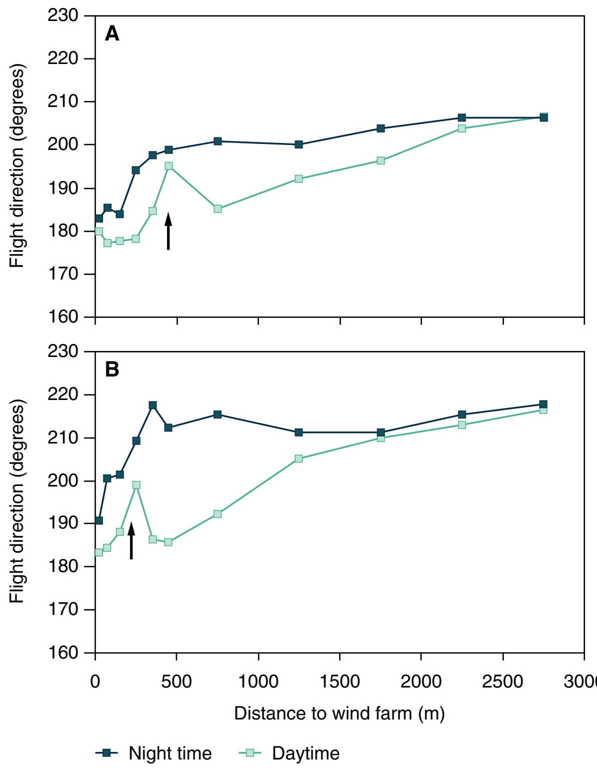


Figure 170. Mean flight direction of southbound bird migration at different distances to the wind farm recorded by radar north of the wind farm during 2003-2005 in relation to wind direction (A: Westerly winds, B: Easterly winds) and time of day (day and night).

Table 53. 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	5.73	4	0.0001	3.12	9	<0.0001
Day	32.90	1	<0.0001	2.52	1	<0.0001
Wind	30.91	1	<0.0001	1.30	1	<0.0001
Distance*Day	1.60	4	0.1723	1.26	9	0.0003
Distance*Wind	0.55	4	0.7025	0.56	9	0.8717
Day*Wind	2.18	1	0.1398	2.53	1	0.1983
Distance*Day*Wind	0.85	4	0.4919	1.11	8	0.1378

The effects of wind direction and time of day on the orientation of bird migration in relation to distance to the wind farm is visualised in Fig. 170. During both westerly and easterly wind directions, birds flying towards the northern edge of the wind farm during daytime, seemingly adjust their orientation to fly in a more southerly direction towards the wind farm at distances of between 1,000 and 2,000 meters. During night time, bird orientation shows no such change. Thus, daytime migrants seemingly adjust flight orientation at long distances of the wind farm in order to make a perpendicular entrance or passing of the wind farm, whereas nocturnal migrants make adjustments in flight orientation very abruptly just before they actually have to enter into the wind farm or above it. This pattern in nocturnal migrants suggests that birds during night lack visual recognition and perception of the wind farm as an obstacle, and likewise, that nocturnal migrants are not attracted to the wind farm by the flashing lights located on the base and nacelles of turbines in the wind farm, even though these are visible at very long distances.

It is evident from Fig. 170, that daytime migrants make marked changes in flight orientation at some distance to the wind farm (indicated by arrows), and that these changes takes place at different distances during westerly and easterly winds. Given that visual observations have shown that most birds approaching the wind farm actually deflect to the west and pass around the wind farm, these points of marked westerly orientation probably reflect the distance where most birds change flight direction. That wind direction affects the distance of this ‘turning point’ of birds approaching the wind farm, may have several explanations. The fact, however, that these ‘turning points’ are only seen during day time, suggests that birds may tend to avoid recognisable obstacles at longer distances when they have to face headwinds than if an obstacle should be passed using tailwinds.

The flight direction of birds that flew towards and actually entered the wind farm (orientation measured in the distance interval 0-50 meter from wind turbine) was on average 184º. Orientation varied, although not significantly, with both wind direction and time of day, being 191º in easterly winds during daytime, and 183º during night time, and being 180º in westerly winds during daytime and 183º during night time. With an orientation of the turbine rows of c. 173º, birds that flew in between turbines most accurately flew in between two rows of turbines during daytime and westerly winds, whereas birds passing during night and easterly winds potentially should cross several turbine rows in their passage of the wind farm.

Deflection east of the wind farm

A total of 1,168 southbound tracks recorded by radar east of the wind farm during 2003-2005 were selected for analyses of lateral deflection of migrating birds. The orientation of these tracks, that all represented birds that were flying towards the wind farm, varied between 175º and 351º. On average the overall orientation of migrating birds in the area east of the wind farm was 248º. A significant difference in orientation was found between years (ANOVA: $F_{2,3984} = 25.81$, $P < 0.0001$, $R^2 = 0.01$; N = 3,987 track segments), relating to deviating mean orientation during 2005 (245º) compared to the orientation recorded in 2003 (251º) and in 2004 (252º). However, the average orientation of birds flying towards the wind farm showed a consistent change from a south-westerly direction when far from the wind farm to a more westerly orientation at close distances to the wind farm in all years (Fig. 171A). As found in the area north of the wind farm, high standard deviations of the means of bird orientation was found at distances of between 200 and 500 m from the wind farm (Fig. 171B), indicating that migrating birds reacted to the presence of wind farm/wind turbines at this distance. That the orientation of bird migration at distances closer than 500 meter from the wind farm shows an almost westerly orientation suggests that birds generally tend to pass the wind farm by flying in between turbine rows.

Thus, as also seen in the area north of the wind farm, birds that fly into the wind farm generally do so in a perpendicular angle to the edge of the wind farm, even though they approach the wind farm from the north or from the east.

Based on data collected during all three study years, the general pattern of migrating birds changing their orientation from a south-westerly orientation to a westerly orientation when flying in close to the wind farm, strongly indicates that migrating birds react to the presence of the wind farm. However, as also found in analyses of bird tracks on the northern side of the wind farm, flight orientation at the eastern side of the wind farm was similarly affected significantly by distance (ANOVA: F_{14} = 25.38, P < 0.0001), and also by wind direction (easterly or westerly (tail- and head-winds)) (ANOVA: F_1 = 13.37, P = 0.0003), time of day (day or night) (ANOVA: F_1 = 132.67, P < 0.0001) and by the interaction between distance to the wind farm and wind direction (ANOVA: F_{14} = 2.79, P = 0.0004).

As migrating birds flying towards the wind farm showed marked changes in their orientation at distances of between 200-500 meters from the eastern row of turbines (cf. Fig. 171A,B), analyses were performed separately on track segments recorded at distances of more or less than 400 m from the wind farm in order to assess bird migration in relation to the wind farm in more detail. At distances of less than 400 m from the wind farm, the mean orientation of migration (256° ± 4.2 SE) was significantly related to distance to the wind farm, time of day, wind direction and the interaction between time of day and wind direction (Table 54). At distances of more than 400 m from the wind farm the orientation of migration averaged 242° ± 1.8 SE, and was significantly related to distance to the wind farm and wind direction, but there was, however, no effect of time of day (Table 54).

The effects of wind direction and time of day on the orientation of bird migration in the area east of the wind farm in relation to distance to the wind farm is visualised in Fig. 172. As just indicated by the previous analyses, there is no marked difference in the orientation of bird migration between daytime and night time under separate wind directions, when birds are farther than 400 meters from the wind farm. During both westerly and easterly wind directions, the mean orientation was approximately 240°. However, when flying in closer than 400-500 m from the wind farm, there is a marked change in orientation from a south-westerly direction to a more westerly direction. During easterly wind directions, birds that migrate during daytime, make the adjustment in flight orientation at longer distances to the wind farm than birds that migrate during night time. During periods of westerly winds, no obvious difference in the point of flight adjustment exists, and these occur very close to the wind farm during both daytime and night time.

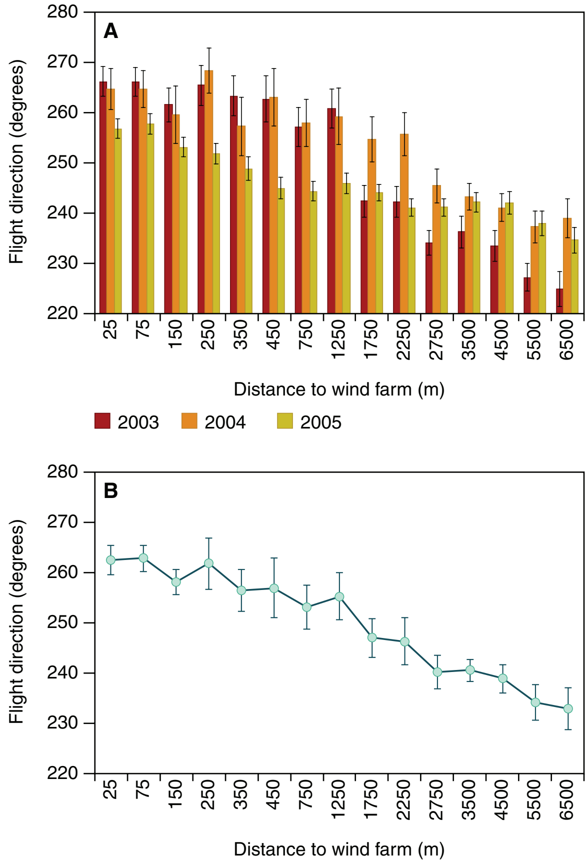


Figure 171. Mean orientation (± SE)in relation to distance (axis shows means of distance intervals) to the wind farm of south-bound tracks of migrating birds recorded by radar east of the wind shown for A) separate years: 2003 (N = 308 tracks), 2004 (N = 193 tracks) and 2005 (N = 667 tracks), and B) as the average and standard deviation between years.

Table 54. 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 400 metres and more than 400 metres from the wind farm.

	< 400 m			> 400 m		
Factor	**F**	**DF**	**P**	**F**	**DF**	**P**
Distance	5.61	6	<0.0001	11.75	7	<0.0001
Day	22.77	1	<0.0001	0.39	1	0.530
Wind	108.42	1	<0.0001	35.60	1	<0.0001
Distance*Day	0.79	6	0.580	1.60	7	0.130
Distance*Wind	1.02	6	0.407	1.92	7	0.063
Day*Wind	22.57	1	<0.0001	2.92	1	0.088
Distance*Day*Wind	0.49	6	0.995	1.60	7	0.132

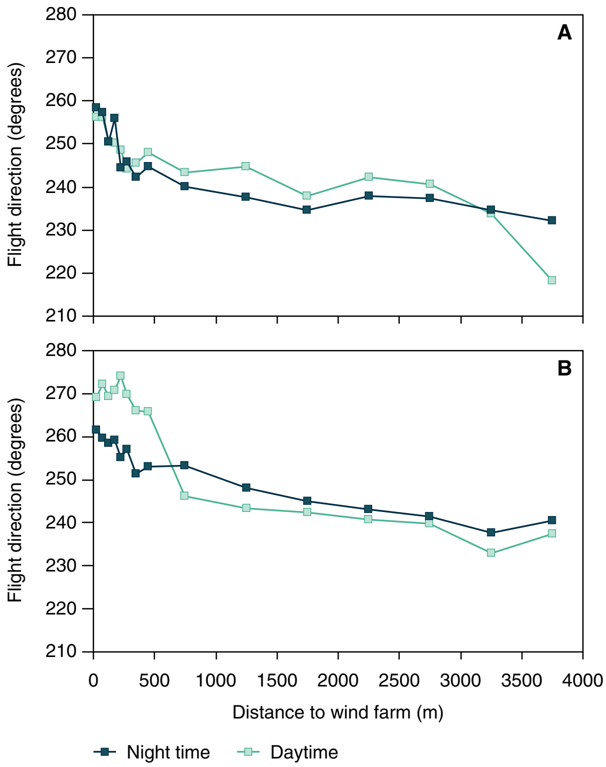


Figure 172. Mean flight direction of southbound bird migration at different distances to the wind farm recorded by radar north of the wind farm during 2003-2005 in relation to wind direction (A: westerly winds, B: easterly winds) and time of day (day and night).

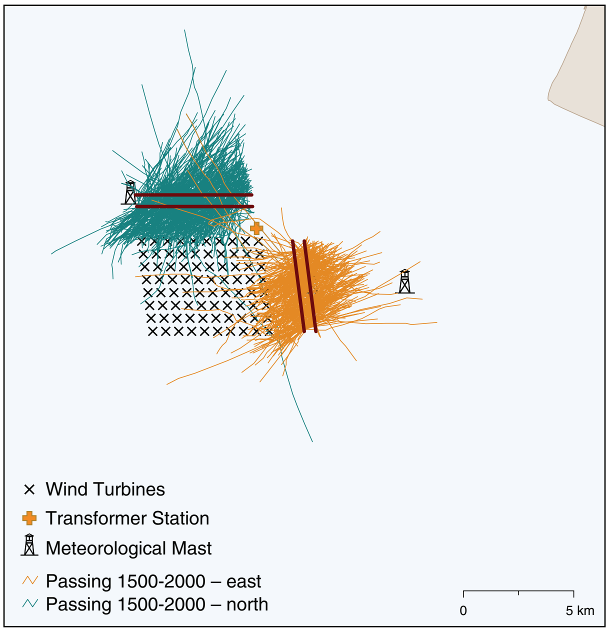


Figure 173. Tracks selected for analyses of the probability of passing into the wind farm. A total of 458 and 342 tracks were selected north and east of the wind farm, respectively. The transects placed at 1,500 and 2,000 m's distance from the wind farm, which were used in selection of tracks, are shown.

Table 55. The percentage of bird tracks entering the wind farm among tracks recorded north and east of the wind farm during 2003-2005.

	North of the wind farm	East of the wind farm
2003	18.5 % (N=22)	20.5 % (N=24)
2004	14.3 % (N=20)	29.3 % (N=12)
2005	13.6 % (N=27)	21.2 % (N=39)
All years	15.1 %	21.9 %

Compared to the marked 'points of turning' found among birds very close to the northern side of the wind farm, no such points were obvious at the eastern side of the wind farm. However, the overall change in flight direction resulted in a more or less perpendicular westward approach of the wind farm, even though the general migration was heading towards southwest. Considering birds that entered the wind farm, the orientation during daytime and easterly winds was exactly westwards (269º), while during all other combinations of time of day and wind directions the orientation showed a slight southerly deflection, ranging between 256º and 262º.

