Investigations of the bird collision risk and the responses of harbour porpoises in the offshore wind farms Horns Rev, North Sea, and Nysted, Baltic Sea, in Denmark

Part I: Birds

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Funded by the
German Federal Ministry for the Environment,
Nature Conservation and Nuclear Safety
(FKZ 0329963 + FKZ 0329963A)

Final Report 2008

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0. Executive Summary

In 2005 we started a two-year project investigating the collision risk of migrating birds in the Danish offshore wind farms Horns Rev, North, Sea, and Nysted, Baltic Sea. The project is financed by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. Access to the offshore wind farms was granted by the Danish Energy companies Vattenfall (formerly ELSAM eng.) and DONG energy (formerly Energi E2).

Data on migrating and other moving birds were obtained using vertical and horizontal radar in combination with visual and acoustic observations operating from an anchored vessel as a working platform. The anchoring positions were chosen along those sides of each wind farm area where birds following the main migration directions were expected to either approach the wind farm or to fly in a very close distance to it.

In 2005, 24 boat trips with 83 observation days, in 2006, 28 boat trips with 82 observation days were carried out. Study periods aimed to focus on migrating birds and thus covered the main migration periods between March and May in spring and September to November in autumn.

These investigations were set out to yield results in the direct vicinity of offshore wind farms in order to offer more insight into the potential risks of those recent developments in the offshore environment. The opportunity to work at the Danish offshore wind farm sites was unique; methods developed during the numerous offshore technical reports in the framework of the Environmental Impact Assessments (EIAs) in the German North Sea had to be adapted both with regard to visual observations, but more importantly with regard to remote techniques, in this case marine surveillance radar. Study design was deliberately chosen to place the observation platform (ship) in the direct vicinity of the wind farm; this way, data and results ought to be complementary to those of the Danish studies during baseline and operation phases; also, observation results can be allocated to areas inside and outside the wind farm and ought to allow the documentation of potential differences between these areas. Focus was to look at the potential barrier effects and collision risk of birds, while habitat loss was not addressed.

Results and experiences gained during our investigations ought to assess available and potentially new methods, particularly remote sensing devices, appropriate for the use in offshore wind farms. It should also yield first results in an existing offshore wind farm with regard to the relevant species and species groups and help for the further conception of post-construction study designs. However, the time period for the study was limited and so were the methodical capabilities at the time of project start.

Results from radar observations are predominantly yielded from the vertical radar, which could work and yield data during almost all observation days, which had already been selected for good weather conditions. Horizontal radar yielded results for only 5% of the observation time, when clutter from a calm sea surface allowed good quality pictures. Visual and acoustic observations again were possible during all observation days.

The different locations hosted different species compositions. At Horns Rev, a number of pelagic species occurred besides seaducks, geese, gulls and terns and a wide range of songbird species. At Nysted, Baltic Sea, a wide range of non-pelagic waterbirds occurred with high numbers of Common Eider, as well as higher numbers of raptor and songbird species.

Data on migration intensity and phenology detected differences between the North Sea and the Baltic Sea location. While at Horns Rev only the autumn 2005 seemed to include periods of mass migration, a generally high migration intensity during all four seasons was registered for Nysted. High variability of the data with regard to intensity and altitude distributions produced a variety of results not easy to generalize. During phases of mass migration the birds registered with radar were generally found at higher altitudes; however, since many birds are aloft during these periods, considerable numbers also flew within wind mill height outside and inside the wind farms.

No general differences of migration intensities or altitude distributions could be detected by radar with regard to inside and outside the wind farms, but differences between species and time of day are detected. There is a tendency, that during daytime less birds are found inside the wind farms; it is assumed that day active birds do avoid the wind farm risk area to a certain degree when migrating. Nighttime data, however, show no systematic differences or avoidance. Visual observations support the daytime results. Pelagic species seem to avoid wind farms at a large scale. Seaduck species, particularly Common Scoter at Horns Rev and Common Eider at Nysted have been registered in high numbers in the vicinity of the wind farms, yet showing a general avoidance to enter the wind farm areas; nonetheless, individuals and groups of those species are found within the wind farm area at all distance bands. Migrating individuals of other species, e.g. Cormorants, seem to avoid the wind farm areas, while generally resident individuals of the same species or generally resident species (e.g. gulls) exhibit the lowest avoidance. Birds of prey do enter the wind farms, yet in low numbers during our observation periods. Songbirds are registered in considerable numbers; while visual observation of those species are difficult beyond some distance, results yielded from the radar show that they do enter the wind farm influenced areas.

Avoidance behaviour is one focus of investigation when looking at potential collision risk. An indirect measure of avoidance is the comparison of species densities between inside and outside the wind farms. A direct measure of avoidance is the analysis of reactions towards the wind farm or individual turbines.

Regarding the densities inside and outside the wind farm, it must be stated that – apart from the tendencies during daytime - both vertical and horizontal radar results do not suffice to show any systematic differences. Differences as measured with the vertical radar are too small and irregular and are overridden by detection problems due to the wind turbine structures and different radar cross section aspects of birds flying towards or away from the radar device. Differences as measured with the horizontal radar – on a selection of radar images from good weather days – are larger showing considerably lower densities inside the wind farms, but are most likely artefacts due to the disturbances of the wind turbines.

Regarding reactions, vertical radar results, manually tracked, show that the majority of signals approaching or leaving the wind farm do not exhibit any altitude changes. The small proportions of altitude changes registered occur for all signals moving towards and moving away from the wind farm and thus are inconclusive. Flight direction angles with regard to the wind farm of approaching signals – taken from the selected radar screenshots - do not show any systematic deflection of signals in dependence of the distance to the wind farms. Both methods have drawbacks. The vertical radar cannot detect, whether a signal is on a course towards a wind turbine or an alley between them. The horizontal radar cannot detect whether a signal is below or above wind turbine height; consequently, results of these remote sensing cannot clearly discern between birds inside or outside the respective risk areas. Hence, reactions would have to be very strong and regular to be picked up with this method. Visual observations have also been used to measure reactions, naturally during daytime. They show that many migrating birds react to the turbines, while resident birds do overall not react. For the Cormorant these different sensibility occurs within one species according to the migration status of the individual birds. Birds of prey show almost no reactions. Of the geese considerable proportions react; Common Scoter show low reacting percentages at the North Sea while Common Eider show higher percentages at the Baltic Sea. Songbirds show varying reacting percentages.

Summarizing the results of this study, we know, that of the vast numbers of migrating birds crossing open waters where offshore wind farms exist or will be constructed, only a fraction comes close to these obstacles. High proportions of waterbirds (pelagic species, seaducks, swans, geese and other) apparently avoid the wind farms at a large scale, thus they do not come even close. Those birds which migrate closer to the wind farms during daytime, such as large numbers of Common Scoter, Common Eider, Great Cormorants, terns and others show a clear, yet not complete avoidance of the offshore wind farms. In conclusion, the above mentioned species groups are effectively avoiding offshore wind farms and not a risk from collisions, at the same time being affected by a habitat loss and barrier effects. In contrast, resident species like gulls and non-migrating Cormorants regularly enter the wind farms; thus, they potentially take advantage of the wind farm area as a new food source but are exposed to a certain collision risk. This is also true for the small numbers of raptors actively flying through the wind farms. Very large numbers of songbirds cross the Baltic and the North Sea. Most of them migrate during favourable weather conditions; then large proportions are flying at altitude bands > 300 m. Nonetheless, a still considerable proportion migrates within the risk area of wind turbine height; our study has shown a daytime avoidance of the offshore wind farms, but at nighttime results were not clear and it must be assumed, that these species pass through the wind farms in considerable numbers. Also, our results have not been able to show significant active avoidance reactions, indicating that a response will occur at very short distance. Thus we assume that those birds do enter the wind farms as they also do on land. In the absence of collision data offshore, onshore studies show that those migrating songbirds apparently cross wind farm areas without colliding. While we conclude, that large proportions of potentially affected birds are not exposed to a collision risk, situations of – unforeseen – inclement weather have the potential to leading to considerable collision numbers, as has been documented for all kinds of structures off- and onshore.

While a large body of new results and conclusions can be drawn from these studies, some results do not live up to the aspirations during the start of the project. The presence of wind turbines has considerably hampered analyses of radar results in the absence of a sound knowledge about radar sensitivity and areas potentially concealed by disturbances (wind turbines) on the radar screen. While valuable results on the bird reactions towards the wind mills have been gained from the visual observations, radar results are sometimes inconclusive. In consequence, no quantitative data have been collected to be entered into collision risk models or to be directly compared to other studies, either during baseline or during operational phases in these offshore wind farms.

Some related research projects have started since 2005. In the chapter “Outlook”, these have been described and a list of research needs has been suggested with following topics: further development of the wind farm sensitivity index (WSI) to include the latest behavioural observation results and further non-seabird species, effects of illumination with regard to attraction and bird-friendly solutions, development of advanced remote sensing techniques adapted to the offshore environment. Effect monitoring studies in offshore wind farms should be designed to include reference sites some 5 to 10 km away to address the topic of large scale avoidance and the compilation of data to be entered in collision risk models. The offshore environment will keep being a challenge for ornithological research, particularly for nighttime investigations and harsh and inclement weather conditions.

1. Introduction

1.1. Scope of investigations

Like other European countries, Germany promotes the extension of renewable energies in order to protect the atmosphere from harmful emissions. The Federal Government of Germany has set the target to double the energy production from renewable sources by the year 2010. Offshore wind farming is supposed to play a major role in order to achieve this target.

The installation of offshore wind farms at a large scale has raised concerns about possible impacts on nature, especially birds and marine mammals. Amongst others, there is concern that migrating birds might collide with the turbines; this may regard slow manoeuvring birds, times of limited visibility (night, fog, low clouds etc.), attraction by the turbine lights or other circumstances. The noise emissions of constructing and operating the wind farms might disturb harbour porpoises (*Phocoena phocoena*). A problem of the current discussion in Germany is that empirical research is not possible, as up to now no offshore wind turbines have been erected in German waters, though several approvals have been granted. Thus, a lack of knowledge about possible ecological problems exists and aggravates the discussion of these topics.

In Denmark, two wind farms in Horns Rev (North Sea) and Nysted (Baltic Sea) are operating since 2002 and 2003 respectively, thus offering the possibility to carry out research relevant to the German discussion about offshore wind energy, to close important gaps of knowledge and thus to provide a more solid base for further decisions. The Danish wind farms are close to German offshore wind farm projects and environmental conditions are generally comparable. In these Danish offshore wind farms we studied relevant issues for the development of offshore wind farms in Germany.

The Danish offshore wind energy activities (Elsam [now Vattenfall] at Horns Rev and Energi E2 [now DONG Energy] in Nysted) are accompanied by a variety of research projects. Baseline studies, technical and progress reports are available (www.hornsrev.dk, http://uk.nystedhavmoellepark.dk). However, the Danish investigations do not cover all aspects and all possible conflicts between offshore wind farming and nature conservation which are relevant for the development in Germany but focus on the issues of greatest relevance from the Danish point of view. In cooperation with Danish scientists, our research programs were tailored to problems relevant to the development in Germany.

This report gives account of two topics relevant to these wind farms:

1) Identifying the collision risk of migrating birds;

2) Fine scaled responses of harbour porpoises.

Ad 1)

The collision risk of migrating birds is considered as a potential problem. There are no natural obstacles on the migration at sea; birds might be attracted by the lights of the turbines, which is a well known phenomena from various other illuminated structures at sea; in addition, in particular slowly manoeuvring birds and birds flying in formations might misjudge or underestimate the speed of the turbine blades; last but not least, in situations of low visibility or inclement weather birds might simply not be able to recognize the wind farm structures. These and so far unknown additional facts support the assumption, that the collision risk of birds with wind turbines at sea is higher than on land. An approval for an offshore wind farm has to be denied according to § 3 of the marine facilities ordinance (Seeanlagenverordnung[1]), if it is assumed to endanger bird migration. As no offshore wind farms have been erected in German waters and as the studies carried out in other countries are not yet sufficient to have a full view of this problem (see below), our study aims at the particular situations associated with bird migration in the direct vicinity of offshore wind farms.

Ad 2)

The project deals with the potential disturbance of harbour porpoises by the presence of wind turbines. Disturbance can be caused by noise emissions of the turbines during operation. Madsen et al. (2006) showed that measurements from under water noise emitted by offshore wind turbines indicate that individual turbines are audible for harbour porpoises at distances up to about hundred meters. The sound emission of wind turbines increases at certain frequencies with wind speed (Ingemansson 2003).

The responses of harbour porpoises to offshore wind farms are monitored by continuous registration of echolocation clicks of porpoises in the wind farms using Porpoise Detectors (POD). PODs are deployed in transects from the wind farm to its surrounding in order to detect responses of the harbour porpoises to the operation of the turbines. Unlike visual observation, a deployment of PODs at the wind farms allows to relate harbour porpoise behaviour directly to the actual operation of the turbines even at high wind speeds.

The ongoing study deals with some key ecological problems which are highly relevant for the development of offshore wind farms in Germany. Thus, the results of the investigations will be of high direct value for future decisions of individual projects as well as for the general German strategy to develop offshore wind farms. In addition, the proposed investigations will evaluate and improve the methods proposed for monitoring the ecological effects of offshore wind farms. As all approved projects are obliged to carry out monitoring programs defined as mandatory by the standard investigation concept (BSH 2003, 2007), applying the methods in practice will help to decide which results can be achieved and whether further refinements of the standards and future monitoring programs are necessary.

1.2. Cooperation with Danish partners

The studies are carried out in close cooperation with Danish scientists who conduct related studies in the wind farms. The access to the wind farms was granted from Elsam and Energi E2 to BioConsult SH.

1) Investigations of birds have been carried out in both wind farms (2001 to 2005), commissioned to the National Environmental Research Institute (NERI) by the respective wind farm companies. Results describe bird occurrences and activities in the areas (species composition, flock size etc.) as well as direct and indirect reactions of birds in relation to the wind farms, as there are lateral changes in migration routes and utilization / avoidances of the wind farm areas; also, surveys of staging, moulting and wintering birds are carried out. In addition, the methods for studies on actual collision risk have been developed and tested (Desholm 2005). With the exception of the actual collision studies, these Danish investiga-

[1] Verordnung über Anlagen seewärts der Begrenzung des deutschen Küstenmeeres (Seeanlagenverordnung -SeeAnlV), vom 23. Januar 1997 (BGBl. I S. 57).

tions focus on larger birds (ducks, geese, gulls), since those species have a longer lifespan and a low reproduction rate and hence a higher impact on population level would be expected. This focus allowed to conduct many of the observations and measurements (visual, radar) from a large distance from the wind farms. Our investigations concentrate on measuring bird occurrence, activities and behaviour in direct vicinity of the wind farms. Altitude distribution of birds as well as occurrence and behaviour of birds inside and outside the wind farm areas are the main topics; methods applied are recordings made via vertically mounted marine surveillance radar as well as visual and acoustic observations.

2) Until now harbour porpoises have been studied in both wind farms by Danish working groups at large spatial scales during ship surveys and by using T-PODs. The data of these studies are very important for our approach in order to interpret possible interannual changes in porpoise numbers and distribution which might affect the presence of these animals in the wind farms and its surrounding on the smaller spatial scale observed in our study. In turn an exchange of the data will also allow a better interpretation of the studies at larger scales which at present do not allow a direct comparison of the data with operational characteristics of the turbines. The T-PODs used were calibrated in cooperation with the Danish National Environmental Research Institute (NERI; Department of Wildlife Ecology and Biodiversity) under laboratory conditions in Roskilde/DK as well as in the field. This assures a direct comparison of the data obtained by the different studies and highly improves the quality of the data. Data can be exchanged as raw data as well as in an analysed form (e.g. daily averages of the relevant click train parameters). Detailed weather data, especially wind strength and wind direction, have been delivered by the companies operating the wind farms, whereas hydrographical data, as water temperature and salinity in the wind farm, are not required for such a small scaled study.

1.3. Description of the offshore wind farms

1.3.1. Horns Rev

The offshore wind farm “Horns Rev” is situated in the Danish North Sea, approximately 35 km west of Esbjerg, Denmark (Fig. 1.1). The wind farm area is located in the south-eastern part of the so-called Horns Rev (“= Horn’s Reef”), some 14 km west-south-west of Blåvandshuk, a prominent headland. Geomorphologically, the Horns Rev formation is described as a terminal moraine ridge, consisting of relatively well-sorted sediments of gravel and sand. The water depth within the wind farm area ranges from 6.5 m to 13.5 m.

The formation Horns Rev is a permanently submerged sandbank. It is made of sandy materials with - especially in the western part - smaller areas of gravel. No persistent reef-like structures have been recorded. Pronounced tidal currents occur and are intensified by the shape of the sandbank. The water body is typically estuarine, with mixing freshwater from river inflow in the East and North Sea water from other directions.

In 2002, the Danish power company Elsam erected 80 turbines with an power output of 2 MW each (Fig. 1.2). As such the total installed capacity is 160 MW. The height of the turbine hub is 70 m and the rotor diameter is 80 m resulting in an overall height of 110 m above mean sea level. The minimum clearance of the rotor above the water surface is 30 m. The turbines are arranged in a rhomboid pattern with a distance of 560 m next to each other.

Each corner turbine is equipped with white permanent light installed at about 10 m height to ensure visibility for ship traffic. The wind turbines are also equipped with red warning lights for the sea and air traffic safety's sake. These lights are mounted on the top of each turbine nacelle; while red lights of the outer rows are flashing (20 to 60 flashes per minute), the lights of all turbines are permanent; intensity of these illuminations is reduced when visibility exceeds 5 km. The wind farm covers an area of approximately 24 km². The turbine foundations including the scour protection cover approximately 14,500 m² of the sea bed, that is less than 0.1% of the total area of the wind farm. A dug in sea cable leads from the transformer platform to the shore. The wind farms operational phase started in autumn 2002 (Elsam Engineering & ENERGI E2 2005)

Fig. 1.1: Location of Horns Rev wind farm (white rhomboid) in the North Sea some 35 km west of the harbour city of Esbjerg, off the peninsula of Skallingen with its western headland Blåvandshuk.

Fig. 1.2: Horns Rev wind farm (photo: BioConsult SH).

The co-ordinates (latitude, longitude / WGS84) of the wind farm corners are:
55° 30.19' N / 7° 47.78' E
55° 30.24' N / 7° 52.57' E
55° 28.14' N / 7° 53.08' E
55° 28.10' N / 7° 48.30' E

1.3.1. Nysted

The offshore wind farm "Nysted" is situated approximately 10 km south and south-west respectively of the Danish cities of Nysted, Lolland and Gedser, Falster (Fig. 1.3). The wind farm area is located about 4 km south of the partly emerged sandbank Rødsand which extends over 25 km from Hyllekrog to Gedser. This formation separates a shallow lagoon area with water depths of 0.5 to 4 m. The tide is negligible (less than 0.5 m), but continuous strong winds may induce considerable currents and change the water depth by up to 2 m.
In this area, a consortium of the enterprises Energi E2, DONG and E.ON Sweden constructed 72 wind turbines with a power output of 2.3 MW each in 2003 (Fig. 1.4). As such the total installed capacity is 165.5 MW. The turbines have a hub height of 69 m and a rotor diameter of 82 m resulting in an overall height of 110 m above the sea. The clearance of the rotor above the water surface is 28 m. The turbines are placed in eight north-south orientated rows separated by a distance of 850 m. Each row holds nine turbines separated by a distance of 480 m. A dug in sea cable leads from the transformer platform to the shore near

Nysted. The wind turbines are equipped with red warning lights for sea and air traffic safety's sake. These lights are mounted on the top of each turbine nacelle; while red lights of the outer rows are flashing, the lights of all other turbines are shining permanently; brilliance of this illumination is adapted to visibility. The turbine foundations are concrete made gravity foundations with special protection against ice. The expected erosion around the bottom plate of the foundations is prevented by a stone protection. The foundations take up an area of about 45.000 m², corresponding to 0.2% of the total area of the wind farm (Elsam Engineering & Energi E2 2005). The wind farm officially started in normal operation December 1st 2003.