4.3.2.3 Probability of birds passing into wind farm area

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 around the wind farm at some point before entering the wind farm, but also the fact that many echoes disappeared on the screen at various distances to the wind farm.

In the analyses of probability of birds passing into the wind farm, the tracks included all had a theoretical chance of entering the wind farm, i.e., they were selected on the criteria that they were oriented towards the wind farm, assessed by the orientation estimated at distance of 1,500-2,000 m from the wind farm, and that they were longer than 2 km, i.e., all tracks had a length long enough to enter into the wind farm. The number of bird tracks that complied with the selection criteria was 458 tracks at the northern and 342 tracks at the eastern side of the wind farm (Fig. 173).

There was a significant difference between the probability of flying into the wind farm, being highest east of the wind farm, where 21.9% (N = 75) of the tracks passed beyond the first turbine row, compared to 15.1% (N = 69) in the area north of the wind farm ($\chi^2_{adj.}$ = 5.79, df = 1, p = 0.016) (Table 55). This difference is probably a result of more massive presence of gulls and terns, as also indicated by the high proportion (68%) of gulls and terns among identified bird tracks in this area, compared to 30% north of the wind farm (see also Fig. 157). Pooling of data from separate areas was allowed as there were no significant differences between years when comparing the area north and east of the wind farm separately (north of the wind farm: $\chi^2 = 1.50$, df = 2, p = 0.471; east of the wind farm: $\chi^2 = 148$, df = 2, p = 0.476).

The probability of flying into the wind farm was slightly higher during easterly wind directions than during westerly wind directions both north of the wind farm (16.9% vs. 12.8%) and east of the wind farm (24.2% vs. 21.9%), although the difference was not statistically significant (north: $\chi_{adj.}^2 = 1.04$, df = 1, p = 0.309; east: $\chi_{adj.}^2 = 1.11$, df = 1, p = 0.739). Likewise, no significant difference in the proportion of birds entering the wind farm was found when comparing daytime and nigh time in the two areas separately, even though more tracks were entering the wind farm during daytime in both areas (north: 22.9% during daytime vs. 10.4% during night time ($\chi_{adj.}^2 = 2.37$, df = 1, p = 0.124); east: 23.8 vs. 20.8% ($\chi_{adj.}^2 = 0.26$, df = 1, p = 0.613). Analysing the effect of day and night on combined data showed, however, that significantly more bird tracks (23.3%) were flying into the wind farm during daytime than during night time (14.9%) ($\chi_{adj.}^2 = 8.42$, df = 1, p = 0.0037). There were no effect of wind direction on the proportion of birds entering the wind farm in the combined data, being 19.5% during easterly wind directions and 17.2% during westerly wind directions.

Of those tracks that did not enter the wind farm, a total of 100 (21.8%) and 68 (19.9%) was recorded to deflect and pass around the wind farm in the areas north and east of the wind farm, respectively. Of the tracks north of the wind farm 97 were deflecting westward and 3 eastward, whereas 289 (63.1%) disappeared for unknown reasons. In the area east of the wind farm 59 tracks were deflecting southwards and 9 northwards, and 199 (58.2%) tracks disappeared.

Disappearance of radar tracks: Common Scoter as an example

In total 96 flocks of Common Scoters were observed visually while approaching the wind farm from the north during spring 2004. Of these, 76 flocks landed on the water, and 52 flocks (68.4%) landed 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. 174).

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 (90.0%) changed their flight direction at distances of more than 200 metres from the turbines, while only two flocks (10.0%) flew in closer than 200 metres from the turbines before they changed flight direction (Fig. 174).

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

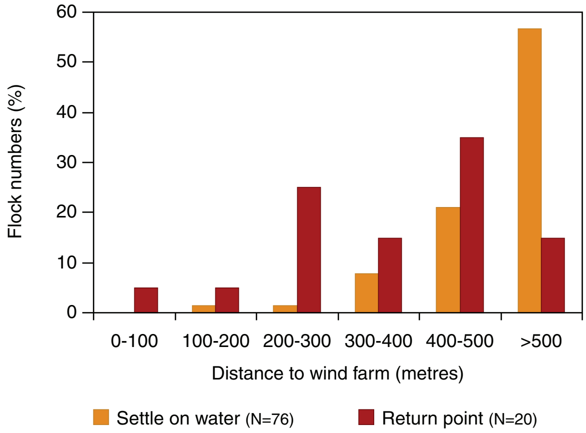


Figure 174. The percentage of flocks in relation to distance to the wind farm of Common Scoter approaching the wind farm from the north that settle on the water or turn away from the wind farm.

4.3.2.4 Flight behaviour inside the wind farm

A total of 202 radar tracks of different bird species entering the wind farm from the north and 155 tracks entering from the east were selected for analyses (Fig. 175).

The mean flight orientation (shown as arrows in Fig. 175) showed a general pattern of birds entering the central part of the wind farm did so more or less perpendicular to the first row, and continued like that inside the wind farm. Birds that entered the wind farm closer to the edges of the wind farm tended to deflect away from the centre of the wind farm, and hence seemingly were seeking out of the wind farm by the shortest possible way. This pattern was recognizable on both sides of the wind farm, although less clearly at the eastern side.

Assessed from the standard deviation of track orientation in the central grid cells (Table 56), the orientation of birds flying inside the wind farm from the north showed much more variation when birds have passed the 3rd row of turbines, indicating that at this point, birds lost the directional orientation and started to make marked changes in flight direction. A similar increase in the standard deviation in tracks entering the wind farm from the east was not found (Table 56), and since the values were consistently lower, birds seemingly continued to use the corridors between turbine rows with a less tendency to deflect (cf. Table 56).

There is no obvious explanation to the marked difference in flying behaviour between birds entering the wind farm from the north and from the east. It is, however, possible that the more frequent occurrence of gulls and terns at the eastern side of the wind farm may have an influence on the result. Gulls and terns were also the species most frequently observed to fly into the wind farm during visual observations, and especially Great Black-backed Gull were often observed when passing in between turbines in a westerly direction.

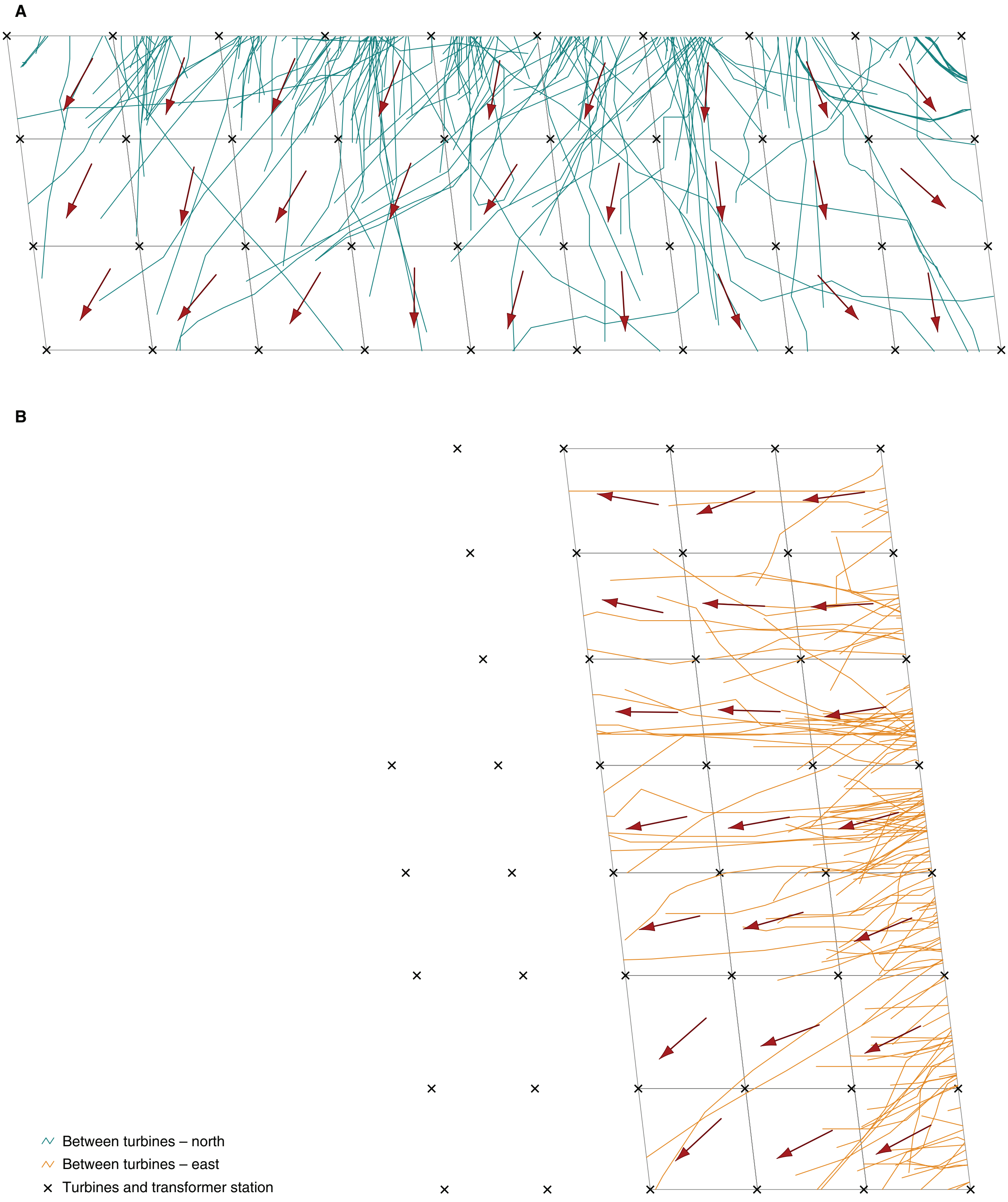


Figure 175. Average orientation (arrows) of birds passing beyond the first three rows of turbines in the Horns Rev wind farm, entering from A) north and B) east.

Table 56. Mean orientation (degrees) and standard deviation of flight orientation of bird tracks passing into the first 3 rows of the wind farm from the north and from the east, respectively. Data include only track segments from the central grid cells to avoid an effect of the wind farm edges. The number of track segments for each row interval is shown.

	North of the wind farm (15 cells)		**East of the wind farm (9 cells)**	
	Mean orientation	**St. Dev.**	**Mean orientation**	**St. Dev.**
1-2 turbine row	196°	32.8 (N=174)	254°	18.8 (N=105)
2-3 turbine row	198°	32.2 (N=67)	263°	18.0 (N=42)
3-4 turbine row	176°	44.7 (N=35)	269°	17.5 (N=25)

5 Discussion

Ib Krag Petersen, Thomas Kjær Christensen, Johnny Kahlert, Mark Desholm, Tony Fox

5.1 Changes in waterbirds distribution at Nysted and Horns Rev

In this report the main focus has been assigned to a description of potential effects on the distribution of bird species from the Horns Rev and Nysted offshore wind farms. This description was based largely on a BACI-type study design, comparing a pre-construction data set with a corresponding post-construction data set. Potential effects on bird distributions during the construction phase has been reported earlier (Christensen et al. 2003, Kahlert et al 2004) and were not described in this report. For both wind farms the construction phase was relatively short, covered by only three aerial surveys, including summer or early autumn surveys, where relatively few birds were present in the areas.

The use of aerial survey method with the aim to derive bird composition and distribution data has been dealt with in previous reports (Noer et al. 2000). A simultaneous coverage of large survey areas within a short time window and the option of using short time windows of optimal weather conditions have proved useful. The present surveys have actually served two quite different purposes. During the EIA-procedure for the two wind farm projects the method was used to make a general description of the bird composition in space and time in an area big enough to hold an impact area and a reference area. In the case of these two wind farm projects the survey set up was only modified slightly during the pre-construction and post-construction phases. A survey design that focuses on a general description of bird distributions in space and time for the EIA-procedure or for more general strategic surveys is optimal.

Two species of diving ducks, Long-tailed duck and Common Scoter, have been shown to avoid the wind farm areas. These species are primarily feeding on benthos-dwelling molluscs, and thus confined to a relatively limited depth interval, with few birds being present at water depths beyond 16 m.

5.1.1 Assessing the effects of Horns Rev and Nysted wind farms on staging and wintering birds

The appearance of large scale wind farms at Horns Rev and Nysted had an effect on the distribution of a number of bird species utilising the area for staging and/or wintering. The effects were found to be highly species-specific, ranging from avoidance of the wind farm areas and adjacent zones to indications of increased utilisation of the wind farm area as a result of attraction to the structures.

Red-throated/Black-throated Divers in the Horns Rev study area showed significant avoidance responses to the wind farm when comparing pre-construction data with corresponding post-construction data. This avoidance effect was found out to a distance of 2 km from the wind farm. At the Nysted study area divers were less abundant, and the available data set from this site did not show statistical significant differences between the pre- and the post-construction data sets. But indications from selectivity indices and from cumulative percentage distance frequency analyses indicated results that were identical to the findings at Horns Rev.

The analysis of a potential effect on the distribution of Common Scoters at Horns Rev was made difficult by the fact that the species showed major changes in distribution across the study area during the study period, since post-construction distribution involved the utilisation of the Horns Rev area to a much higher extent than previously, so a full BACI-design analysis therefore was not possible. The distribution of Common Scoters at Horns Rev clearly indicated that the birds responded to the presence of the wind farm by general avoidance of the actual wind farm area, but with concentrations of birds in its near vicinity of few hundred metres. The depth of the wind farm area is within the favoured depths for Common Scoters. At the Nysted study site, too few Common Scoters were counted to detect avoidance behaviour. However selectivity indices and cumulative distance frequency distribution of Common Scoters supported the indication that Common Scoters are avoiding the wind farm.