Fig. 1.3: Location of Nysted wind farm (white rhomboid) in the Baltic Sea south of the twin island of Lolland and Falster near the towns Nysted and Gedser.

Fig. 1.4: Nysted offshore wind farm (photo: Energi E2).

The co-ordinates (latitude, longitude / WGS84) of the wind farm corners are:
54° 34.20’ N / 11° 40.02’ E
54° 33.60’ N / 11° 45.54’ E
54° 31.56’ N / 11° 45.54’ E
54° 32.14’ N / 11° 40.08’ E

The sea floor at the wind farm consists of glacial sediments and the area is mainly covered by sand or silt (Hansson 2000). Areas with gravel or shells occur, but no reef-like aggregations have been recorded. The water is throughout brackish, being a mixture of saline water from Kattegat and freshwater of inner Baltic origin.

2. Bird study - Collision risk of flying birds

2.1. Methods

2.1.1. Operation platforms and investigation sites

Data on migrating and other moving birds were obtained by operating from an anchored vessel as working platform using marine surveillance radars in vertical and horizontal mode in combination with visual and acoustic observations. In Horns Rev wind farm area MS Søløven/Copenhagen, a former buoy-laying vessel of 46 m length was the survey vessel. In Nysted wind farm area it was MS Christoffer/Svendborg, a former beam trawler of 40 m length.

The anchoring positions were chosen along those sides of each wind farm area where birds following the main migration directions were expected to either approach the wind farm or to fly in very close distance to it. I.e., during spring migration anchoring sites were chosen along the western and southern edge and during autumn migration along the eastern edge. Along the northern side of each wind farm anchoring was impossible due to technical restrictions. The anchor was dropped at a distance of 150 to 300 m away from the edge of the wind farm. As sea cables run between the single wind turbines, anchoring closer to the wind farm was not possible. The anchored vessel could be moved by wind or tidal currents in a distance between roughly 200 and 400 m away from the wind farm. The positions in particular and the resulting areas covered by vertical radar and visual observations are shown in Fig. 2.1 and Fig. 2.2; orientation of the vertical radar is such, that bird migration is expected to fly parallel to the radar beam.

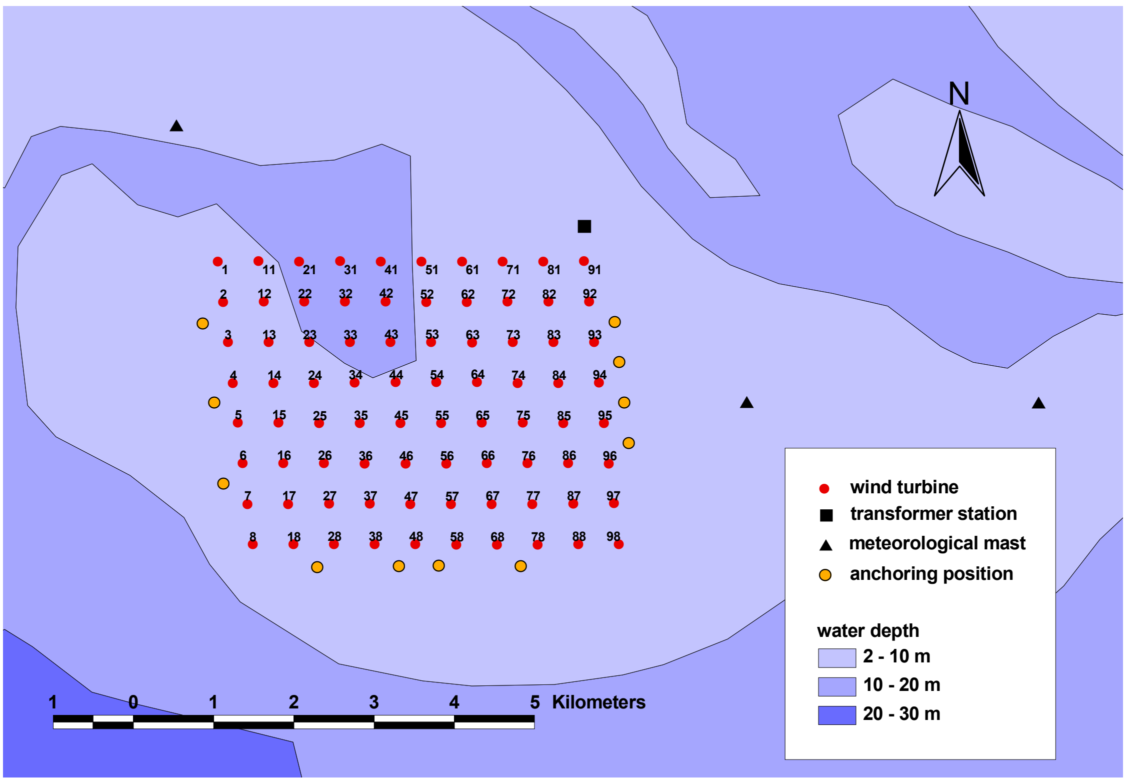


Fig. 2.1: Anchoring sites in Horns Rev wind farm. The positions at the western and southern edge were acquired in spring, those along the eastern edge were acquired in autumn.

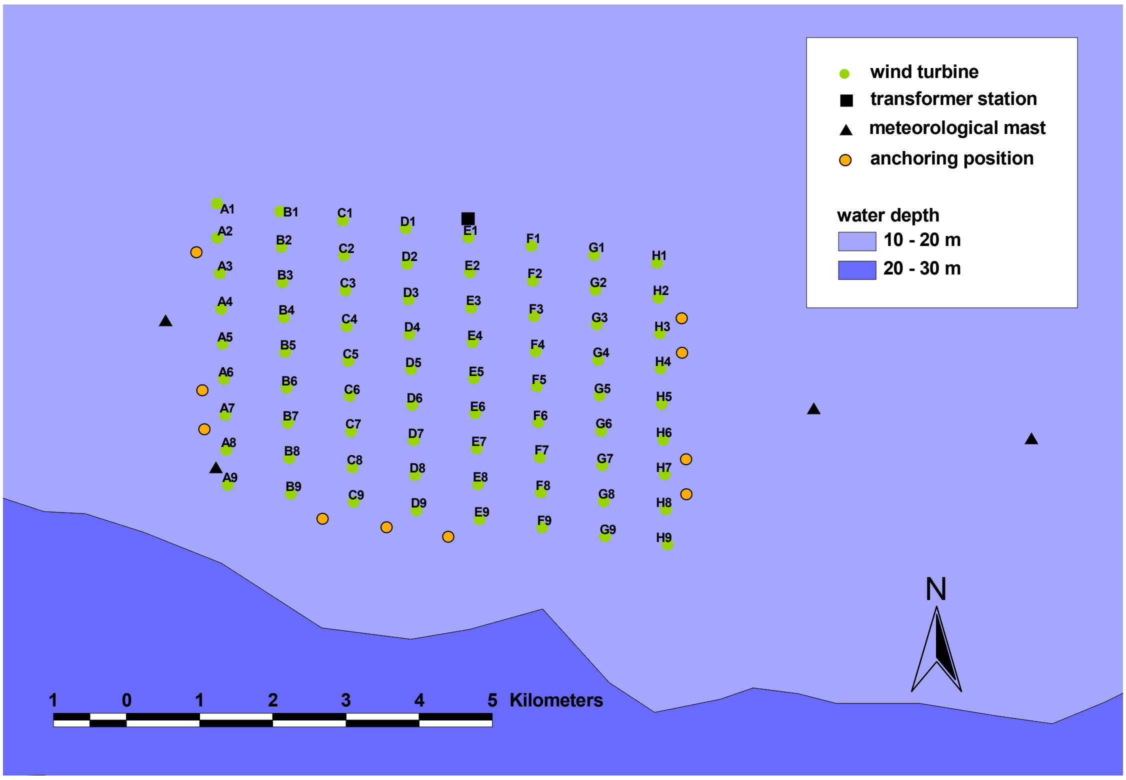


Fig. 2.2: Anchoring sites in Nysted wind farm. The positions at the western and edge southern were acquired in spring, those along the eastern edge were acquired in autumn.

2.1.2. Observation periods

The project aimed to focus on migrating birds and hence to cover the main migration periods; thus investigations were carried out during spring migration (March to May) and autumn migration (September to November). Details of trips and observation periods are listed in Tab. 2.1, Tab. 2.2 and Fig. 2.3. In 2005, 24 trips with 83 observation days, in 2006, 28 trips with 82 observation days were carried out.

In general, weather and sea state conditions suitable to carry out ship based surveys are more frequent at Nysted, Baltic sea. Strong winds and a sea state higher than 4 (waves > 1.5 m) will produce considerable disturbance on the radar screen and will largely influence analyses of lower altitudes; visual observations also benefit from good weather conditions. Consequently, more observation days are achieved in the Baltic Sea than in the North Sea.

In spring 2005, the project had a late start due to administrational reasons. Thus, the month of March 2005 was not covered at all. During the first trips in April 2005, installing and testing the equipment as well as the hardware and software caused some delays and resulted partly in different methods applied and different data formats. While for the Nysted radar and visual observation data have been obtained in the desired form from middle April 2005 onwards, trips on the North Sea were additionally hampered by inclement weather, further reducing the data available during spring 2005. In autumn 2005, the full program could be achieved with only a few days lost due to technical failures and repair trips. Trips lasted from 2 to 6 days and covered the entire period from September 5th to November 19th; different timing resulted from different weather conditions in the North and Baltic Sea. Apart from the first and last days of each trip, radar observations ran almost 24 hours a day. In spring 2006, cold weather in March delayed the start to March 13th; the full program was achieved until May 12th. In autumn 2006, the program started ran September 5th and ran well up to October 20th; after that date, inclement weather, in particular strong winds and rain allowed only a few short additional trips in the Baltic Sea (Nov 2-5, Nov 17-19), but no more trips to Horns Rev, North Sea.

Tab. 2.1: Observation periods [ship days] in the two wind farm areas in 2005 and 2006

Spring 2005			
Horns Rev		**Nysted**	
observation period	**observation days**	**observation period**	**observation days**
30.03.2005 – 01.04.2005	2	03.04.2005 – 07.04.2005	4,5
11.04.2005 – 15.04.2005	3,5	11.04.2005 – 15.04.2005	3,5
12.05.2005 – 16.05.2005	4	26.04.2005 – 30.04.2005	4
		05.05.2005 – 07.05.2005	2
		12.05.2005 – 16.05.2005	4
		22.05.2005 – 24.05.2005	2
	9,5		20
Autumn 2005			
Horns Rev		**Nysted**	
observation period	**observation days**	**observation period**	**observation days**
05.09.2005 – 10.09.2005	5	05.09.2005 – 10.09.2005	5
17.09.2005 – 20.09.2005	3	16.09.2005 – 20.09.2005	4
26.09.2005 – 28.09.2005	2	25.09.2005 – 27.09.2005	2
01.10.2005 – 07.10.2005	6	05.10.2005 – 09.10.2005	4,5
14.10.2005 – 17.10.2005	3	11.10.2005 – 14.10.2005	3
29.10.2005 – 02.11.2005	4	16.10.2005 – 20.10.2005	4
16.11.2005 – 19.11.2005	3	27.10.2005 – 30.10.2005	3
		08.11.2005 – 10.11.2005	2
	26		**27,5**
Spring 2006			
Horns Rev		**Nysted**	
observation period	**observation days**	**observation period**	**observation days**
13.03.2006 – 15.03.2006	2	13.03.2006 – 15.03.2006	2
21.03.2006 – 23.03.2006	2	21.03.2006 – 24.03.2006	3
31.03.2006 – 03.04.2006	3	27.03.2006 – 02.04.2006	6
15.04.2006 – 17.04.2006	2	06.04.2006 – 09.04.2006	3
21.04.2006 – 26.04.2006	5	11.04.2006 – 14.04.2006	3
02.05.2006 – 04.05.2006	2	23.04.2006 – 26.04.2006	3
10.05.2006 – 12.05.2006	2	02.05.2006 – 04.05.2006	2
		09.05.2006 – 11.05.2006	2
	18		**24**
Autumn 2006			
Horns Rev		**Nysted**	
observation period	**observation days**	**observation period**	**observation days**
05.09.2006 – 07.09.2006	2	06.09.2006 – 10.09.2006	4
12.09.2006 – 15.09.2006	3	14.09.2006 – 18.09.2006	4
23.09.2006 – 27.09.2006	4	25.09.2006 – 27.09.2006	2
0).10.2006 – 14.10.2006	5	04.10.2006 – 06.10.2006	2
17.10.2006 – 19.10.2006	2	09.10.2006 – 13.10.2006	4
		18.10.2006 – 20.10.2006	2
		02.11.2006 – 05.11.2006	3
		17.11.2006 – 20.11.2006	3
	16		**24**

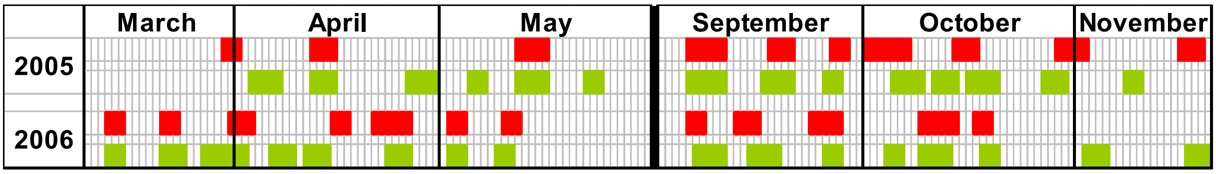


Fig. 2.3: Visualization of observation periods across the years 2005 and 2006

- days at Horns Rev, North Sea
- days at Nysted, Baltic Sea

Tab. 2.2: Summary: Observation days [ship days] in the two wind farm areas in 2005 and 2006

Wind farm	Season	Year	observation days
Horns Rev	spring	2005	9,5
		2006	18
	spring total		**27,5**
	autumn	2005	26
		2006	16
	autumn total		**42**
Nysted	spring	2005	20
		2006	24
	spring total		**44**
	autumn	2005	27,5
		2006	24
	autumn total		**51,5**

2.1.3. Radar investigations

Two X-band ship surveillance radars with a power output of 10 kW and 25 kW respectively were used for the radar observations. One of them was run in the ordinary way with the antenna rotating horizontally (horizontal radar) while the other one was operated with the scanner tilted by 90° so that the antenna was rotating in vertical orientation (vertical radar).
On MS Søløven both radars were mounted on one mast, the one on top being the horizontal radar and the other one on half-mast position being the vertical radar. On MS Christoffer the two radars were mounted on top of two separate masts. The bases of these scanners could be tilted by 90°, thus each of the radars could be operated both in vertical and horizontal mode (Fig. 2.4).

Fig. 2.4: Set up of horizontal and vertical radar on the MS Christoffer

The two radar devices in use on each ship were a Decca BridgeMaster E and a Raytheon Pathfinder. The Decca was used as the vertical radar only while the Raytheon mostly was used as the horizontal one. In case of failure of the Decca or for the reason of comparison the Raytheon on MS Christoffer could be run in vertical mode, too. For technical specifications of the radar devices see Tab. 2.3.

Tab. 2.3: Specifications of radar devices

brand	Decca Litton Marine Systems	Raytheon
type	BridgeMaster E-series	Pathfinder
power output [kW]	25	10
frequency [MHz]/wavelength [mm]	9,410±30 / ~31.86	9,410±30 / ~31.86
horizontal angle of radar beam [°]	1	1.15
vertical angle of radar beam [°]	24	~25
rotational speed [min^{-1}]	28	24
antenna length [mm]	2,440	1,830

Both radars operated around the clock when the ship was on position.

The aim of the vertical radar is to show flight altitudes of birds which is impossible by means of horizontal radar. It was set to a range of 500 m and 1,500 m respectively alternating every 30 minutes. No clutter filters were used (neither sea nor rain). The gain was tuned to the highest possible level before error echoes appeared. Wake duration (defining the length of the target trail) was set to maximum level within each range (30 s at 500 m, 45 s at 1,500 m). Further settings during vertical operation see.

Vertical radar alignment: The vertical radar could be adjusted / turned such that it rotates parallel to the expected bird migration; since the ship was always positioned at that side of the wind farm where bird migration was expected to enter the wind farm (chapter 2.1.1), the vertical radar rotation pointed more or less directly into the wind farm (see Fig. 2.1and Fig. 2.2). At Horns Rev, North Sea, the tides turned the anchored ship some 180° every six hours, while at Nysted, Baltic Sea, hardly any tidal effect is notable. However, currents and moderate to strong winds may also move or turn the ship, thus radar adjustments were necessary. For periods, when the alignment of the radar had been different more than 45° from the desired direction, radar data were excluded from analyses.

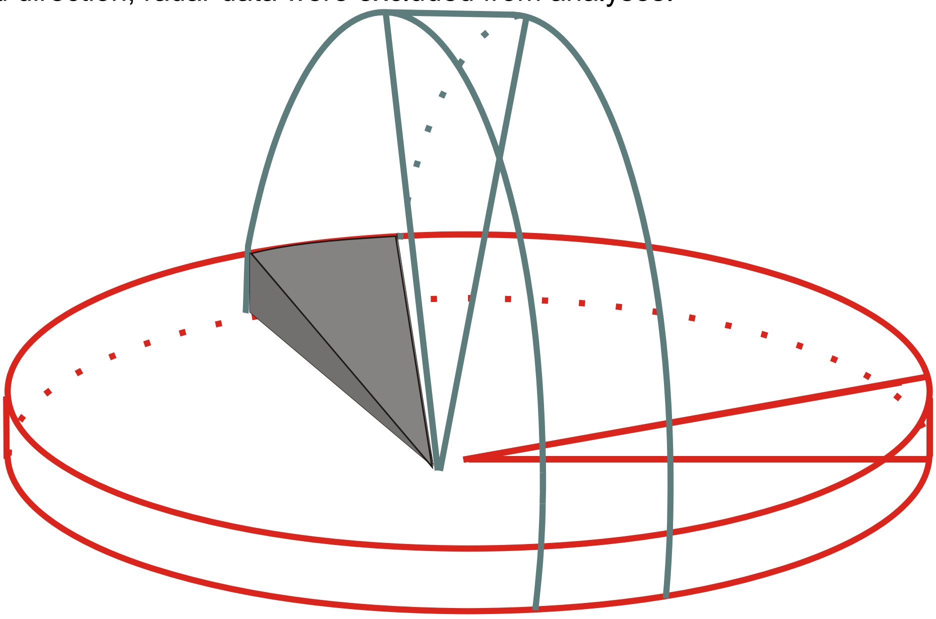


Fig. 2.5: Graphical visualization of areas covered by horizontal (red) and vertical (grey) radar and potential overlap (shaded) (Figure taken from N. E. Jensen, DHI, written comm.).

Tab. 2.4: Settings of radar devices

parameter	Decca BridgeMaster E-series		Raytheon Pathfinder	
range	~500 m	~1,500 m	~930 m	~2,780 m
pulse length/prf	„short“ (0.05 µs) / 1,800 Hz		0.09 µs / 3,000 Hz	0.35 µs / 2,000 Hz
target trails	„long“ (30 s)	„long“ (45 s)		

Radar images of the vertical radar (screenshots) were captured using two different methods: in 2005, the screen signal was captured via a framegrabber card onto a mobile PC using custom-made software by HaSoTec GmbH, Rostock. In 2006, digital pictures of the radar screen were taken using a digital camera (Canon Powershot G2 – 4 Megapixel). This way, better resolution pictures were achieved in comparison to the framegrabber. One image of the radarscreen (screenshot) was stored every 150 seconds, that is some 24 screenshots per hour.

The horizontal radar, aimed to show flight directions of birds has to be projected in North-up mode in order to show true flight directions; for some periods in 2005 this had not been the case. The range was set to 1.5 nautical miles (~2,780 m). A filter to suppress sea clutter was used to a certain extent if necessary. Otherwise the settings were identical with those of the vertical radar. Screenshots of the horizontal radar were taken only using a digital camera (see above).