During observations of flight trajectories of birds around the Horns Rev wind farm in the spring of 2003 and 2004 Common Scoters were observed to avoid flying between the wind turbines (Christensen et al. 2004, Christensen & Hounisen 2004). When flying birds avoid the wind farm area, this will influence where birds settle to feet or rest. Thus the avoidance patterns shown by flying birds are likely to contribute to the overall avoidance distance shown by the distribution of the species when counted during aerial survey or during visual observation.

This increased avoidance of the area of the wind farm and surroundings by Common Scoter in the post construction phase may be caused by several factors. The physical presence of the turbines is one major potential factor, but the increased boat and helicopter traffic associated with the maintenance of the wind farm could be another.

Analyses of food preference of Common Scoter at Horns Rev in March 2005 showed that American Razor Clam *(Ensis americanus)* was the sole prey species at this site (Petersen et al. in prep, Freudendahl & Jensen 2006). Razor Clams of 6 to 9 cm were most abundant in the intestines of the birds. Razor Clams are difficult to sample due to their ability to rapidly escape deep into the sediment when disturbed. Thus information on neither size-class distribution nor geographical distribution across the study area was available.

Long-tailed Duck in the Nysted study area had a preference for the wind farm area during the base-line study, but showed a significant post-construction avoidance of the wind farm area and the adjacent 2 km distance zone when comparing data sets from the pre-construction and the post-construction phases. The effect was reduced with increased distance from the wind farm. In the entire study area total numbers during the post-construction phase were similar to or bigger than those of the pre-construction phase. This suggested that the reduced preference for the wind farm area was unlikely to have its origin in a general decline in abundance in the entire area (see Kahlert et al. 2006). While Long-tailed Duck was almost absent (selectivity index = -0.91) in the wind farm area during the construction phase in 2003 (Kahlert et al. 2004), the occurrences were closer to the expected number during the post-construction phase (selectivity index = -0.35).

Red-breasted Merganser, only present in the Nysted study area, showed indications of an increased preference of the wind farm site and its 2 and 4 km zones after the erection of the wind farm. Increased fish availability in the area in the post-construction phase could possibly be an explanation for this increase.

A priori, the hypothesis was forwarded that gulls could be attracted by wind turbines. Gulls attracted to boats by the possibility of food discards may consider the service boats as a potential source of food items. Boat activity increased in the area during the construction phase of the wind farm, when gulls showed increased preference for the wind farm sites at both Horns Rev and Nysted. During the post-construction phase no significant difference between pre- and post-construction selectivity for the wind farm areas was found.

Data from aerial surveys showed a slight increase in the relative numbers of Herring Gulls during construction of the wind farm, which may indicate an attraction effect (Kahlert et al. 2004). However, this could not be shown for Herring Gulls during the construction phase at Horns Rev (Christensen et al. 2003). During the post-construction phase there was no evidence of attraction or avoidance effects of the Horns Rev or Nysted wind farms by Herring Gulls.

No firm conclusions can be made on the effect of the wind farms on Little Gull. It was indicated that the species is attracted to the wind farms, with higher preference for the wind farm sites and the surrounding zones after the establishment of the turbines. The change was only significantly different for the 2 km zone around the wind farm.

Arctic/Common Tern showed no significant response to the establishment of the Horns Rev wind farm. Selectivity indices indicate an avoidance response in the wind farm area, but an increased utilisation of the 2 km zone around the park.

Results from selectivity index calculations for Guillemot/Razorbill at Horns Rev indicate that these species avoid the wind farm area and the 2 and 4 km zones around it after the erection of the turbines. The results were not statistically significant when analysed on a subset of the data, mainly due to large confidence intervals in the data set.

Bird distributions clearly reflect the attractiveness of the environment in which the birds find themselves. Generally, the patterns in density of birds gathered over the surface of the open sea reflect two dominant features of the environment, namely their food availability and (to a lesser and largely unknown extent) safety from predation. The direct threat of true predation is likely low in the vicinity of the wind turbines, because there are few avian or sea mammal predators of waterbird that are abundant or active in the area. However, there are abundant studies that show that human disturbance, including that caused by man-made objects, represent a quasi-predatory stimulus that initiates avoidance. Hence, the avoidance of the immediate vicinity of the turbines shown by some of the species described above could be ascribed to this hypothesis. However, we cannot entirely rule out the alternative explanation, namely that changes in food supply have been responsible for the changes in the distributions that appear to reflect an avoidance of the turbines. It was decided at a very early stage that it was simply too costly (and in the case of pelagic fish prey likely impossible) to initiate studies of changes in the abundance and distribution of avian prey items to account for their abundance and distribution. However, this alternative explanation is unlikely for a number of reasons. The BACI design specifically tests differences between before and after construction to assess changes that account for both the impact area and a control. These show generally that the significant reductions in densities of the key species described above within and in the vicinity of the wind-farms after construction did not also occur in the control areas. The exception was for Common Scoter at Horns Rev, where it was clear that a vastly different distribution post construction to that pre construction clearly did reflect some very major change in feeding distribution and therefore likely was the result in large scale changes in food abundance and/or availability. The lack of birds within the area between the turbines is however, likely to have been significant, given the reticence of the species to fly in the vicinity and between the rows of turbines (as shown by radar and visual observations). Hence, even in the absence of convincing statistical support for avoidance by this species, it is concluded that this species is also subject to habitat loss as a result of behavioural avoidance of turbines when swimming, foraging or merely resting.

5.2 Migrating birds at Nysted Wind Farm

5.2.1 Natural migration patterns at Nysted

Gedser Odde and the adjacent part of the Baltic Sea has long been recognised as one of the foremost sites in Denmark for observing substantial daytime avian migration of a range of species, especially in autumn.

The extensive studies reported here in relation to the Nysted wind farm carried out in the 388 km^2 study area from an observation tower at the Rødsand Sandbar, 6 km west of Gedser Odde, confirmed the importance of the study area for migrating birds. This study also added substantially to our knowledge of bird abundance, flight trajectories and their variation in response to various factors.

In the general description of bird migration, visual observations were supported by radar monitoring, which helped categorise the various species according to their occurrence and flight patterns. Coming from the direction of Gedser Odde, Common Eider, Wigeon, Pintail and Little Gull were typical of the true waterbird migrants, which passed the buoy-transect in a westerly direction during the autumn, approaching the wind farm area from the east. Different goose species could partly be assigned to the same category. During spring Common Eider (March/April), Brent Goose (May) and divers (March/April) were the most numerous amongst true waterbird migrants. In addition to the offshore areas, Common Eiders and Brent Geese also exploited an important spring migration corridor from west to east, north of the Rødsand Sandbar.

Common Eider was the most numerous bird species, and after that Cormorant, Sandwich Tern, Herring Gull, Long-tailed Duck and Red-breasted Merganser contributed second most to migration intensity in the study area. These could all be characterised as staging waterbirds. This meant that as well as a migration pattern, their prolonged presence in the area involved local movements, which at times included substantial reversed migration (i.e. in the opposite direction to the main migration orientation). Moreover, Cormorants were known to use the Rødsand sandbar as a nocturnal roost from which foraging trips (mainly to adjacent offshore areas) were undertaken on a daily basis. There were also strong indications that suggested that Sandwich Tern and Herring Gull exhibited similar behaviour. Furthermore, the study area acted as a spring staging and gathering area for diving ducks - mainly Long-tailed Duck, Common Eider and Red-breasted Merganser.

A long bird list was presented in the EIA technical background bird report (Kahlert *et al.* 2000), which showed species that were relevant to consider in relation to the projected wind farm plans for the area (Kahlert et al. 2000). This list was mainly based on the extensive studies compiled from visual observations at Gedser Odde in the late 1980s, which at the time of the EIA was the best documentation of the daytime migration in the area (Christensen & Grell 1989). The present study of visual bird movement has now provided much more fine-grained information, so that we can discriminate between the relative abundance of birds occurring at Gedser Odde and of those further west at the buoy-transect just 5 km east of the wind farm. During the autumn, this area represented the approach area to the wind farm for the mainly westerly migrating waterbirds.

The baseline observations of birds in the approach area, including both migrating and locally moving birds, suggested that this particular area was not nearly as important (even before the erection of the turbines) as the historical autumn data compiled at Gedser Odde had previously suggested. For some species, the population may have declined since the 1980s, for example, this is possibly the case for Wigeon and Black Tern (Clausager 2003, Delaney & Scott 2002), although the main migration period of the latter species was not monitored in the present study. Furthermore, some species passing Gedser Odde may take a more southerly course onwards, which precluded them from approaching the wind farm area in comparable numbers to those seen from land (possibly the case for many Little Gulls and divers). The same may apply to birds of prey and passerines, because the telescope observations made at the buoy-transect reported here detected between 4 and 10% of the numbers in the approach area on autumn migration that were reported from Gedser Odde. However, the broad-fronted migration of these species groups from the mainland areas may add to this percentage at the northern gate of the wind farm area.

The major differences between the estimates of the intensity of bird migration in the vicinity of the wind farm area based on historical data from Gedser Odde 10 km away and those from the present study emphasises the need for recent and site-specific data to inform the EIA-process for offshore wind farms. However, being privileged to gather seven years of site specific data under the present study, gave the unique opportunity to obtain a more fine-grained assessment than a literature study combined with one year of EIA-preparing field observations (Kahlert et al. 2000). Nevertheless, there were no major differences in the species or the issues considered in the EIA from those raised in that report.

Furthermore, even if the approach area monitored from the observation tower tended to be less important for migrating birds than the EIA suggested, three species still occurred in internationally important numbers (i.e. more than 1% of the biogeographical population): Cormorant (autumn), Dark-bellied Brent goose (spring and autumn) and Common Eider (spring and autumn). For Common Eider, the present migration volume estimates corresponded to about one third of the entire biogeographical population and the species comprised c. 60-80% of all visual migration activity at the buoy-transect. Hence, the study area seemed to have maintained its numerical importance even though a dramatic decline has been recorded in Baltic population of Common Eider in recent years (Desholm et al. 2002).

In addition, Pintail (0.9% of the biogeographical population) and Barnacle Goose (on the basis of strong indications of occasional mass migration through the area) may also potentially occur in internationally important numbers. The international importance of the study area for some species emphasised the obligations of the Danish government to protect these and other species in accordance with the international legislation and conventions. In the case of Barnacle Goose, observations at the buoy-transect failed to confirm mass migration events in the area. This emphasised the risk of missing significant migration events during visual observations as a result of using a "short field trip-approach" compared to the extremely time-consuming continuous observations undertaken by Christensen & Grell (1989) in the 1980s.

5.2.2 Effect on birds of the Nysted Wind Farm

5.2.2.1 Effects during construction

The effects of the construction work on migration patterns of birds were studied during the spring of 2003. Due to the prevailing eastward direction of migratory birds during this period, the results from the eastern edge of the wind farm area were used to describe the flight patterns after they had passed the wind farm area.

In spring 2003, construction activities had commenced on site, and continued day and night. During the construction phase at night, the relative number of flocks, which traversed the eastern edge of the wind farm area, was lower than during the base-line period. Such a pattern was not found during the daytime. Construction activities during the day included the presence of several ships and work associated with the developing foundations as well as occasional noisy activity, did not appear to affect the flight trajectories of birds. By contrast, the flight patterns in spring 2003 suggested that construction work could have affected the flight corridors of the birds at night, when the most conspicuous difference to construction activities during the day was the strong lights used during the hours of darkness. Birds generally navigate in relation to natural sources of light such as the sun and the stars. However, they are also attracted towards light, e.g. to lighthouses, illuminated oil rigs and other man-made structures (see review in Wiese et al. 2001), although this conflicts with the results from the Nysted windfarm. Attraction effects seem to occur predominantly during periods of drizzle and fog (Weir 1976) and it has been suggested that the illuminated area is increased during such conditions because of refraction of light on air droplets (Wiese et al. 2001). This may create an environment in which migratory birds loose their orientation, leading to circular flights around well-lit man-made structures (Bourne 1979).

Our observations were carried out almost exclusively at good visibility (> 1 km) at nighttime. Therefore, we would not necessarily expect to detect such an attraction effect. It may be hypothesised that sources of light mounted at the construction site could displace migratory waterbirds, which were likely to constitute the majority of spring migratory birds during the night. Hence, as waterbirds approached the construction site in good visibility they may have had several other points of reference by which to navigate, and at a distance they may have associated the lights at the construction site with a city or land. Many waterbirds which undertake nocturnal migration would usually avoid crossing land areas unless flying at high altitude (cf. spring migration of Common Scoter across Jutland, Pedersen 1988)

Even if the migration route through the wind farm was used less at night, (possibly as a result of the construction work) it must be concluded that the effects on the flight behaviour were minor, temporary and of relative short duration.

Overall, flight trajectories did not change dramatically in spring 2003, i.e. the main migration route was located north of the wind farm area just as was observed during the base-line study.

Regarding the potential for collisions with structures associated with the construction work, the apparent avoidance response observed would actually reduce this potential risk, at least under conditions of good visibility. However, given that flying birds may be attracted to lights during foggy conditions we cannot exclude the possibilities of elevated collision risk during such periods.

The design of the studies undertaken to assess the effects of the construction phase on migrating birds was not as robust as the studies undertaken during the subsequent operational phase. Construction coincided only with a single spring of observations, and for which only two years of prior base-line studies existed with respect to flight trajectories. For this reason, we have put little emphasis on the pre- and post construction migration intensities, which were significantly lower during the construction phase compared to the base-line study. However, this most likely resulted from sub-optimal weather conditions for migratory birds during the few observation bouts undertaken during the construction phase.

Hence, the results from the studies during construction cannot be replicated at the Nysted wind farm. Nevertheless, valuable information was compiled on aspects about which little is currently known, but which will contribute to knowledge compiled from other European countries in the future.

5.2.2.2 Effects on birds during operation, lateral distribution

Both the hypothesis that birds would undertake lateral avoidance when approaching the wind farm, and the alternative hypothesis that they would be attracted by the wind farm were confirmed, although the avoidance response had the most significant consequence for the overall migration intensity in the wind farm area. Thus, attraction was as predicted restricted to cormorants and gulls, which used the super-structures of the wind farm as a substrate on which to roost. Hence, it was confirmed that responses amongst migrating and locally moving birds towards offshore wind farms were highly species-specific.