Vertical and horizontal radar cover different sampling areas with a small area of overlap (Fig. 2.5). No attempt was made to synchronize radar results, that is to identify which radar results on the horizontal radar would reappear on the vertical radar and *vice versa*. To our knowledge up to date, this option does not exist for marine surveillance radars.

To analyse the data obtained by vertical radar the HaSoTec-software was used. For analysis, the single screenshots were uploaded as a background layer in a coordinate system. Radar signals considered to represent birds (single individuals or flocks) were marked manually on the screen; screenshots covered partly by rain clutter are marked accordingly and excluded from the analysis, since only part or none of the screen area can be analysed; for the separation and exclusion of insects or unknown objects see below. The software calculated the altitude, the direct and the lateral distance from the radar. In addition to these parameters the following attributes were stored for every screen shot: date, time, position of the vessel, heading of the radar and side of the wind farm. In case of the horizontal radar screenshots, additionally, the angle of a track as well as its length were registered. All data were stored into text files, later transferred to databases and tables fur further analyses.
Databank operations: All vertical radar recordings (screenshot, tracing of signals) were classified for inside the wind farm ("wf") and outside the wind farm ("non-wf"). Although the position of the ship was always in a distance of 180 - >300 m outside the wind farm, data / signals between the ship and the wind farm are by definition "inside" the wind farm("wf"). Data were assigned to "day" for the period from civil twilight in the morning (45-50 min before sunrise) to civil twilight in the evening (45-50 min after sunset) and to "night" for the other times.

2.1.3.1. Vertical radar: Presentation and analyses of data

Screenshots

A "screenshot" is a snapshot of the radar screen, showing the current situation; yellow signals are counted as birds, tracks visible on the screen (light blue) but without an actual signal (yellow) were not considered for analyses (see examples in Fig. 2.9 and Fig. 2.10).
To describe "migration intensity", the number of signals per screenshot either on the horizontally or vertically turned radar is used, separated for different ranges. Migration intensity is given for varying time intervals of interest (hour, day, longer time intervals, season) and can be separated for pre-defined altitude classes and areas within or outside the wind farm.

Signals tracked

In addition to analysing screenshots, radar signals were recorded and tracked using transparencies fixed on the radar screen. Each newly appearing signal was marked and followed as long as it was visible on the screen, this way transferring it with a permanent marker onto the transparency; periods of 150 s were covered twice every half hour.
This method allows to analyse further parameters:

- length of tracks, providing an integrated sum of screenshots;
- direction and change of direction of tracks depicting "reactions" (change of altitude) of birds.

Corrections of raw data

<u>Correction factor area:</u>

To analyse altitude distributions, a correction of the actual signal count in separate altitude bands of the radar screen is necessary. The radar screen shows a full circle; used in a vertical position, only the upper half circle applies. Here, the representation of altitude classes captured by the circular radar screen decreases with increasing altitude (Fig. 2.6). To compare parameters per altitude class (e.g. number of signals), they must either represent densities or should refer to the same area. Thus, for each altitude band (50 m intervals for the range 500 m, 100 m intervals for the range 1.500 m) a correction factor has been calculated. To yield a comparable number of signals per altitude band, the signals counted in the altitude band of the radar circle must be multiplied with the correction factor (see Fig. 2.6 and Tab. 2.5).

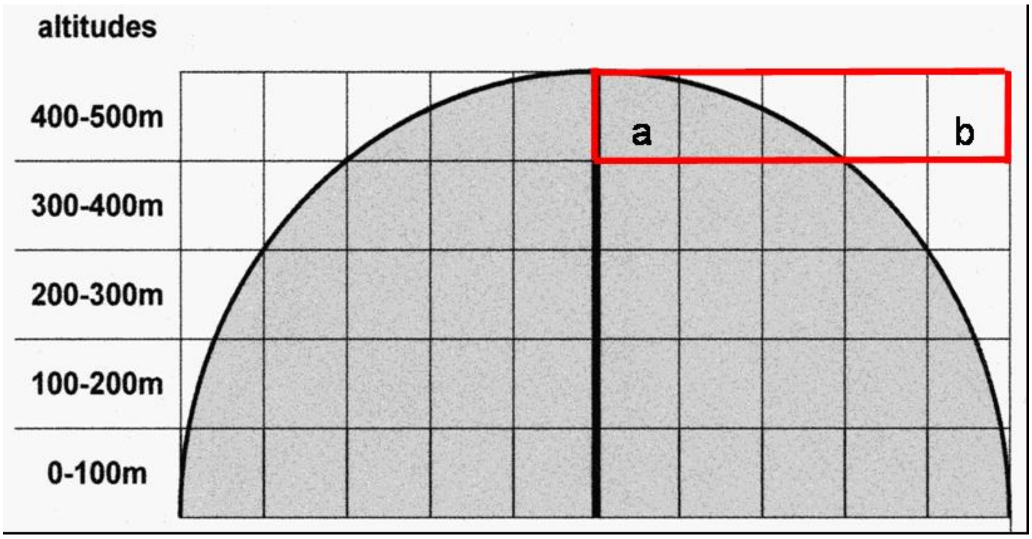


Fig. 2.6: Graphical example of area correction per altitude band. E.g. for the altitude band 400-500m the grey area (a) represents the radar screen, but signal counts in (a) must be corrected to also account for area (b) to be comparable with the other altitude bands.

Tab. 2.5: Area correction factors per altitude band, separate for the radar ranges 500 m and 1500 m

range = 500 m		range = 1500 m	
altitude bands [m]	correction factor	altitude bands [m]	correction factor
0-49	1.0005	0-99	1.0003
50-99	1.0076	100-199	1.0047
100-149	1.0304	200-299	1.0087
150-199	1.0638	300-399	1.0274
200-249	1.1186	400-499	1.0475
250-299	1.1919	500-599	1.0691
300-349	1.3158	600-699	1.1103
350-399	1.4993	700-799	1.1494
400-449	1.8692	800-899	1.2156
450-499	3.2841	900-999	1.2931
		1000-1099	1.3612
		1100-1199	1.4970
		1200-1299	1.7943
		1300-1399	2.1307
		1400-1499	4.0161

<u>Correction for distance-dependent detection probability:</u>

The distance of a bird or any signal source to the radar considerably influences its detection probability. The radar beams power strongly decreases with distance; this applies to the sent and to the received signal. The area or volume (of airspace) covered by the radar increases with distance; this increase or variation depends on the characteristics of the radar beam and its side lobes. This two-way reduction in energy density leads to the so-called 4th power law, which says that the received power decreases with the 4th power of the distance between the radar and the target; doubling of the distance leads to a 16 times weaker echo (Eastwood 1967, for further information, the “radar equation” and mathematical descriptions see e.g. Bruderer 1997). A combination of these factors leads to a distance dependent detection probability with low detection capacity at short distance, increasing detection up to a distance of optimal detection and decreasing detection probabilities with further increasing distance. These detection probabilities differ for different sized birds. Additional factors confound the detectability and thus the analyses of signals; birds in head-on or tail-on view evoke weaker detections than birds in side-view. Further, wing beats influence echo size; bird sizes cannot be detected and frequently bird flocks may appear as one signal (Bruderer 1997). Thus a radar image of an even density of birds will show regions of different densities.

The most common approach to account for distance dependent detection probabilities is the “distance correction”, following Buckland et al. (2001). Assuming that detection probability can be described as a function of distance, results of this specific function are used to correct count data, such as those from point and line transects. The technique has been applied to radar data in several studies (e.g. Stahl & Nehls 2004, Hüppop et al. 2004). It is described as follows: time periods with mass migration are used to assume an even distribution of birds aloft; radar data from the low altitude bands (< 150 m) are loaded into Distance (Vs. 5.0) (Thomas et al. 2006) to find the most appropriate distance function. Those consists of a model (key function = probability density function – defining the shape type) and an extension function (series expansion – defining the shape dimensions).

Radar data of the survey period have been pooled into eight different classes. They are separated for the two different ranges used, 500 m and 1500 m. The years 2005 and 2006 are separated because different techniques have been applied to capture the images of the vertical radar screen (screenshots – see above). The radar images produced in the North Sea have been separated from those in the Baltic sea because different radar devices will have different detection functions (e.g. Wendeln et al. unpubl.). For each of these 8 classes, an individual model and extension function has been calculated (Tab. 2.6).

Tab. 2.6: Distance correction of radar data: parameters and terms of key and series expansion functions for the Decca BridgeMaster E-series 25 kW Radar separated for the two radar devices, year and ranges (Buckland et al. 2001).

	Horns Rev North Sea				Nysted Baltic Sea			
year	2005		2006		2005		2006	
range	500 m	1500 m	500 m	1500 m	500 m	1500 m	500 m	1500 m
key function	uniform	uniform	uniform	half-normal	uniform	uniform	uniform	uniform
adjustment function	cosine	cosine	cosine	cosine	cosine	cosine	cosine	cosine
key function a_1				568.80				
series expansion b_1	0	0.6541	-0.5909		-0.2607	0.4211	-0.3953	0.2657
series expansion b_2	-0.6901	-0.7241	-0.2736	-0.5229	-0.1348	-0.5189	-0.1348	-0.5191
series expansion b_3	0	-0.4875	0.1481	0	-0.1445	-0.2895	-0.1445	-0.1413

For seven cases the “uniform”, for one case the “half-normal” model applies; the extensions are all of the type “cosine series”. For the distance-correction of the data, each signal must be multiplied with a factor > 1 according to the individual model and dependent on its distance from the radar device.

Key function “Uniform” with cosine adjustment terms:

$$g(y) = \frac{1}{w} * (1 + \sum_{j=1}^{z} b_j * (\cos \frac{j * \pi * x}{w})$$

with

g(y) : distance dependent detection probability

w: range considered (500 m or 1500 m)

j: starting number of adjustment term

z: ending number of adjustment term

b: parameter of the extension function

x: distance of signal to radar

Key function “Half-normal” with cosine adjustment terms:

$$g(y) = e^{(\frac{-x^2}{2*a_1^2})} * (1 + \sum_{j=2}^{z} b_j * (\cos \frac{j * \pi * x}{w})$$

with the same parameters as above, plus

a_1: parameter of the key function.