Lateral avoidance responses towards wind farms were expected, as it seemed to be the most frequently occurring response when birds approach wind farms. Hötker et al. (2004) mentioned 81 bird species, which showed avoidance behaviour responses to wind farms. Furthermore, Winkelmann (1992) showed that a lateral response was the most frequent way of avoiding a wind farm shown by birds.

The avoidance response undertaken by the migrating birds at the Nysted Offshore Wind Farm was shown by deriving a causal relationship of inter-related variables, which confirmed that birds deflected laterally. This could be illustrated as follows:

Birds changed their orientation as they approached the WF → The probability of birds crossing the WF was reduced → Less migration intensity was observed in the WF

The present study of avoidance responses focussed on waterbird migration passing the study area twice annually mainly along an east-west axis. However, data on movements of birds from other directions including those that came from the direction of the mainland areas (presumably passerines, doves and raptors) were also gathered, although their migration was typically broad fronted and apparently not as intensive in this area as that of the waterbirds. This fact, combined with reduced radar detection probability and relative lack of opportunity to visually confirm species identification on the migration route of terrestrial bird species led to less conclusive results about avoidance in this species group.

In contrast, a well-defined migration corridor of waterbirds was evident through the study area, of which a substantial proportion crossed the wind farm area during the base-line study. This migration route lost a substantial degree of its importance during the operational phase due to the marked avoidance response shown by the waterbirds as they approached the wind farm. During the autumn, the Common Eider-dominated flocks of waterbirds showed initial deflection response at 3-5 km from the windfarm as a slight lateral response, showing more pronounced change in orientation at distances closer than 1 km. Little has been published on response distances of waterbirds, but on the same Common Eider-dominated migration route further to the northeast in Kalmarsund, Sweden, deflection tended to occur at comparable distances (Pettersson 2005). However, radar data show evidence of changes in migration directions at greater spatial scales. These suggest that the possibility cannot be excluded that (at least amongst Common Eiders rounding Gedser Odde in autumn under conditions of excellent visibility) some birds may react to the sight of turbines by modifying migration trajectories at 10-15 km distance.

The first analyses of the orientation of the western migrating waterbirds towards the wind farm, which suggested that birds would show a general avoidance response, was confirmed by studying how the probability for an approaching waterbird flock would change by the transition from the base-line period to the operational phase. During the base-line study, 40% of the flocks of waterbirds crossed the eastern gate, which emphasised the importance of this as a pre-construction trajectory through the wind farm area. This figure was consistently reduced to 8-9% during the operational phase. In relative terms, this meant that if 10 flocks traversed the eastern gate during the base-line periods, 8 of these flocks would deflect and avoid the wind farm during the operational phase and 9 out of 10 specifically for flocks of Common Eiders. The significant avoidance response amongst Common Eiders was, however, likely to be overestimated insofar as visual species identification was restricted to ca 6.5 km and did not cover the entire radar range (11.1 km). Hence during the base-line study, most flocks identified to Common Eiders were migrating at the same latitude as the wind farm, which due to their westerly orientation gave them an extremely high relative probability of detection.

In addition to Common Eiders, sufficient data were available to investigate the avoidance response of day-migrating geese. At first sight, the results of the goose data could suggest a lesser avoidance response amongst this species group, since 14% (but not statistically significant), of geese which passed the eastern gate entered the wind farm. However, the vertical radar data showed that geese generally migrated at altitudes above the wind farm (Blew et al. 2006). Hence, what may appear as a vague avoidance response on the horizontal radar is more likely to result from geese migrating at high altitude during the entire study period.

The nature of the avoidance response at the Nysted study site was influenced by time of the day (day/night). It was evident that approaching waterbirds were able to detect the wind farm and take avoidance measures, which was supported by previous investigations at the Tunø knob wind farm, where Common Eiders and Common Scoters also showed avoidance, especially during moon-lit nights (Tulp et al. 1999). The present study showed that, at night, birds tended to approach the wind farm closer (less than 1 km) before showing responses by marked altering direction under most weather conditions than by day (1.5-3.5 km and under certain circumstances up to 5 km). Analysis of average track orientation over much wider areas also suggests that under conditions of extremely good visibility, Common Eiders rounding Gedser Odde may even react at far greater distances (possibly up to 10-15 km). Furthermore, birds were more inclined to enter the wind farm at darkness, as 6 out 10 flocks, which crossed the eastern gate during the base-line study, avoided the wind farm during the operational phase compared to daytime when 9 out of 10 flocks showed avoidance (both overall and specifically for Common Eiders).

There are several interpretations of these patterns. First, it could result from the reduced visibility at night, which leads to a closer approach to the wind before a reaction is triggered to the stimulus of the farm at night. In other words, the birds may merely have discovered the wind farm at a much later stage in their approach. This has been put forward as a likely explanation for reduced avoidance responses shown by birds at night (e.g. Pedersen & Poulsen 1991). However, data from vertically mounted radar (Blew et al. 2006) suggest that birds may make vertical deflection at night to avoid the turbines, a feature that could not be detected with horizontal radar.

A similar methodological caveat could result if birds migrate to a larger extent at altitudes above the wind farm during the night compared to the daytime. In fact, birds generally do migrate at higher altitudes at night (Eastwood & Rider 1965, Alerstam 1977, Hüppop et al. 2004). Finally, the nocturnal waterbird migration may involve other species than those during the day (which could be confirmed by visual verification) which exhibit lesser avoidance responses. This may be possible during spring, when it has been suggested that wading birds dominate the nocturnal waterbird migration, but not during the autumn, when little acoustic confirmation of the waterbird species involved existed (Blew et al. 2006). It was not possible in the present study to determine the relative likelihood of each of these potential explanations being the correct interpretation.

It was also not possible to investigate the effects of visibility on avoidance in further detail with respect to absolute visibility, due to lack of sufficient data. Firstly, restricted visibility at biological relevant distances (< 1 km) was a rare event both during spring and autumn. In addition, waterbirds tended to show much reduced migration intensity during periods of restricted visibility (this study, Pettersson et al. 2005).

The effects wind may have on waterbird migration were investigated, although the unpredictability of these effects may generate little general information on the effects of wind farms. However, wind effects turned out to be an important factor, which could explain substantial variance in the bird data and thus increase the performance of the statistical predictive models. Wind direction influenced the flight patterns of birds and their probability of passing the eastern gate of the wind farm. For example, during autumn, this probability was significantly increased during periods of southerly crosswinds. There were at least two explanations to this pattern. Firstly, the preferred avoidance route around the turbines was a route to the south-west (either as a result of a barrier effect of the Rødsand Sandbar or because of their preferred general orientation towards their wintering areas). However, this route was associated with more effort, because of greater risk of adverse crosswinds or direct headwinds when the wind was in that quarter. Furthermore, southerly crosswind was previously shown to concentrate migration at the latitude of the wind farm, where the probability that any flock would actually cross the wind farm area is also greater. These data emphasise how important local, site-specific elements may be in influencing migration routes, timing and volume. This is important, because it may not only be the migration volume in the approach area at the same latitude as the wind farm which influences migration patterns, but also the migration which is occurring at the periphery of the area.

Finally, the probabilities of birds crossing the eastern gate of the wind farm may be influenced by scale. In this respect the data collection protocols for the present study were initially heavily constrained by the restricted range of possibilities regarding where to place the observation tower at a sheltered site. This in turn restricted the flexibility of monitoring the approach area of the wind farm area during the autumn season, when the highest migration volume of potentially sensitive species occurred. In addition, the performance of the radar restricted the bird detection range to a circular area of 6 nautical miles, which was a sensible range in order to cover the coastal migration of waterbirds potentially at risk of crossing the wind farm area. However, the probability of observing flocks crossing the eastern gate increased with decreasing range (for example, as observed amongst daylight migrating Common Eiders), which tended to be identified out to a maximum distance of 3.5 nautical miles. Therefore, more confidence was put into the relative difference between the base-line study and the operational phase, which was not ideal, but seemed more robust to changes in scale. This emphasised the importance of incorporating a base-line study, and lowers the risk of deriving erroneous conclusions on the effects of a wind farm.

Avoidance leads to a lateral deflection and a possibly a compensation in the flight trajectory after a flock of birds had passed a wind farm. Pettersson (2005) calculated these detours to amount to c. 1.5 km and 2 km at two small offshore wind farms in Kalmarsund (at Utgrunden and Yttre Stengrund). He further estimated that for each of these wind farms the migration route for a Common Eider, coming from the breeding areas in the Stockholm archipelago and wintering in Danish waters (800 km), would be extended by 0.2-0.4%.

At Nysted, a linear avoidance response at 3 km from the wind farm was the general pattern and a similar compensatory adjustment of the orientation would lead to a detour of c. 5.5 km or 0.7% of the entire migration route, assuming that a bird would approach the wind farm at its median latitude. At nighttime, avoidance tended to occur at 500 m. This would correspond to a detour of 3.9 km or 0.5% of the migration route. The detour is greater at Nysted compared to the wind farms in Kalmarsund (Sweden) because of the larger size of the Nysted Offshore Wind Farm, and a cluster of turbines of the nature of this site would probably be more representative of future offshore wind farms than those in Kalmarsund. For Common Eiders departing the Baltic in autumn specifically, it is interesting to speculate whether they would actually need to compensate for their avoidance response. Most waterbird flocks avoiding the wind farm deflected to the southwest, i.e. in the same direction as their main wintering areas in the Kieler Bight and the Wadden Sea area. Hence, the birds may simply maintain a westerly or southwesterly orientation after having passed the wind farm. In this case, where no compensatory re-orientation was necessary or made, the extension distance to the migration routes would be halved.

An extension of the migration route of this magnitude at each of these wind farms on the Common Eider migration route would be difficult to discriminate from other factors which would cause similar increases in energy expenditure (such as adverse weather conditions). However, although individually these increases to energy expenditure on migration may be considered trivial, we should be aware that more serious cumulative energetic effects may accrue from repeated such avoidance responses of birds that pass several wind farms (or other sources of human disturbance) along their annual migration routes.

Although the overall detour for migrating eider at all three existing wind farms (Nysted, Utgrunden and Yttre Stengrund) would amount to a c. 1% extension to the overall length of the migration route, there was little risk that a Common Eider would pass all three wind farms during the same season. At the Swedish wind farms, the proportion of all passing birds that showed avoidance was relatively small (9 and 16%). In addition, the greatest displacement of the migration routes occurred at Nysted during autumn, while the flight trajectories were most modified at Kalmarsund in spring. Hence, in the present context, it is concluded that the extra energy expenditure that was incurred by Common Eiders as a result of one large and two small offshore wind farms was negligible. Nevertheless, energetic implications of avoidance will inevitably be revisited in the future if more wind farms are to be constructed along the same migration corridor, as each wind farm could potentially extend the migration route by a magnitude of 0.2-0.7% (although with high individual variance).

Finally, avoidance by migrating birds of wind farms results in less flight activity (migration intensity) within the wind farm area, which reduces collision risk. *A priori*, it was expected that migration intensity would be a parameter that was less sensitive than others subject to before-and-after comparisons of migration patterns (e.g. response distance and probability of crossing the eastern gate). Thus, overall migration volume in the entire region (southernmost Scandinavia) was likely to affect the local migration intensity at Nysted. Regional migration volume is influenced a suite of weather parameters along the migration route together with the time elapsed since the last major migration event (e.g. Alerstam 1977). For example, after a prolonged period of adverse weather conditions during the main migration period of a species, the sudden onset of favourable weather conditions for passage is likely to precipitate a major migration event. However, even if favourable weather conditions prevail, migration intensity may decline if the bulk of birds have already passed. These patterns make it extraordinarily difficult to model local migration volume and to discriminate wind farm effects from natural occurring migration events. Nevertheless, during the base-line study, it was predicted that a significant lateral deflection would be associated with a real barrier-induced reduction in migration intensity at Nysted.

Given the clear avoidance responses shown both during spring and autumn migration periods and the discrimination between head- and tailwind, known to influence the migration volume substantially, significant and dramatic reductions in migration intensity at especially the eastern gate during daytime supported the prediction that the avoidance behaviour of birds would lead to substantially less flight activity in the wind farm area. In the eastern part of the wind farm area the reduction was 57% both during spring and autumn, even correcting for base-line level and impaired detection rates by radar at long distance. Day-migrating waterbirds tended to contribute most to this reduction. Nighttime and periods of headwinds represented conditions where reductions in migration intensity at the gates were less significant. The weakened response at night confirmed results from other analyses (see above), while periods of headwinds may comprise a larger proportion of local staging birds, which may show a greater extent of habituation towards the wind farm.

5.2.3 Modelling bird collision risk and measuring collision rates

5.2.3.1 Monitoring

The development of the TADS started in 2000 by first bringing the different pieces of equipment together and secondly testing the performance and optimising the hard- and software (Desholm 2003, Desholm et al. 2005, Desholm et al. 2006). The TADS has now been mounted continuously for more than two years (Desholm 2005a, Desholm 2005b) at the Nysted offshore wind farm and have been collecting data for more than six months over this period. So, in terms of hardware performance, the TADS has proven resistant to the harsh and salty environment of the Baltic Sea.

As a collision monitoring tool the TADS has been constrained by several factors. First of all by the very nature of the bird-wind turbine collision phenomenon being a very rare and unpredictable event. This was reinforced by the behaviour of the chosen focal species, the Common Eider, which in several different ways shows avoiding responses to the turbines (see below) and thus to the field of view of the collision monitoring TADS, making a quantification of the number of Common Eider collisions by direct impact measurement an almost impossible task. Of course we could have applied more TADS in this study, but here the price of this equipment made this option impossible. Common Eiders do and will collide with the turbines at the Nysted offshore wind farm but in such low numbers that direct quantification is difficult. Even though the set-up was designed for large bird species (e.g. ducks and geese), we managed to record a passerine bird/bat falling in to the water after colliding with the rotor-blades. So the TADS can record these bird-turbine collision events.