For data of the 500 m range (Fig. 2.7), detection probability for the 25 kW radar used in the North Sea increases up to 250-300 m and slightly decreases beyond this distance; the 25 kW radar used in the Baltic Sea has a maximum detection probability around 450 m.

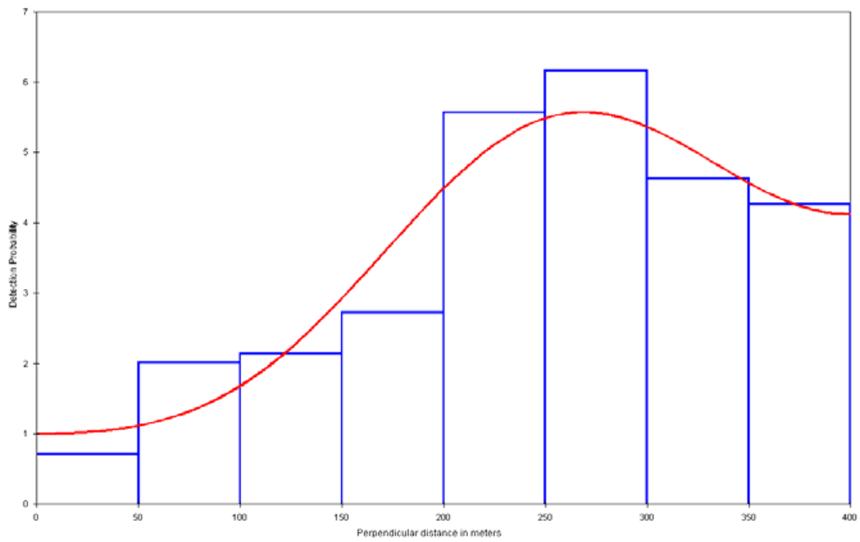


Fig. 2.7: Example: Horns Rev, vertical radar, range 500 m, year 2006, left-truncated at 65 m. Key function “uniform”, “cosine series” expansion with 3 adjustment terms. Shown is the histogram of the signals in blue and the detection function in red.

For the range 1500 m (Fig. 2.8), detection probabilities generally peak at around 400 to 550 m and decrease from there on. The decrease beyond 1000 m is generally strong, since the detection of small birds considerably decreases at those distances. Consequently, correction factors of > 10 and even > 50 may would apply beyond 1000 m. Since the altitude 1000 – 1500 m is not in the focus of our study, only data up to 1000 m were used for further analyses.

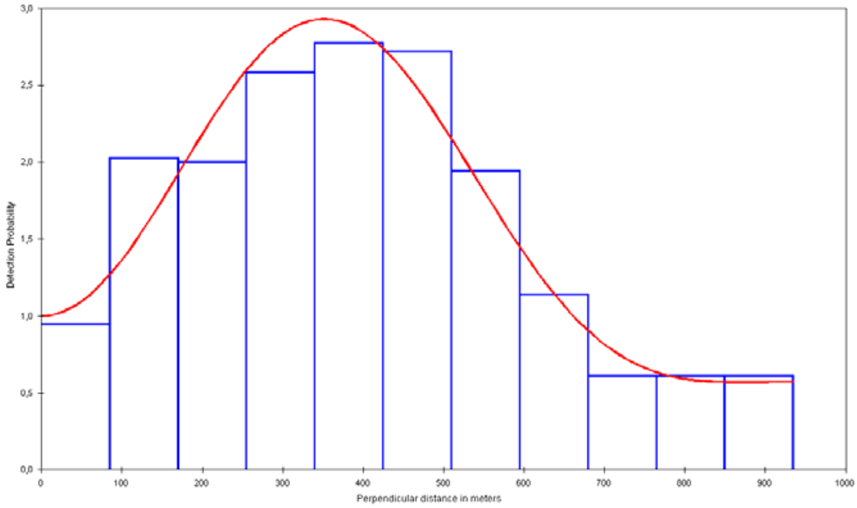


Fig. 2.8: Example: Nysted, vertical radar, range 1500 m, year 2005, left-truncated at 100 m, right-truncated at 1000 m. Key function "uniform", "cosine series" expansion with 3 adjustment terms. Shown is the frequency distribution of the signals in blue and the detection function in red.

<u>Separation of periods with high from those with low migration</u>: For each season and wind farm as well as separated for night- and daytime data, (distance-corrected) data were sorted after number of signals across the entire radar screen. Of these, the five days/nights with the highest numbers are "periods with intensive migration", whereas the other days/nights are the "periods with less intensive migration".

2.1.3.2. Vertical radar: Exclusion of clutter, insects, unknown objects or noise

It is generally assumed, that a signal appearing yellow on the radarscreen and producing an echo/trial is a bird or a bird group. However, conditions occur, when signals appear on the screen in high numbers, being somewhat different in shape, and also move over the screen in very regular manner. An assumption is, that those signals are insects or other disturbances such as particles drifting with the wind. It is not always possible to discern between those different types of signals, and for the current radar hard- and software setup, only visual data / screenshots have been available for signal identification. To exclude wrong/false signals to the best degree possible, all screenshots with more than 20 signals each were double-checked. This included assessing the screenshots before and after for obvious patterns as well as looking for certain characteristics such as signal shape, detection range, regularity, active signal movements and such. All screenshots potentially representing insects or unknown objects are excluded from further analyses.
Clearly, wind turbines themselves appear on the radar screen, this way "hiding" potential signals in those areas. In addition, disturbances caused by the wind turbines or structures on

the ship appeared on the screen, e.g. in cases when signals appeared as half circles or "mirrored" wind turbines on the opposite side.

A circle of 50 to 70 m directly around the radar was always disturbed and could not record any signals (Figures Fig. 2.9 and Fig. 2.10).

Rain is clearly detectable on radar pictures as large yellow areas. Pictures containing more than 1-2% of rain were excluded from analyses.

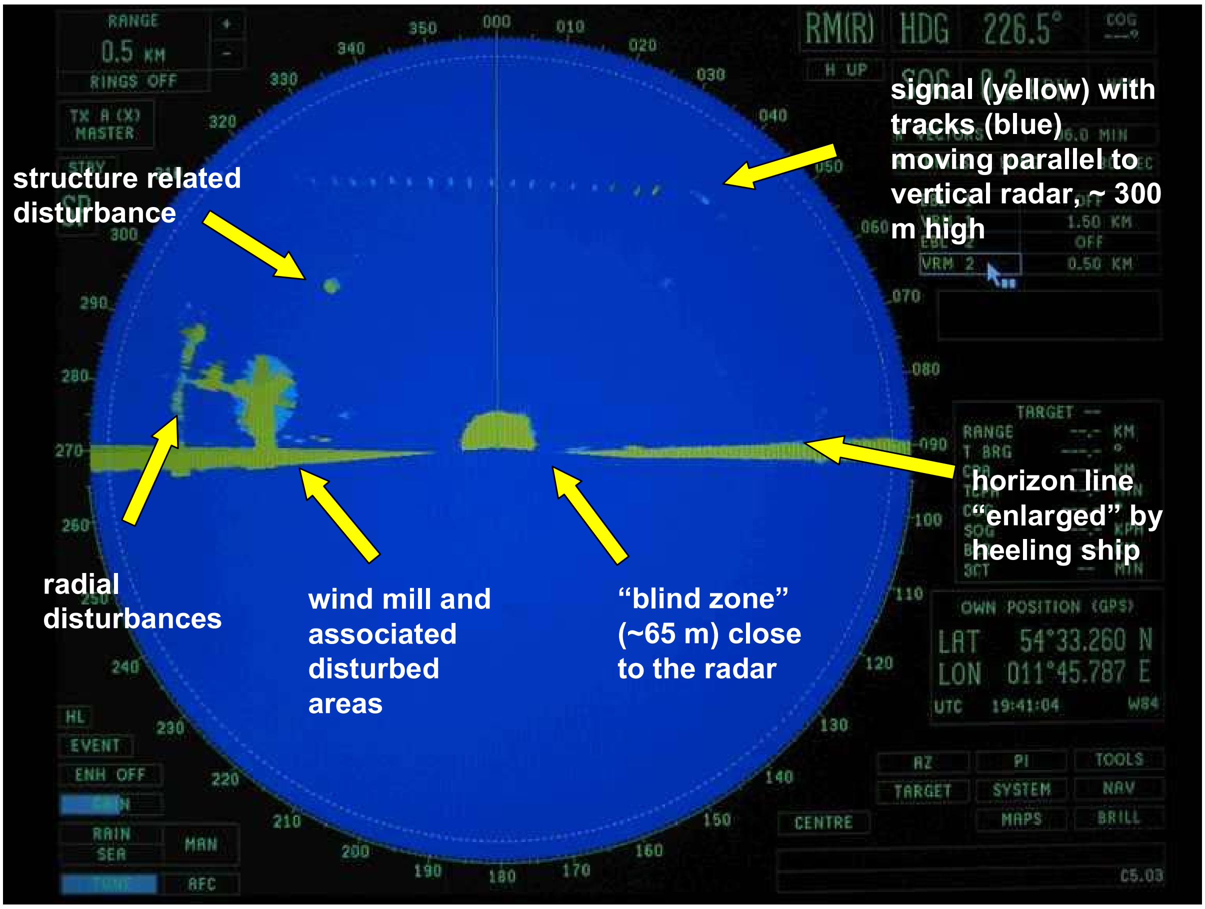


Fig. 2.9: Nysted – exemplary radar screenshot (digital camera) 500 m - showing little noise due to sea clutter near the sea surface, disturbances due to wind turbines on the left side plus a "streak" produced by the wind turbine, a weak yellow disturbance carried over from left to right as well as a point shaped disturbance on the left side probably also produced by a wind turbine.

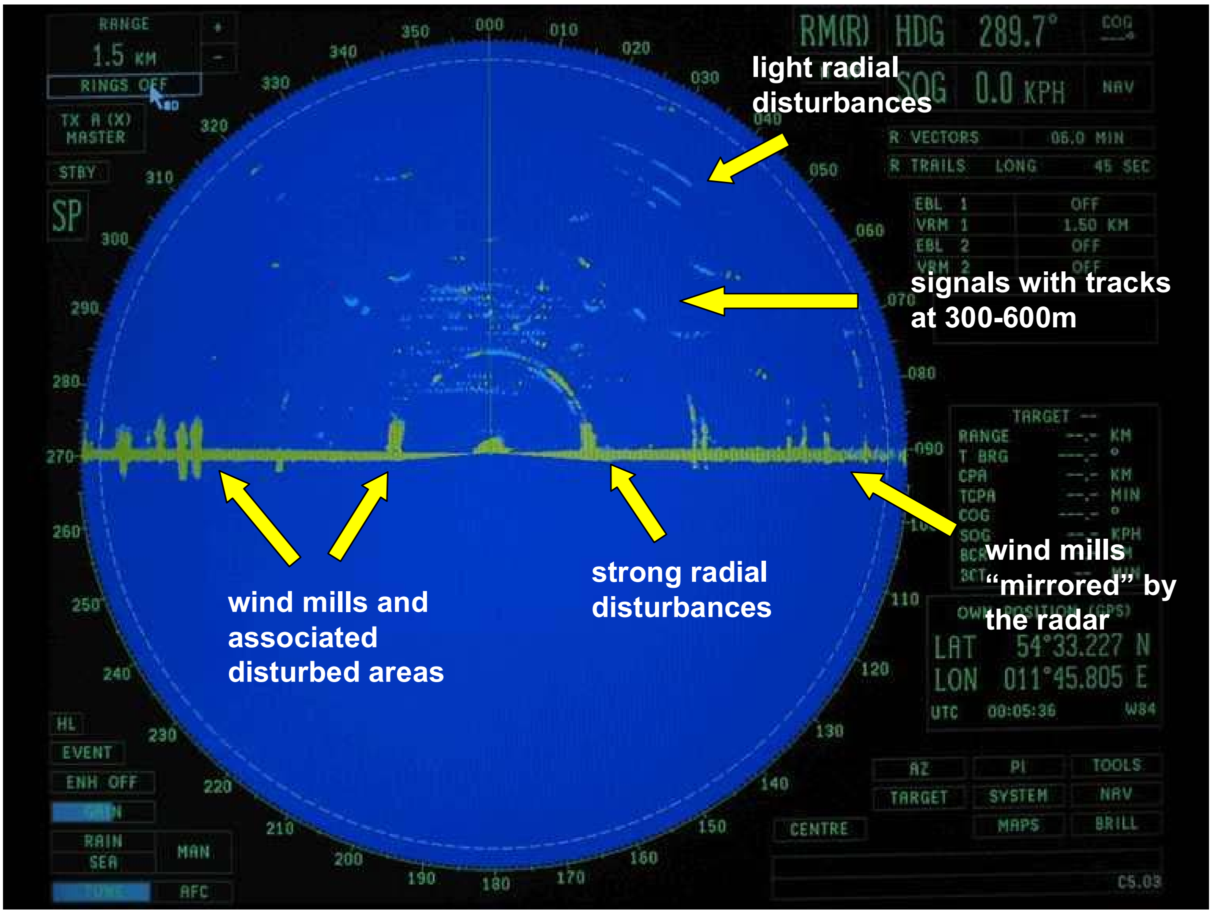


Fig. 2.10: Nysted – exemplary radar screenshot (digital camera) 1500 m - showing some noise due to sea clutter near the sea surface, disturbances due to wind turbines on the left side, disturbances by mirrored wind turbines on the right side, a yellow disturbance and blue disturbances carried over from left to right from the wind turbines on the left side.

2.1.3.3. Radar time

Radar time is summarized in Tab. 2.1 and Fig. 2.11. Radar time in spring 2005 was hampered due to a late start as well as initial hard and software changes, resulting partly in different methods applied and different data formats. Thus, radar data for spring 2005 are available in the desired form for Nysted, while for Horns Rev, only a few very short trips yielded the required data formats. From autumn 2005 onwards, radar operations ran almost 24 hours a day; during the first day of each trip, radar operations usually started in the late afternoon and during the last day, radar operation ceased in general at 10-11h in the morning. The recording of “traced signals” was increased over the observation period, as it was recognised that these additional data allow a better detection of bird signals and can help considerably in data interpretation.

Tab. 2.7: Hours of radar observations and number of screenshots

Horns Rev – North Sea			
Season	**time of day**	**hours of radar observation**	**number of screenshots**
Spring 2005	day	109	3.258
	night	53	1.450
Autumn 2005	day	262	5.675
	night	292	6.922
Total Horns Rev 2005		**716**	**17.305**
Spring 2006	day	219	4.674
	night	153	3.382
Autumn 2006	day	158	3.464
	night	176	3.831
Total Horns Rev 2006		**706**	**15.351**
Total Horns Rev		**1.422**	**32.656**
Nysted – Baltic Sea			
Season	**time of day**	**hours of radar observation**	**number of screenshots**
Spring 2005	day	178	6.317
	night	77	2.924
Autumn 2005	day	243	5.596
	night	285	6.679
Total Nysted 2005		**783**	**21.516**
Spring 2006	day	289	5.500
	night	212	4.406
Autumn 2006	day	216	4.048
	night	288	5.449
Total Nysted 2006		**1.005**	**19.403**
Total Nysted		**1.788**	**40.919**

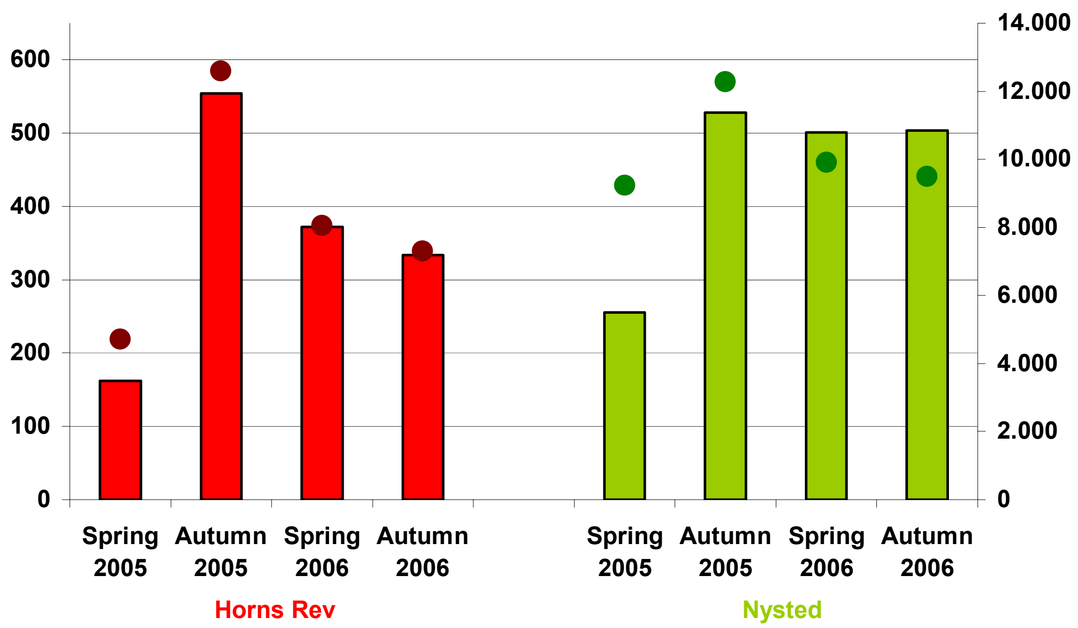


Fig. 2.11: Radar time. Bars = hours of radar observations, left axis; dots = number of screenshots, right axis.

2.1.3.4. Horizontal radar: Presentation and analyses of data

A prerequisite for the use of horizontal radar at offshore locations is a calm sea state (wind speeds less than 2 m/s). Otherwise the signals will be concealed by sea clutter, caused by strong reflections of a rough water surface. Screenshots of the horizontal radar from 2006 were screened for periods of calm sea state; from these periods screenshots are selected for analysis.

In Horns Rev, nine time periods yielded horizontal screenshots of a total of 143 hours; of those, 779 screenshots could be selected for analyses. Compared to the potential number of screenshots of all radar hours (Tab. 2.7), 5.1% of the horizontal radar screenshots are suitable for analysis.

In Nysted, ten periods yielded horizontal screenshots of a total of 168 hours; of those, 1.647 screenshots could be selected for analysis. Compared to the potential number of screenshots of all radar hours (Tab. 2.7), 8.5% of the horizontal radar screenshots are suitable for analysis.

Analysis of screenshots was conducted comparable to those of the vertical radar. Additional features in the software were to record angle (1-360°) as well as length of track in the data output. No effort was made to manually track signals of the horizontal radar.

2.1.4. Visual observations

2.1.4.1. Presentation and analyses of data

Visual observations (so-called „sea watching“) were carried out from a location on the vessel providing good surround-view combined with good accessibility and a reasonable height above water level which is necessary to detect and track flying birds.

On MS Søløven this location was the stern deck with ca. 3 m height. On MS Christoffer it was the bridge deck with ca. 3.5 m height. On both vessels the theoretically most suitable deck on top of the wheel house was not suitable because of the microwave radiation of the radars.

Visual observations were carried out along a transect line, one side of the transect leading from the ship into the wind farm, the other side leading from the ship into the opposite direction (Fig. 2.12). The transect was supposed both to meet the wind farm area more or less perpendicularly and to be more or less identical with the radar beam direction of the vertical radar (see Fig. 2.1 and Fig. 2.2).