During the four seasons, we managed to monitor the airspace around the turbine for 56% of the 180 days study period and here, with regard to monitoring efficiency, it was the weather (i.e. unfavourable wind directions, drifting clouds, rain) that acted as the constraining factor. Despite the relative low number of animals (birds, bats, moths) triggered automatically by the TADS, its performance at the wind farm was rather conservative between years. Hence, the number of animal-triggered sequences per season was rather homogeneous if monitoring period was taken into account. On average over the four seasons, the TADS recorded one individual per 140 hours of monitoring with a range of 126-167 hours.

5.2.3.2 Modelling

The model framework

Instead we designed the TADS-study as a two-project sample protocol, with the continuous collision monitoring 24 hours a day, only interrupted by the collection of input data for the predictive collision model when we expected high numbers of migrating Common Eiders.

The applied values for the model input parameters were obtained partly from the data collected during the present study and partly from the literature. Five out of seven parameters have been derived from this study (n_1, r_1, r_2, r_3, and n_m) and two parameters originate solely from other publications (c and r_4). However, the probability of passing the sweeping rotor-blades by chance is split in to a head-wind and a tail-wind situation, and the choice between these two values is made by the model in accordance with the re-sampled wind direction drawn initially at each model iteration. The approach of making input values dependent on the wind is a new feature in this much improved model, but is an obvious improvement, since wind is known to exert such an influence on the migration pattern of birds as well as on the orientation and rotation speed of wind turbines.

Avoidance behaviour

To use the TADS as a tool for collecting data on the near rotor blade avoidance response necessitates the passage of sufficient numbers of bird flocks passing the field of view during the study period. Only one passerine bird was observed in the very near vicinity of the rotor-blades (vertical viewing mode) showing a 180 degrees u-turn as an evasive action. In the horizontal viewing mode, 198 flocks of waterbirds (mainly Common Eiders) were observed passing within a few hundred metres of the turbines. Of these only 2.5% performed evasive behaviour. This low number can be explained by the fact that this sample of flocks also contained the many flocks that had corrected their migration heading outside the field of view of the TADS. Again we were constrained in estimating a relatively rare event, here the evasive actions by the migrants, due to the very low sample size.

The final conclusions in this report, regarding the horizontal avoidance behaviour of waterbirds flying within the wind farm, support the findings that they avoid to a high degree flying in the near vicinity of the individual turbines (Desholm & Kahlert 2005). At present, surveillance radar is the most efficient and reliable technique for collecting these kind of data (Desholm et al. 2006).

Altitude distribution

Our sample size of 198 flocks were used for a thorough comparative analysis of the flight altitudes between Common Eider flying outside and inside the wind farm. When first corrected for coverage, the data reviled that Common Eiders tend to adjust their altitude below the lower reach (<30 m) of the rotor-blades when flying within the wind farm. So not only do the Common Eiders avoid flying inside the wind farm and close to individual turbines to a high degree, they are also actively decreasing the collision risk, when flying inside the wind farm, by partially avoiding the vertical risk zone during both day (at lower altitudes) and night (above turbine height).

The interesting question whether there is a difference in the altitude distribution of migrating Common Eiders between day and night can not be tested directly on altitude data in this study, since only very few observations of birds have been recorded during the night. This may in part be explained by the relative low number of Common Eiders migrating at night compared to day-time (Alerstam et al. 1974, Desholm 2005b). However, as described previously in this report, this lack of flocks passing the field of view of the horizontal operating TADS is more likely to be caused by the waterbirds flying above rotor-blade height when flying in the wind farm area at night. These findings are supported by the study by Blew et al. (2006) who conducted a boat-based vertical radar study on avian migrants in the Nysted wind farm. They found that birds (all species grouped together) flying in the wind farm area tend to fly less frequent in the lower 100 m altitude segment at night compared to during day-time. This was evident, even though their vertically operated ship radar underestimated the migration volume in the lower 50 m above the water surface, the altitude segment mainly used by day-time migrating Common Eiders, to an unknown degree.

Collision estimate

The estimated average number of collisions of 44.4 Common Eiders during one autumn migration period equals 1.2 individuals per turbine per year, which lie within the published estimates at a coastal wind farm (Winkelman 1992). Caution should be taken though when comparing very site-specific estimates, since for obvious reasons local conditions, such as migration volume, species composition and topography, most likely will play a significant role in affecting the number of local collisions. Therefore it is important to compile and publish species specific behavioural data, which can be applied in future studies at other locations experiencing different local conditions. In the past, there has been a common tendency to publish estimates of the number of collisions per turbine per year only. Unfortunately, such site-specific data is of little value at other sites unless local conditions are very similar. Since this is rarely the case, the data on numbers of collision per turbine per year from one study can rarely be applied without modification at other wind farms. This is unfortunate, considering the relatively heavy resource demands involved in undertaking these kind of investigations.

The deterministic collision prediction model for Common Eiders at the Nysted offshore wind farm (Desholm 2005b) estimated a mean of 68 and lower and upper limit of 3 to 484 collisions per autumn migration season. The stochastic model presented in the present report incorporates variance estimates of the different parameters, and hence, can much more reliably predict collision rate estimates with appropriate confidence intervals. Applying this more sophisticated modelling approach, we can now, with a high statistical certainty, predict that less than 50 Common Eiders, on average, will collide with turbines at the Nysted offshore wind farm during each autumn, which amounts to less than 0.022% of all Common Eiders passing the study area.

From the outset of this study, we planned to use the TADS as a validation tool for the estimated (from the model) number of collisions. However, since no Common Eiders were actually observed to collide with the turbine during the TADS monitoring such a validation proved to be difficult. Instead, our lack of observations of collisions is supported by our model results. If the mean number of 44 Common Eiders are divided by the 72 turbines at Nysted and multiplied by two (to account for the same number of birds passing the wind farm in spring; Desholm et al. 2003, Kahlert et al. 2000b, 2004, 2005) we end up with an annual number of 1.2 individuals at each turbine. Considering this figure, together with the fact that the TADS covers 1/3 of the area sweep by the rotor-blades and about half of the study period (ME = 56.4%) results in a crude estimate of 0.2 colliding individuals pro annum to be detected by the TADS. This confirms that the probability of a single deployed TADS detecting any collisions, given this extreme low number of collisions, is almost non-existent. Thus, if the collision frequency is too low to be validated by the limited number of TADS, then the outcome from the collision model can explain and validate the zero-data from the TADS monitoring. From this, we conclude that no species came anywhere near the increase in annual mortality of 1% caused by wind turbine collisions at Nysted necessary to trigger mitigation mechanisms to reduce the effects of this impact.

In conclusion, it is recommended that to quantify wind farm related mortality amongst flying animals, it is necessary to first apply a modelling approach based on best possible available data, the predictions from which can then be validated by the application of a programme of post construction direct collision monitoring. If the collision frequency is substantial the TADS data can be used to validate the model estimate and if very few collisions occur the model can help explaining why no collisions are measured. Finally, the TADS and radar technologies can provide vulnerable input for the collision model (Chamberlain et al. 2006, Desholm et al. 2006) especially at night where the human eye is of limited use. So, even though most studies suggest that situations with low visibility will constitute the high risk periods (Garthe & Hüppop 2004, Fox et al. 2006), the present findings show that this is not necessarily the case for all species. At least not for the Common Eiders.

5.3 Migrating birds at Horns Rev

5.3.1 Natural patterns of bird movements

Systematic bird observations at Blåvands Huk, located c. 14 km from the Horns Rev wind farm, started in the 1960s. Since then, this location, the western most point of Denmark, has been recognized as a focal point for bird migration. It's location position between the open North Sea coast north of Blåvands Huk and the extensive tidal area of the Wadden Sea (an area of international importance for many bird species just south of Blåvands Huk), help explain the high numbers and species diversity of birds recorded at this site. Blåvands Huk is famous for the occurrence of waterbirds, seabird and waders migrating over the sea and along the coastline, especially in autumn, when up to 6,000 divers, 4,000 Gannets, 400-500 Cormorants, 6,000 dabbling ducks, 30,000 Common Eiders, 40,000-60,000 Common Scoters, 8,000 Oystercatcher, 3,500 Knot, 1,400-1,500 skuas, up to 1,500 auks, 15,000 terns and up to 25,000 gulls can pass in a single day (Kjær 2000, Jakobsen in print). It has, however, also been recognised that large numbers of migrating terrestrial bird species, i.e., raptors and passerines, also pass the Blåvands Huk area.

At Blåvands Huk, southbound movements of seabirds are generally substantial; even in spring period, when northward bird movements are expected to dominate. This pattern of movements reflects staging birds showing southwards movement to compensate for nocturnal northward drift caused by marine currents. Southwards movements at Blåvands Huk and Horns Rev may, however, also be related to birds at sea avoiding low-pressures systems (cyclones), which normally show a more northerly course when crossing the North Sea (see Mouritsen 1991). In addition, both the coastal and offshore areas, including Horns Rev, are exploited by high numbers of gulls and terns, moulting sea ducks, and by staging waterfowl and seabirds, as documented from ship and aerial bird surveys performed both in summer and in winter (Joensen 1973, 1974, Laursen et al. 1997).

Of the most numerous focal species, the occurrence of Gannet and Common Scoter recorded by visual observations at Horns Rev during the present study were at expected levels, or even higher than expected for Common Scoter in spring. Conversely, the number of both staging and migrating Red- and Black-throated Divers was lower than expected. The highest number of divers recorded on Horns Rev and in the adjacent areas, has been found to occur in winter and spring (Laursen et al. 1997), which have been confirmed by numbers observed during aerial surveys in February and March (this study). Although no visual studies were performed during February, only relatively few divers were observed during March in all study years, at a time when divers is present in the general area in substantial numbers (cf. Table 4). However, if staging divers in the Horns Rev area are optimally distributed with respect to food, and likewise are not frequently disturbed, there may be no need for the birds to move around, with the consequence that records of flying divers during this period may underestimate the actual occurrence. During spring migration, however, divers are expected to make directional flights in the direction of the breeding grounds, and the lack of substantial migration of divers throughout this study was rather surprising. A possible explanation may be that the few days with observation in relation to the length of the migration period may have taken place on days where no marked diver migration occurred. At Blåvands Huk, days with substantial diver migration seem to be unpredictable and are probably associated with some special conditions, i.e., weather, both locally and regionally.

Given the documented occurrence of extensive bird migration, and large numbers of staging and wintering birds in the area, the pattern of bird movements at Blåvands Huk and Horns Rev is complex, involving both long-distance migrants passing through the area, migrants that make short stops in the area before moving on, and local movements by staging and wintering species staying in the area for shorter or longer time periods. At Blåvands Huk, daily southward movements of, for example, divers and diving ducks, is recognised as compensatory movements performed by the birds to compensate for nocturnal drift by the dominating northward current taking the birds away from the preferred daytime foraging areas during the night.

In the vicinity of the Horns Rev wind farm area, the overall pattern of bird migration was expected to be comprised by both migrating and staging species. However, in relation to undertaking an assessment of the avian collision risk presented by Horns Rev wind turbines, the species expected to be at highest risk included divers, Gannet, Common Scoter, skuas, gulls and terns, although the occurrence of all species was recorded during the present study. For these focal species, their selection was based upon i) their occurrence in internationally and nationally important numbers and ii) the risk associated with their specific behaviour, for example, those species likely to fly at the altitudes of the turbine rotor blades, as outlined in the EIA (Noer et al. 2000).

Based upon both visual and radar observations performed during the present study, the focal species exploited the area differently, although clear flight patterns could not be established for all species, due to inadequate or infrequent observations. Gannets apparently used the shallow reef area just north of the wind farm as a foraging site and often showed dispersal movements to and from this area. Common Scoter exploited the area just to the north and northwest of the wind farm for staging, making marked movements to and from this area, probably to more attractive foraging areas, especially during spring 2003 and 2004. Gulls and terns were observed flying both outside and inside the wind farm. The impression was gained that these species commuted to the study area from nocturnal roost sites along the coast, and that the general area was exploited for daytime foraging. Foraging terns were frequently observed in higher numbers over the reef proper, rather than closer to and inside the wind farm. Gulls, however, were found to make more determined daily movements towards the turbine area. It was the impression of the observers, that, especially, Great Black-backed Gull, used the wind farm as a way-point when arriving from more coastal areas, as many individuals were visually observed to fly into the wind farm from the east and pass through the area.

With the exception of Common Scoter, all species recorded during the present study showed no marked difference in their seasonal occurrence at Horns Rev when compared to the general phenology compiled from many years of observation at Blåvands Huk. As expected, Gannets were most numerous during late spring and early autumn, gulls occurred all year round, and terns showed highest numbers during spring and autumn migration periods. Skuas occurred at the same periods as terns, as would be expected, since terns are the preferred victims of the cleptoparasitic skuas. The high numbers of Common Scoters recorded during spring at the wind farm and further westward, have however, not been matched by similar high counts from the coast, suggesting that Common Scoters may have a more offshore distribution at this time, which go undetected from observers at the coast.

Even though the phenology patterns recorded at Blåvands Huk match with the occurrence of birds recorded during the present study, it is important to emphasise that the results and conclusions in relation to the bird exploitation of the area, are based on data collected after construction of the wind farm. Consequently the present data provide a picture of bird occurrence, behaviour and movements when the wind farm was in operation, without any possibility for comparison with the patterns of exploitation of the area previous to erection of the wind farm. A study design protocol that included data collection before, during and after construction of the wind farm would have been much more effective in judging the true effects on birds number, distribution and behaviour (a BACI design), but was not possible as no observation platform was available in the area pre-construction.

5.3.2 Effects of human activities during construction and operation

No quantitative data on human activities were collected at Horns Rev during the present study. During the period of wind farm construction no bird observations were made in the area. However, at certain times during the study period (during wind farm operation), the level of human activities in the wind farm may have exceeded the level of activity expected during normal operation. During these activities, i.e., large vessels removing turbine nacelles or mounting rotor blades, no obvious effects on the presence and behaviour of birds were observed.

Likewise, the activities of transporting staff between turbines for normal inspection and maintenance by helicopter (hoisting people to and from the turbine nacelles) or by ship, generally did not result in marked bird reactions. This is probably because most activities were performed inside the wind farm where bird numbers were anyway very low. On one occasion, helicopter activity at a turbine at the northern edge of the wind farm, resulted in a massive flush of Common Scoter present in the area just north of the wind farm, which took to air in avoidance (Fig. 176). Less conspicuous reactions of Common Scoter in this area were, however, also recorded when the smaller boats were operating at the northern turbine row or had just sailed outside the wind farm for shorter periods.

The effects of human activities in relation to repair and maintenance of the wind turbines in the Horns Rev wind farm on the occurrence of birds in the area were assessed to be of minor importance because of the already low density of birds within the wind farm. At the observed levels of activity, boats and helicopter traffic did not appear to have a permanent effect on the exploitation of the area by birds, as, i.e., most of the Common Scoters disturbed by helicopter, were recorded landing in the same area after the helicopter had left the area. However, given the disruptive potential of low flying helicopters, an increase in the level of helicopter activity may have more profound or potentially permanent implications on the distribution of Common Scoter in the general vicinity and maybe on other species as well.

5.3.3 Effects of the wind farm on bird movements during operation

As stated in the EIA report (Noer et al. 2000), the risk of collisions between birds and wind turbines may depend on the resulting avoidance or attraction response to the wind farm or to single turbines by individual bird species. Likewise, birds that frequently fly in altitudes of the turbine rotors may be more at risk than species flying below or above the rotors, although birds flying at lower altitudes potentially may collide with the turbine towers.

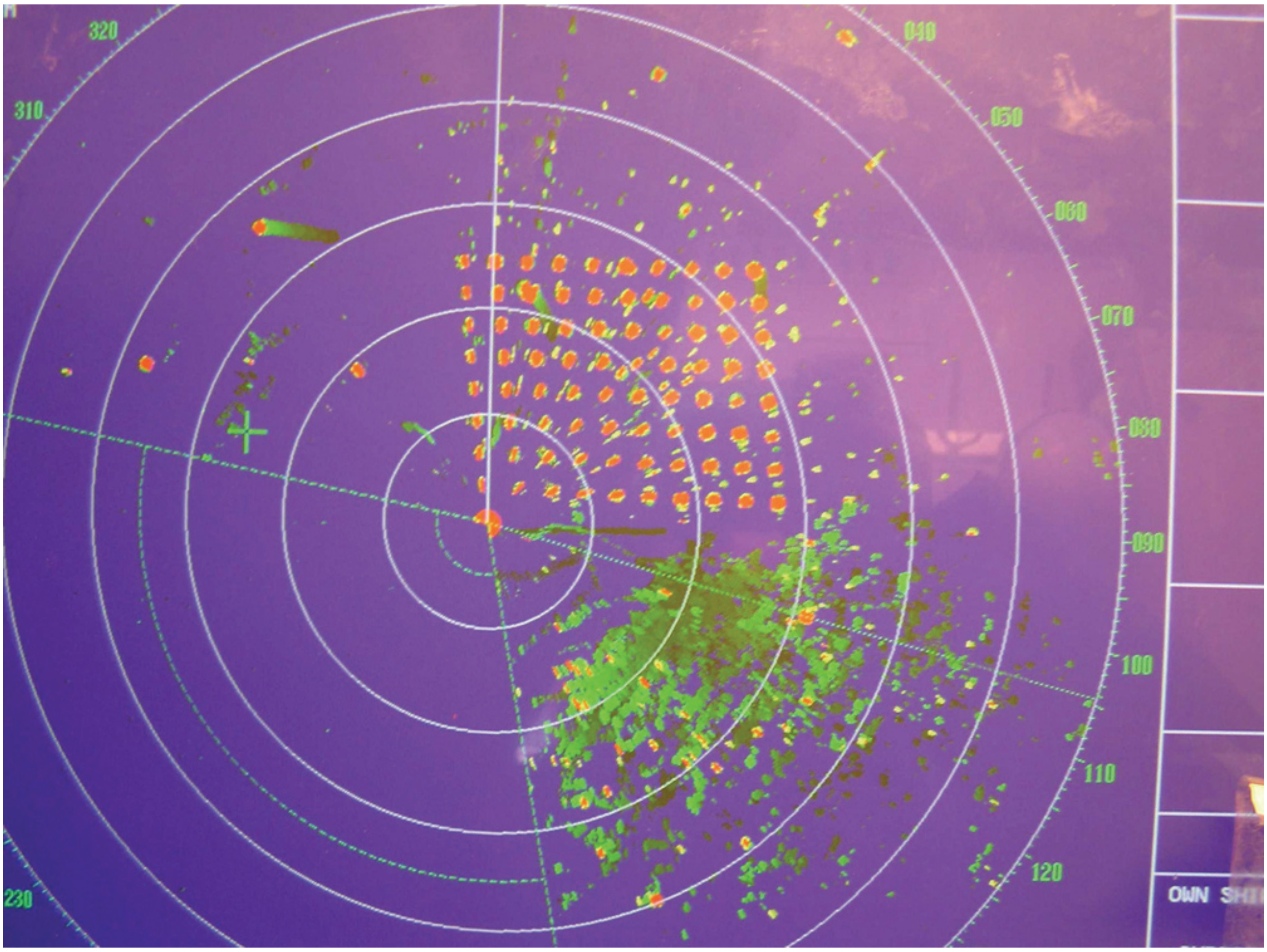


Figure 176. The radar screen during the take off of Common Scoters resting in the area just north of the wind farm in spring 2004, as a result of helicopter activity on the northern turbine row. The actual locations of the flocks of Common Scoters are seen as red dots, whereas the dotted green lines represent a 3 minute afterglow of previous echo locations. The afterglows thus show the trajectory of individual echoes of flying birds. One ship heading east is located southeast of the wind farm. Wind turbines and meteorological masts are seen as red dots. The picture was taken c. 5 minutes after the helicopter left the area.

Avoidance effects

Based on the numbers of birds recorded by visual transect observation and the calculated species specific migration intensity at the four transects within and outside the wind farm, much higher migration intensities of divers, Gannets, and Common Scoters occurred outside than inside the wind farm. Given that only very low percentages of these species actually were recorded at the edge and inside the wind farm, the present results suggested that these species actively avoided the wind farm and only reluctantly, or by accident, flew in between turbines. As markedly higher numbers and migration intensities were found on transects outside the wind farm, the data likewise indicate that these species generally were exploiting adjacent areas, and in many situations were flying within a short distance from the wind farm, i.e., birds recorded on the transect north of the wind farm, all were within 550 m to 1,000 m from the nearest wind turbines.

The records of the high numbers of Common Scoters exploiting the area just north of the wind farm, showed that for this species at least, the birds avoided to fly close to the wind farm when arriving to the roosting/foraging area during undisturbed conditions, and even avoided the wind farm during the incident where the birds were flushed due to helicopter activity on one of the closest turbines (see Fig. 174 and Fig. 176). In both situations, only very few birds were recorded closer than 200 m to the turbines, even though several thousand birds were present in this particular area for a long period of time, especially in spring 2004. Similar data were not available for divers and Gannets due to low numbers, although Gannets clearly showed marked deflections close to the wind farm in several situations, as recorded by radar (see Fig. 151).

Amongst Common Scoter the proportion of birds recorded to fly into and within the wind farm increased over the study years from 0.03 % in 2003 to 5.3% in 2005. This could be interpreted as reflecting a reduction in the strength of their behavioural response towards the wind farm. However, this increase was not matched by a similar increase in actual numbers, and since there existed a significant correlation between the number recorded inside the wind farm and numbers in the area north of the wind farm, the occurrence inside the wind farm matches with numbers that could be expected to occur in the wind farm simply by chance. Consequently, any reduced response by Common Scoter to the presence of the wind farm could not be substantiated by the present data. That the increased percentages of Common Scoters inside the wind farm probably did not reflect habituation is supported by visual observations, which only recorded flying birds inside the wind farm and not birds foraging or resting in between turbines.

With the exception of Little Gull, the migration intensity of gulls and terns recorded outside and inside the wind farm did not show a consistent difference, suggesting that these species did neither show an avoidance response nor an attraction response to the wind farm area. Neither were there any consistent differences between migration intensity at the edge of the wind farm compared to migration activity inside the wind farm. As large gulls frequently were observed to make directional flights when passing through the wind farm, the comparable intensity of migration outside and inside the wind farm may reflect this behaviour, and not reflect that gulls exploited the central parts of the wind farm, i.e., for foraging or resting. Likewise, comparable levels of migration intensity of terns at the edge and inside the wind farm may not reflect that terns exploited the central wind farm area, but rather reflect a bias from an 'edge effect'. Inclusion of terns beyond the first and last turbine on the transect classified as 'inside' the wind farm, may falsely have increased the level of migration intensity obtained inside the wind farm. Throughout this study, visual observation frequently recorded terns foraging around turbines at the edge of the wind farm, and also recorded directional migration of smaller flocks into the wind farm. However, these flocks or individuals were in several cases observed not to pass beyond the second row of turbines, but to make turns and leave the wind farm area again. In some periods, the same flocks were seen to make repeated entrances and returns, thus increasing the recorded level of migration intensity of terns on the two transects located at the edge and within the wind farm, respectively. Consequently, the comparable level of tern activity inside wind turbines is at least to some extent an effect of terns exploiting the outer edges of the wind farm.

The pattern of birds more frequently being recorded at the edge of the wind farm was similarly recorded for gulls and Cormorants resting on the turbine platforms c. 8 m above sea level. During normal operation of the wind farm, all records of resting or perching Cormorants and 91% of the gull records were made on turbines at the edge of the wind farm. Conversely, in August 2004 when all turbines were stopped, 18% of the records of Cormorant and 73% of the records of gulls were made on turbines inside the wind farm, suggesting that especially the gulls were sensitive to active turbines. Consequently, the general reluctance to exploit the central area of the wind farm seems, at least for these species, to be affected by the presence of active turbines in all directions, as gulls were observed to sit on active turbines in the outer rows of the wind farm.

Thus, in relation to specific species, there seem to be at least two levels of bird perception of the wind farm as a disturbing element in the Horns Rev area. First, as most bird species actually were recorded in very low numbers inside the wind farm, the wind farm seems to elicit a general avoidance response on the suite of species recorded at Horns Rev. Secondly, for the species of gulls and terns that did not show a general avoidance response, there may be an edge effect, as most birds actually were recorded within the edges of the wind farm, i.e., not frequently observed beyond the second row of turbines, and likewise that these species mostly used turbines at the edge of the wind farm as perching and resting platforms. The marked increase in birds resting on turbines in the central wind farm area at the time when all turbines were stopped, suggests that the movements of actively rotating turbines is a key element in determining the absence or presence of birds inside the wind farm area.

Knowledge of species specific reactions towards single wind turbines and wind farm is generally limited and almost non-existing when considering offshore conditions. In one study of an offshore wind farm consisting of 10 turbines, Common Eiders have been found to be less attracted to decoys placed 200 m from the turbines, than to decoys placed 300 m and 500 m from the turbines (Guillemette et al. 1998, 1999). This species did not exploit the Horns Rev area, but the response distance corresponded well with the reactions found in the Common Scoter in the present study. In terrestrial habitats, Pink-footed Goose has been shown to be present at a distance of 100 m from turbines in a line and 200 m from wind farms (Larsen & Madsen 2000), whereas foraging Barnacle Goose have been found to show a significant decline in density within 25 m from wind turbines (Percival 1998).

The general analyses of radar recordings of both northbound and southbound bird migration at Horns Rev showed that the overall migratory pattern was to pass around the wind farm and that the birds adjusted their flight orientation at distances of more than 4 km from the wind farm (see Fig. 167). This pattern of general avoidance of the wind farm was probably the main reason for the low probability of birds that were heading in direction of the wind farm at a distance of 1,500-2,000 m to the wind farm to actually fly into the wind farm, averaging 15% and 22% of the birds or bird flocks, north and east of the wind farm, respectively.

Given the low percentages of birds/bird flocks that entered the wind farm, the overall avoidance response should thus encompass c. 75-85% of the total volume of bird migration occurring at Horns Rev. In the present study, avoidance, defined as echoes that turned and passed around the wind farm, was only documented in c. 20% of the recorded bird tracks, whereas c. 55% of the tracks disappeared within close distance to the wind farm (<1,500 m). Loss of bird echoes was, however, frequently observed when the birds or group of birds landed on the water or made turns, which resulted in the radar having a lesser 'bird area' to produce an echo from, than if the birds were 'seen' from the side. However, since both behaviours could be interpreted as avoidance reactions towards the wind farm, the present estimate of overall avoidance was considered reliable, potentially and even an underestimation, as some of the birds that were recorded to pass into the wind farm, probably did this high above the turbines, especially during night time.

Taking into account the species specific occurrence within the wind farm, recorded both visually and by radar, a large part of the birds entering the wind farm was represented by gulls and terns. Consequently, avoidance behaviour by species other than gulls and terns may be stronger resulting in higher proportions of avoidance than the estimated 75-80%. – Given that the percentage of birds recorded to fly into the area did not differ significantly between all study years, the pattern of avoidance was relatively consistent, which probably was a result of the relatively similar occurrence of species in separate years. As the number of gulls and terns recorded by radar was highest on the eastern side of the wind farm in all years, the occurrence of these species probably led to the higher proportion of radar tracks going into the wind farm on this side compared to the northern side.

The overall orientation of southward bird migration recorded by radar was south-southwest, and probably constituted a continuation of southbound bird migration along the coastline north of Blåvands Huk (cf. Fig. 5). In relation to the wind farm, the orientation of bird migration changed significantly with distance to the wind farm. At far distances the orientation was southwest, but changed with decreasing distance to being south in birds approaching the northern row of turbines and west in birds approaching the eastern row of turbines. Thus, most birds or bird flocks that actually flew into the wind farm did this perpendicular to the wind farm, and this pattern was consistent between all study years.

Assessed from the standard deviation in flight orientation at different distances to the wind farm, the flight orientation of birds showed most variation at distances of between c. 200 m and 500 m from the wind farm. Thus at this distance to the wind farm, birds seemingly made some marked corrections in their flight orientation, probably as a result of approaching the wind farm. A similar pattern of change in the orientation of bird migration at distances of between 200 m and 500(-700) m from the wind farm was found in the more detailed analyses of the orientation of bird migration. Assessed from this data, the distance of the point of change was affected by the wind direction, being closer to the wind farm during westerly wind directions than during easterly wind directions.

At the northern side of the wind farm, the area least influenced by local gull and tern movements, the pattern of bird orientation similarly showed distinct differences between day- and night time migrants. During daytime, migrating birds seemingly adjusted their flight orientation to fly more directly towards the wind farm at long distances (1,000-1,500 m), whereas night time migrants made marked changes only when within c. 500 m from the turbines. Likewise, the orientation of birds that flew into the wind farm was more southerly orientated during daytime than during night time, suggesting that during daytime, birds passed the wind farm area more precisely in the passages between turbine rows than during night time. The pattern of bird migration east of the wind farm did not show so marked differences as north of the wind farm. However, birds that migrated during easterly winds and during daytime, made the most precise perpendicular entrances to the wind farm. As before, the inclusion of more gulls and terns in this area probably affected the results, as tracks of long distance migration were mixed with local movements.

Birds that flew into the wind farm from the north continued southward inside the wind farm. However, assessed from increasing standard deviation values, the birds started to be less directional in their orientation when they passed the 3rd turbine row, suggesting that at this point, birds were affected by the presence of turbines in all directions around them. For birds entering the outer rows, a clear deflection was made towards the edge of the wind farm, indicating that birds left the wind farm area the shortest possible way. Again, this pattern was less clear in bird tracks entering the wind farm from the east.

Attraction effects

In the analyses of both visual and radar observations made in relation to bird migration and flying behaviour at Horns Rev, no attraction effect from the wind farm could be documented. Visual observations of Great Black-backed Gulls showed, however, that this species frequently were passing the wind farm area in a westerly orientation. As this behaviour was observed in all study years and almost on a daily basis, it was considered that the wind farm was used by this species as a way-point, when birds were seeking to fly to offshore foraging areas. Whether the higher numbers of other gull species and terns recorded at the eastern side of the wind farm reflect a general tendency for attraction in these species is less clear, but may be a possibility. An impression of the wind farm being used as a reference point for migration was, however, also recorded for Wood Pigeons, as several flocks passed straight above the wind farm, and even made deflections to pass over the meteorological masts, when passing in a south-easterly direction. These flocks may have migrated for hours over the open North Sea, and probably reacted to the presence of the wind farm at a long distance.

The creation of a hard bottom substrate from adding scour protection around the turbines monopile foundations had the potential to increase the biodiversity of benthic invertebrates and the presence of schooling fish in the area. During the present study no bird species were found to be attracted by this habitat change, although the few Cormorants recorded to rest on turbines were observed to forage around the turbines. No other fish-eating birds, i.e., divers, mergansers or auks were observed in consistently increasing numbers in the vicinity of the turbines. On a few occasions, swallows *Hirundo rustica* were observed to fly intensively around the base of the monopiles, probably foraging on colonial insects inhabiting the splash zone there (Bio/consult A/S 2005). However, these birds were probably not attracted to the wind turbines as a foraging patch, but were migrants that accidentally passed the area. Exhausted passerine bird species were frequently observed resting in small numbers on the transformer station (see Christensen et al. 2006).

In relation to the more general migration of birds, the recorded adjustment in flight orientation at longer distances to the wind farm during daytime than during night time indicate that some diurnally migrating bird species reacted to the presence of the wind farm by visual recognition. During night time, adjustment in flight orientation did not occur at long distances and birds made corrections at distances of less than 500 m from the wind farm, indicating that the safety and traffic lights mounted on the turbines did not have an observable attraction effect on nocturnally migrating birds, at least on long distances. That more birds actually were recorded to orientate their flight trajectory towards the wind farm during daytime suggests that at least some species may have been attracted towards the wind farm at a long distance, but subsequently avoiding the wind farm when being close to the turbines.

Collision risk

Based on the data and results generated by this study the risk of collision between birds and wind turbines at Horns Rev was considered to be extremely low. This statement is based on the marked avoidance of the wind farm area shown by almost all recognised species, and the fact that most approaching birds (>70%) deflect and fly around the wind farm, and on the low exploitation of the area within the wind farm. Further support comes from the fact that most records of resting birds were on turbines located at the edge of the wind farm (the outer row). In addition, the fact that the proportion of birds that actually flew into or passed the wind farm area was higher during daytime, when visual perception of the turbine towers and moving rotors was possible, would likewise reduce the overall risk of collisions between birds and turbines.

This study only recorded the levels of lateral bird avoidance, so an unknown proportion of birds may likewise show vertical avoidance, by increasing flight altitude when passing the wind farm. At Horns Rev, nocturnal bird migration may thus occur at higher altitudes than diurnal migration, even though Blew et al. (2006) did not find marked differences in the altitudinal distributions of migrating birds between daytime and night time at Horns Rev. Nocturnal migration has, however, been found to be less intensive at low altitudes in several studies (Alerstam 1990, and references herein, Common Eiders at Nysted this study), and at the Nysted wind farm, nocturnal migration has been found to occur at higher altitudes than during daytime (Blew et al 2006), although the altitudinal distribution of migrants to some extent is generally influenced also by wind force and direction (Alerstam 1990, Krüger & Garthe 2001).

As stated in the EIA (Noer et al. 2000), the risk of collision was expected to be higher during periods of poor visibility, i.e., during nights and periods of heavy rain, snow or foggy conditions. During the present study, inadequate data were obtained to describe the behaviour of birds during such conditions. However, the flying activity of birds in the area was apparently reduced during the few hours experienced with heavy fog, as similarly described by Petterson (2005). At Horns Rev observations could not be made during periods of heavy rain, due to low visibility and to the inability to separate between echoes of rain and echoes of bird on the radar.

The data on occurrence of the focal species inside the wind farm and on their general behaviour at Horns Rev, suggested that divers, Gannet, Common Scoter, auks, skuas, gulls and terns did not exhibit a high risk of colliding with the turbines. With the exception of gulls and terns, these species were only seen flying inside the wind farm in extremely low numbers, relative to much larger numbers outside the wind farm.

Based on the visual observations, divers, auks and skuas were virtually absent in the area close to the wind farm, and this implies a low collision risk for these species. A low risk of collision for Gannets and Common Scoters, which occurred close to the wind farm, is based on the high avoidance of the wind farm area by these species, and for Common Scoter also based on the low flying altitudes (below turbine rotors) consistently observed throughout this study. Due to the frequent occurrence inside the wind farm, gulls and terns are expected to have some risk of colliding with the wind turbines. However, generally these species were observed to fly at altitudes lower than the rotor blades, and hence to occur in low risk altitudes.

Without records of bird-wind turbine collisions, and without the detailed modelling approach undertaken at Nysted, based on continuous surveillance data, quantification of a potential increase in mortality associated with the erection of the wind farm was not possible for the species occurring at Horns Rev. In consequence, no conclusions in relation to the criteria of a 1% increase in annual mortality (that would trigger mitigation mechanisms to reduce the effects of impact from collisions) could be made. Given the lack of observed collisions and general avoidance of the wind farm by most bird species, the present study found no indications that the Horns Rev wind farm imposed increases in annual mortality in bird populations present in the area that potentially would exceed 1%.

6 Conclusions

6.1 Background

For the purposes of the discussion section, we take as our starting point Figure 1 in Fox et al (2006), and look at what we can conclude from the experiences from data collection and analysis at the two Danish offshore windfarms. This framework is helpful in structuring the discussion, even though there is considerable overlap in the scope of the subjects (see Fig. 6). We start therefore by distinguishing between proximate local effects (the results of simple responses shown by the birds to offshore turbines) from ultimate population impacts (the consequences of effects on the changes in overall population size, by changes in reproductive success or survival).

6.1.1 Measuring local effects

If we consider first the responses of birds exposed to a novel and therefore unfamiliar, potentially threatening visual stimulus (which includes the rotating turbines that present for most of the time a constant movement), then our hypothesis would be that birds will choose to avoid the vicinity of this area. The nature of the response depends upon whether the bird is passing through the area (e.g. on migration or commuting between feeding and nesting areas) or if the bird is in some way resident, linked to the vicinity by use for feeding and/or roosting. Our prediction would be that if birds show a response to rotating turbines and/or disturbance from the maintenance traffic associated, we would see patterns in bird distribution that reflect avoidance of the vicinity of the turbines. Although both sources of disruption to bird distributions and movement require some assessment of the patterns of distribution prior to and after turbine construction, the two measures need different methods of data collection. If the turbines present a barrier to movement, we need to map the densities of bird movements before and after construction (for example using remote sensing, such as radar), whereas if we are to assess displacement from the preferred feeding distribution, we need to be able to map the distribution of feeding birds prior to and following construction (in these studies using aerial surveys of bird distributions). Not only do these two sets of effects have different means of data collection, but their consequences for changes in population size differ. Barriers to migration and movement may have different ultimate consequences than displacement from preferred feeding distributions.

The next set of effects we considered were the effects of changes in habitat, either through physical loss of habitat under the turbine foundations and anti-scour structures, or the added novel habitat gain (usually in the form of hard substrates and boulder reef) created by the foundations and anti-scour structures. In addition, other changes in management may accrue from the construction of the turbines – for instance, reduction or elimination of human fishing activity may enhance specific benthos communities and fish stocks locally, creating more attractive conditions for benthos-feeding and fish-eating birds. In the two case studies described here, the physical loss of habitat was considered trivial, consisting of less than 4% of the total area of the wind farm, and any effect of such change would be difficult to detect, let alone differentiate from the more major effects of behavioural displacement described above. The only easily detected phenomenon associated with these changes would be the arrival of novel species attracted to completely new food resources (for example eiders attracted to feed on blue mussels on the foundations of turbines, where no such food resources had existed prior to construction). In the event of any effects of such changes in habitat, these would be detected by the aerial survey protocols which were specifically designed to compare the before and after distribution and abundance of birds inside and outside of the wind parks.

The final effects were those of turbine collisions, which required some forecasting of magnitude and then post construction monitoring to determine how effective the predicted risk models proved to be in forecasting collision rates.

6.1.2 Measuring population impacts

As stressed in earlier sections, it is one thing to demonstrate local effects, in terms of changes in behaviour, distribution or abundance of birds, but it is much more difficult to measure the "impact" of constructing wind farms in the offshore environment, in terms of how they affect their vital rates (survival and reproductive success) and ultimately change population size. Since governments are obliged to protect populations through maintenance of both their habitat and numbers, changes in population size represent the ultimate measure of success in meeting targets set by international legislation, conventions and agreements. As we have also discussed previously, environmental impact assessment legislation increasingly requires an assessment of the cumulative effects of many similar and differing development pressures on individual populations, and it is also considered that the most appropriate means of meeting these requirements are through developing models to predict the consequences of developments (such as wind farms) for changes in avian vital rates to measure impacts at the population level.

The EU Directive 85/337/EEC (as amended by Directive 97/11/EC) requires some assessment of the cumulative effects and impacts arising from each proposed wind farm development (including associated on- and offshore infrastructure development, including road improvements, power lines, transformer stations, under sea cables, etc.) and from other projects (which may include both other wind farms and other relevant human development projects), that impact upon the same flyway populations. Such assessments are extremely difficult in the absence of a common currency, since human development pressures may, for example, enhance energy expenditure, destroy habitat, inhibit nesting or kill birds, none of which are directly comparable in terms of their impacts. It is therefore essential to establish a common measure with which to compare these various effects, to gauge the effects of individual developments in terms of contributing to overall impacts at the population level. The opportunity to define the impact in terms of the contribution to changes in annual population size offers one of the few possibilities to compare very different effects overall and to make an assessment of their cumulative results. Such an approach is neither simple nor easy, but the framework described in Fig. 6 offers some possibility of attaining this goal.

If we consider the measure of impacts at the population level result from changes in vital rates (namely annual survival and reproductive success) which affect the difference in total abundance of a population from one year to the next, this gives an overall objective towards which we can work to convert local effects to population impacts. For collision risk, this is relatively easy, since each death represents one less individual surviving (see Fig. 6), and we can compare the annual death rate from collisions to, for example, the known annual hunting bag in Denmark (or some other estimates of human-induced mortality), or the average overall mortality rate measured by ringing recoveries. For other effects, scaling up from proximate local effects to ultimate impacts represents more of a challenge. However, if we estimate the extra energetic costs of effects to the individual incurred by responding to turbine presence and infer the relative additional cost at that stage of the life cycle, then it may be possible to convert the additional energy lost or expended into consequences for fitness. For example, we can measure how much further a Common Eider flies to avoid Nysted (Fig. 6), use conventional flight energetic models to estimate what energy this extra flight requires (e.g. Pennycuick 1989) and compare the extra energy consumed to fly this distance compared to the total expenditure of a migration episode. Similarly, using individual based models that incorporate the behaviour of birds, we can model the consequences of habitat loss and gain for enhanced/reduced energy intake and/or increased/decreased energy expenditure that occur as a result of responses to the construction of turbines (e.g. West & Caldow 2006). If these changes in energy balance are sufficient to affect fitness, they too can be used as a measure to compare with the magnitude of other pressures on the population, potentially at other times of year and in areas geographically remote for the wind farm locations. However, developing such species-specific models will need considerable investment and this remains the highest research priority for the future.

However, for the meantime, for the purposes of this report we conclude that these are issues to be addressed in the future. The construction of the two offshore windfarms considered in the present report represent the first ever large scale development of wind resources in the marine environment and their geographical separation and biogeographical differences ensure little likely mutual cumulative effect. For these reasons, we here confine ourselves to conclusions relating merely to the local effects of construction, rather than attempting the more ambitious challenge of demonstrating any impacts at the population level.

6.2 Scope of conclusions

It is important from the outset to establish the scope of the conclusions that follow. Firstly, it is essential to appreciate that the conclusions that we can draw from these investigations relate solely to the findings of the studies undertaken at Horns Rev and Nysted under the prevailing circumstances of the time. Our conclusions are of a preliminary nature because 3 years of post construction studies are highly restricted in evolutionary time. To date the responses we describe have shown no evidence of change, either through individual habituation (the decline in response of an individual bird to a specific stimulus, such as a wind farm) or by the collective experiences of birds moderating response over longer time periods. We cannot preclude such changes will not happen in the future, as the collective experiences of birds over several years may (or may not) contribute to modifications to the responses that we observe now.

Secondly, it is important to stress that throughout this report and the course of these investigations, we have placed particular heavy emphasis on waterbirds. We have done this for four major reasons. Firstly we consider that the bird populations most vulnerable to added mortality from collisions will be those long-lived species showing low reproductive potential to make good high annual losses. Elasticity analysis based upon our current knowledge of the population dynamics of a range of different species (to be presented elsewhere, Desholm in prep.) confirms these are the most sensitive to such elevated mortality rates, and ranks large bodied waterbirds highly amongst those at greatest risk, making such species the natural focus of our investigations. Thirdly, and self-evidently, the threat of habitat loss in the marine environment is the exclusive domain of waterbirds exploiting such maritime habitats. Fourthly, in our consideration of the relative importance of, and risk to, individual species, waterbirds figure prominently, not least because many are subject to special protection measures under international legislation and conventions. Finally, although radar has given the opportunity to track other species, observations of species other than waterbirds have been difficult at the two study areas, not least because visual verification of birds of prey and (especially) passerines is extremely difficult. At Horns Rev, the passage of such species was relatively rarely observed. At Nysted, broad front migration does occur, but as reported here, the majority of migrating birds of prey and passerines are concentrated by Gedser Odde and Hyllekrog, to the east and west of the Nysted wind farm site respectively, so that the observation tower witnessed 10-15% the level of migration movements witnessed at Gedser, for example. This does not mean that observations of other species were not made or that the implications of the windfarms for these species were not considered, merely that they do not feature prominently in these conclusions because it was considered more cost effective to concentrate effort on waterbirds.

6.3 Local effects

6.3.1 The barrier effect

Central to the assessment of all effects of offshore wind farm construction on birds is the question of whether birds avoid flying near the turbines. Regardless of whether this avoidance is the result of the mere presence of turbines, the rotation of the rotors or the maintenance traffic associated with their upkeep, avoidance by flying birds has implications for migration routes (by adding potential energetic costs), feeding distribution and collision rates. It has therefore been important in this series of investigations to determine the species specific magnitude and nature of avian avoidance of wind farms and to see whether such a response shows modification over time.

We conclude that the results from radar studies showed that birds generally demonstrate avoidance behaviour at both of the two Danish offshore wind farms, although the responses are highly species specific. At Horns Rev, radar tracks of birds show adjustments in their northward and southward flight tracks around the periphery of the wind farm which create a circular avoidance pattern out to 5 km. These data also show that between 71 and 86% of all bird flock radar trajectories heading for the wind farm at 1.5-2 km distance ultimately avoided entering into the wind farm between the turbine rows. At Nysted, comparison of baseline large-scale autumn migration orientation gathered by radar with data gathered post construction confirmed similar large scale avoidance patterns there as well, with 78% avoidance by approaching birds. In the case of Nysted, the availability of before/after data provides greatly more confidence in the conclusion that this change was the direct result of the construction. Southward migration of non-waterbirds (largely birds of prey, pigeons and passerines) at Nysted also showed marked avoidance patterns approaching the northern fringe of the wind farm post construction compared to the baseline.

Specifically, we conclude that the proportions of birds approaching the wind farm area post construction and crossing the wind farm area have decreased relative to the pre-construction baseline. At Nysted, the proportion of autumn migrating birds (largely large waterfowl and mostly Common Eider) rounding Gedser Odde that avoided passing through the wind farm area varied little between 91 and 92% after construction compared to 52-76% during the baseline period when no turbines were present in the area. The latter comparison offers a more robust demonstration of avoidance, in that the data demonstrate a reduction of between 63 and 83% in the use of the windfarm airspace by migrating birds post construction compared to that prior to construction.

We conclude from the patterns observed in the radar traces that these patterns reflect birds making (i) gradual and systematic modification to their flight routes in response to the visual stimulus of the wind farm, with (ii) more dramatic changes in flight deflection close to the outermost turbines. This is confirmed by the responses shown in the radar tracks at Horns Rev, where minor adjustments in flight orientation were observed at 1-2 km range and major reorientation at 200-500 m range, typically to fly between the turbine rows perpendicular with the end of the wind farm or to follow the outer edge of the wind farm and avoid entry altogether. At Nysted, amongst birds heading directly for the wind farm, it was possible to show slight deflections in flight orientation at 1.5-5 km distance, with a more radical deflection at less than 1 km from the outer turbines. However, we cannot exclude the possibility that some birds (notably Common Eiders rounding Gedser Odde in excellent visibility) react at 10-15 km by modifying their flight orientation. Such changes in flight route were not present in the baseline pre-construction data and hence can be interpreted as a direct consequence of the erection of the turbines

We conclude that changes in flight direction occurred closer to the wind farm at night, and that because it is more difficult for migrating birds to detect the wind farm at night, the proportion of birds crossing the wind farm will be greater at night than by day. At both Nysted and Horns Rev, the lateral deflection tended to occur closer to the wind farm at night (0.5 km) than by day (1.5 km or more). At Nysted, although there was still a remarkable level of avoidance effect by night (6 out of 10 flocks), this was less pronounced than by daytime (9 out of 10). Observations using the TADS at Nysted provided unexpected evidence that despite the relative abundance of radar traces at night crossing the wind farm, infra-red monitoring over extended periods of night-time detected no movements of birds below 120 m during the hours of darkness, even during periods of heavy migration. This suggests that the lateral response that is also detected amongst night migrating birds may well occur above turbine height. The constraints of night time observation unfortunately mean that visual verification of the species involved is not possible, but at least some of these birds must be Common Eider flocks which are known to migrate under cover of darkness, although in lesser numbers than by day.

We cannot draw major conclusions about poor visibility (e.g. as a result of fog or precipitation) affecting the avoidance response, because too few observations of intense migration traffic occurred during periods of poor visibility to enable such an assessment. It is well known that waterbird migration typically ceases or reduces markedly during periods of poor visibility (e.g. Petterson 2005) and indeed during the observations reported here, the arrival of fog and active rain associated with frontal systems resulted in the cessation of active migration that had been observed during the prevailing period of good visibility. The lack of observations during periods with <1 km visibility at either of the observation platforms therefore precludes providing and support for any major hypothesis that such conditions modify the avoidance response.

We stress that these responses are those shown by waterbirds generally (except where otherwise specified), and at Nysted by eiders in particular because they are the most abundant species present. Nevertheless, it is clear that the avoidance responses are highly species specific, that individuals show different responses to wind farms and that all birds can potentially enter the wind farms. It is clear that some species were almost never witnessed flying between the turbines despite their abundance outside (e.g. divers and Gannets), others rarely do so (e.g. Common Scoters) or generally avoid flying a long way into the wind farm (e.g. terns), whilst others (e.g. gulls, especially Greater Black-backed and Herring Gulls) showed no sign of avoidance at all.

Observations did not strongly support the alternative hypothesis that some flying birds of certain species show a lateral attraction response to the wind farm. Attraction seemed to be highly species specific, with small numbers of gulls (especially Greater Black-backed and Herring Gulls) and cormorant attracted to a limited extent to the turbine foundations as loafing areas. Specific support for the hypothesis that these species show a gradual and systematic deflection towards the wind farm was hard to establish, and there was little supporting evidence for changes in local abundance of these species in the vicinity of and within the wind farm based on the aerial survey data. There was no support at all for the hypothesis that large nocturnal migrating waterbirds were attracted to the wind farm (e.g. as a result of the illumination see Lensink et al. 1999). There were frequent autumn mass social foraging events witnessed by Cormorant at Nysted pre- and post-construction within the wind farm area, but there was no evidence of any attraction effect post construction. As no aerial surveys were undertaken in autumn here post construction, there is no support for this hypothesis from data on bird densities.

6.3.2 Changes in feeding/resting distribution

We conclude from the results of the aerial surveys, comparing pre-construction distributions of birds with those post construction, that the most numerous species generally demonstrated avoidance behaviour in their distribution patterns at both of the two Danish offshore wind farms (most notably divers, Common Scoter and Long-tailed Ducks), although the responses are highly species specific. The results confirmed that most species occurred in low abundance and these species showed little detectable response to the construction of the wind turbines. However, certain species (generally the more numerous and those of highest conservation concern) showed strong avoidance. Divers at Horns Rev showed no selection for the wind farm area prior to construction but significant avoidance between the turbines and out to 2 km and 4 km after construction as well as significant and major reductions in density post construction. Long-tailed Duck at Nysted showed significant selection for the wind farm area pre and post construction, but significant reductions in density post construction. Terns and auks at Horns Rev showed no significant selection for the wind farm area prior to construction but avoidance afterwards. Many species showed avoidance both before or after turbine erection and so for these species no firm conclusion can be drawn (e.g. Gannet, Common Eider, Common Scoter, Herring Gull and Little Gull at Horns Rev). The response of Herring Gulls at Horns Rev is difficult to interpret, but the general reduction in the strength of avoidance of the wind farm area and 2 km zone suggests a slight (but not statistically significant) increase in bird use of the general area and surroundings. The interpretation of the use by Common Scoter of the Horns Rev wind farm is also difficult, because of the absence of birds in the vicinity of the wind farm during the baseline, but the appearance of very large numbers post construction. The extreme scarcity of visual observations of Common Scoters flying in between turbines and the lack of observations during aerial surveys post construction (when up to 381,000 were present in the general area) confirm that this species was also amongst the species that showed almost complete avoidance of flying or swimming between the rows of turbines, despite very large concentrations in the surrounding waters.

We conclude from the results of the aerial surveys, comparing pre-construction distributions of birds with those post construction, that no bird species demonstrated enhanced use of the waters within the two Danish offshore wind farms. No species showed significant increases in density within the wind farm post-construction. Little Gulls were generally more abundant in the post construction years at Horns Rev and the densities in the zone 2 km around the wind farm post construction were significantly greater than in the baseline, but there is no evidence this was the result of the construction of the wind farm.

Although the displacement of birds as a result of behavioural avoidance of the wind farms represents effective habitat loss, it is important to assess the relative loss in terms of the proportion of potential feeding habitat (and hence the proportion of birds) affected relative to the areas outside of the wind farm. For most of the species considered here, that proportion is relatively small and therefore likely of little biological consequence. The additional costs of many other such wind farm effects may, however, constitute a more significant effect and represents a high priority when considering cumulative effects of many such developments along an avian flyway in the future.

6.3.3 Collision risk/rate

Although the avoidance responses documented in the sections above mean that the erections of turbines in the sea do have a major effect on the local distribution, abundance and flight patterns of birds in the immediate vicinity, the corollary is that fewer birds come within the risk zone of the rotor blade sweep zone, reducing the probabilities of collision. As shows below, the avoidance responses at greater spatial scales resulted in reduced probabilities of birds approaching the risk zone of collision with turbines.

The results of the radar studies above provided evidence that many bird species showed avoidance responses at distances of up to 5 km (and potentially more) from the turbines, and within a range of 1-2 km, that more than 50% of birds heading for the wind farm avoid passing within it. Hence, avoidance responses shown by birds remote from wind farms at distances more than 1 km reduce collision risk substantially, and radar evidence from both sites show further adjustments at distances less than this, where many birds adjust flight trajectories to fly along the outer edge of the wind farm.

The radar studies also confirm that many birds entering the wind farm re-orientate to fly down between turbine rows, frequently equidistance between turbines, further minimising their risk of collision. Hence, amongst those birds penetrating within the rows of turbines, their chosen trajectories take them along routes away from the areas of highest risk. There is also evidence that birds readjust flight orientation once within the park to take the shortest exit route, further minimising collision probability.

Results from the TADS study confirms that waterbirds (mostly Common Eider) reduce their flight altitude within the wind farm, flying more below rotor height than they do outwith the wind farm.

A stochastic predictive collision model estimated the numbers of Common Eiders, the most common species in the area, likely to collide with the sweeping turbine blades each autumn at the Nysted offshore wind farm. Using parameters (including those described above) derived from radar investigations and TADS, and 1,000 iterations of the model it was predicted with 95% certainty that out of 235,000 passing birds, 0.018-0.020% would collide with the turbines in a single autumn (41-48 individuals).

It was predicted that such a low level of probability of collision at any one turbine, the TADS monitoring system would fail to detect a single collision of a water bird during more than 2,400 hours of monitoring and this proved to be the case. This level of monitoring resulted in 11 bird detections well away from the sweep area of the turbine blades, 2 passing bats, two passing objects that were either small birds or bats, a moth and one collision of a small bird.

No bird species came anywhere near the increase in annual mortality of 1% caused by wind turbine collisions at Nysted necessary to trigger mitigation mechanisms to reduce the effects of this impact. Most probably this was also the case at Horns Rev as well.

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A R&D projects' catalogue is available in an electronic version on the World Wide Web.
Included in the annual report is a list of the publications from the current year.

Final results of bird studies at the offshore wind farms at Nysted and Horns Rev, Denmark

This report presents data on monitoring investigations of birds carried out during 1999-2005 in relation to the construction of the world's first two large offshore wind farms at Horns Rev and Nysted in Denmark. We consider the hazards turbines posed to birds and the physical and ecological effects that these cause. We propose a series of hypotheses relating to these effects on birds at the two sites, testing to see if birds do indeed show reactions to the turbines once erected, relative to their "unaffected" behaviour we monitored during pre-construction baseline studies. In this way, the effects of the construction of the wind farms at sea could be predicted from our hypotheses and validated by post construction monitoring and data collection which was a condition of planning permission for the Danish projects. Throughout, we have restricted our studies primarily to waterbirds, because these are the species that exploit the offshore environment in general and the two study areas in particular, because Denmark has a special responsibility for the maintenance of their populations and the habitat that they use and because long lived birds with relatively low annual breeding success (which include many waterbirds) are those most susceptible to additional mortality.

National Environmental Research Institute
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