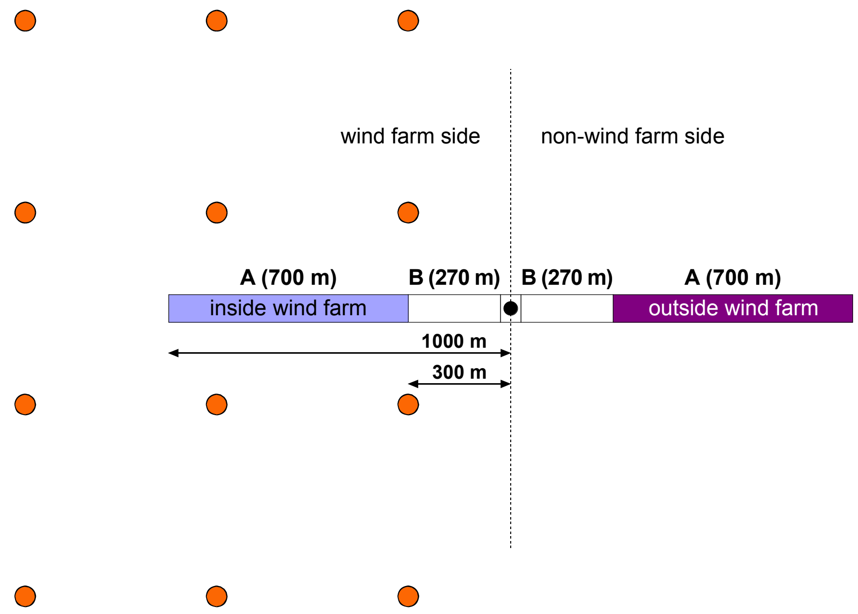


Fig. 2.12: Position of the observation platform in relation to the wind farm. The ship is indicated as black dot (●) lying ca. 300 m off the outermost row of wind turbines (orange dots). The transect is divided into two distance classes (A and B) on either side. The 30 m closest to the ship on either side were disregarded. Note that the transect is a line in fact. Here it is shown as a broad band to illustrate and label the distance classes. Here the pattern of the turbines is ideal square, resembling neither the situation in Horns Rev nor in Nysted. The distances between the turbines correspond to those in Horns Rev.

Birds were counted in two distance classes on each side (cf. Fig. 2.12). Class A covered a 700 m range from the edge of the wind farm until 1000 m inside the wind farm and from 600 m off the wind farm until 1300 m off the wind farm respectively. Hence it was classified as “inside wind farm” and “outside wind farm” respectively.

Birds flying between the edge of the wind farm and the vessel (except the 30 m closest to the vessel) and the corresponding distance on the opposite side were recorded as class B; that is “wind farm side” and “non wind farm side”, respectively.

Birds crossing the transect within 30 m around the vessel were not regarded at all.

Visual observations of flying birds (including migration as well as movements from/to/between feeding and/or resting sites) were carried out on days at sea from before sunrise until after sunset including the twilight periods of some 20-30 minutes before sunrise and after sunset. Birds were counted during observation intervals of 15 minutes each, one per every half hour, with a minimum of 5 minutes between them.

Observing along the transect was done without any optics. Birds had to be spotted naked eye. Optics (binoculars with 8 to 10-fold magnification) were only used for identification or clarification if necessary.

When sight range fell below 1000 m due to poor weather conditions, systematic observations were stopped, but observations continued to keep registering potential effects (chapter 2.3.3)

In every counting unit two experienced observers (one covering the transect heading into the wind farm, the other covering the opposite transect) recorded all flying birds crossing the transect line between the vessel and 1000 m distance. After every interval the observers swapped sides to avoid observer dependent biases.

The following data were gathered:

Species, whenever identification was possible, otherwise the recognized taxonomic level.

Distance from the observation platform. For further differentiation if applicable the transect was split into three sub-ranges (0 to 30 m [excluded from analysis], 30 to 300 m [class B], 300 to 1000 m [class A] (cf. Fig. 2.12).
Flight direction: Compass directions in 1/8 were used (NW, N, NE ...) plus „no obvious or changing direction".
Flight altitude was recorded in four classes: 0 – 5 m; 5 – 30 m; 30 – 110 m; >110 m. These classes were chosen referring to the following characteristics (Fig. 2.13): just above water surface; below the altitude range swept by the wind turbine blades (rotor range) but not just above water surface; within rotor range; above height of the wind plant.

Furthermore data about age and sex of the birds were gathered if possible as well as the birds association with vessels and behavioural remarks according to the international ESAS-codes (Camphuysen & Garthe 2001).

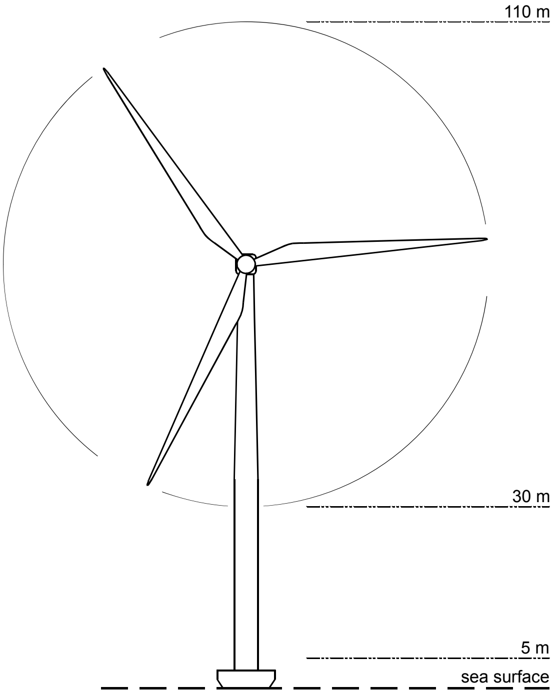


Fig. 2.13: Flying birds were recorded in four altitude classes referring to the rotor range of the turbines (the fourth class being the one above turbine height).

Special attention was paid to reactions of birds towards the wind turbines. For this purpose flocks/individuals between the observation platform and the wind farm and inside the wind farm (thus distance class A + B as well as the nearest 30 meters on wind farm side) were tracked and observed with respect to their behaviour in the proximity of the turbines. Birds from the opposite side were not included. These focal observations were done whenever the situation allowed. So, birds were tracked when occurrence of birds crossing the transect did not draw too much attention to follow single birds and when birds came close to the turbines within a reasonable observation range. The following behaviour of birds approaching the wind farm was rated as obvious reactions: change of flying altitude; change of flight direction; disintegration of flocks; interruption of a continuous flight movement (like sudden circling or hovering). Only the fact that a reaction occurred or not was recorded, not the character of the reaction.

All counted numbers are based on observation events and not necessarily on single individuals. Since it is impossible to keep track of single individuals for longer periods, some individuals especially of stationary species might have been recorded repeatedly (e.g. Great Cormorant and Common Eider in Nysted, Common Scoter in Horns Rev, gulls except Little Gull in both areas). So, presented numbers can be considered as a measure of general presence of a taxon in the area. However, for passing migrants the number should be identical with the number of individuals (e.g. birds of prey, passerines).

In general, data of visual observations are presented for entire taxa. However, with regard to gulls, Little Gull was excluded and treated separately in Horns Rev wind farm area. This procedure seemed appropriate for several reasons:

- While all other abundant gull species are resident at least for longer periods and certain individuals are likely to be present in the area for the duration of several hours or even days, Little Gulls pass by during directional migration and hence show a very different occurrence pattern (low probability of double counts).
- Body size of Little Gull is much smaller than that of most other gulls in the area and hence the recording conditions are different for that species.

In Nysted Little Gulls occurred in far lower numbers, thus numbers overall were too small to treat them separately there.

Wind

Weather data were made available by the companies running the wind farms. In both of them there were measuring masts (three in Horns Rev and four in Nysted) recording a wide spectrum of meteorological data from different locations and altitudes in ten minute intervals. This database provided appropriate data about wind speed and wind direction.

To determine the winds influence on the flight altitude of a bird the wind burden for the bird has to be assessed. This was done by calculating the tailwind component (TWC), a common measure used in aviation and recently in many ornithological investigations, too (e.g. Fransson 1998, Åkesson & Hedenström 2000, Dierschke & Delingat 2001, Hüppop et al. 2004):

$$TWC = \cos(\varphi) \cdot v ,$$

with φ being the angle between theoretical exact tailwind direction and real wind direction at present, and v being the present wind speed.

I.e. the TWC equals the wind speed for exact tailwind and it equals the negative wind speed value for exact headwind. However, TWC doesn’t express the birds wind burden well in crosswind situations with reasonable wind speeds and it fails completely at exact crosswind (90° at either side) when the TWC equals zero. TWC was calculated for every recorded bird from flight direction and weather data unless it was impossible because the bird was circling or taking an unsteady direction.

Statistical procedures

Further analysis of the processed observation raw data was done at the base of systematic taxa, mostly species. Species were pooled in a lower taxon (e.g. families) for presentation and statistical analyses when either not enough data sets were available for single species level or when birds of a certain taxon could not be identified to species level (e.g. terns) or when it didn't seem meaningful to have a closer look at species level (e.g. gulls).

To look at wind farm avoidance for certain taxa, numerical distributions (results of the transect counts) of both transect sides (inside and outside the wind farm) were tested for significant differences. For this purpose all observation intervals were excluded in which the taxon in question did not occur on either transect side. That way a reduced data set was created in which the respective taxon was present in every interval, inside or outside or both. Still, many nil values existed in the set and data were not normally distributed. With the objective of using the counted values rather than ranks computing a Generalised Linear Model (GLM; McCullagh & Nelder 1989, Crawley 2007) was chosen to compare inside-counts with outside-counts, assuming quasipoisson distribution.

In a next step it was tested whether the vertical distributions from the two sides (the proportions per altitude class) were different. Such differences might potentially be seen as reactions to the wind farm. That was done by executing two Generalised Linear Mixed-Effects Models (LMER) with a change in the fixed effect and running an ANOVA between the two models afterwards. In model 1 the variable "inside/outside wind farm" was set as fixed effect, the variables "season" and "TWC" were set as random effects to exclude possible effects on the altitude distribution from the calculation which might be caused by seasonal influences or the wind direction in relation to the birds flying direction. In model 2 the variable "altitude" was added as a second fixed effect, the random effects remained the same. If the ANOVA for the two models is significant the factor altitude must differ significantly between inside and outside the wind farm.

All statistical processing was done with the software "R", version 2.5.1.

2.1.4.2. Observation time

In spring visual observations were conducted for 75 and 182,5 hours in 2005 and 2006 respectively in Horns Rev. In Nysted this was done in 219,5 and 238,5 hours respectively (Fig. 2.14). In autumn 237 and 139 hours were covered in both years respectively in Horns Rev. In Nysted autumn visual observations were done for 233,5 and 186 hours respectively (Fig. 2.15).

During some ship days, visual observations were not carried out as PODs had to be handled then (hence the difference between Tab. 2.1 and Fig. 2.14 and Fig. 2.15).

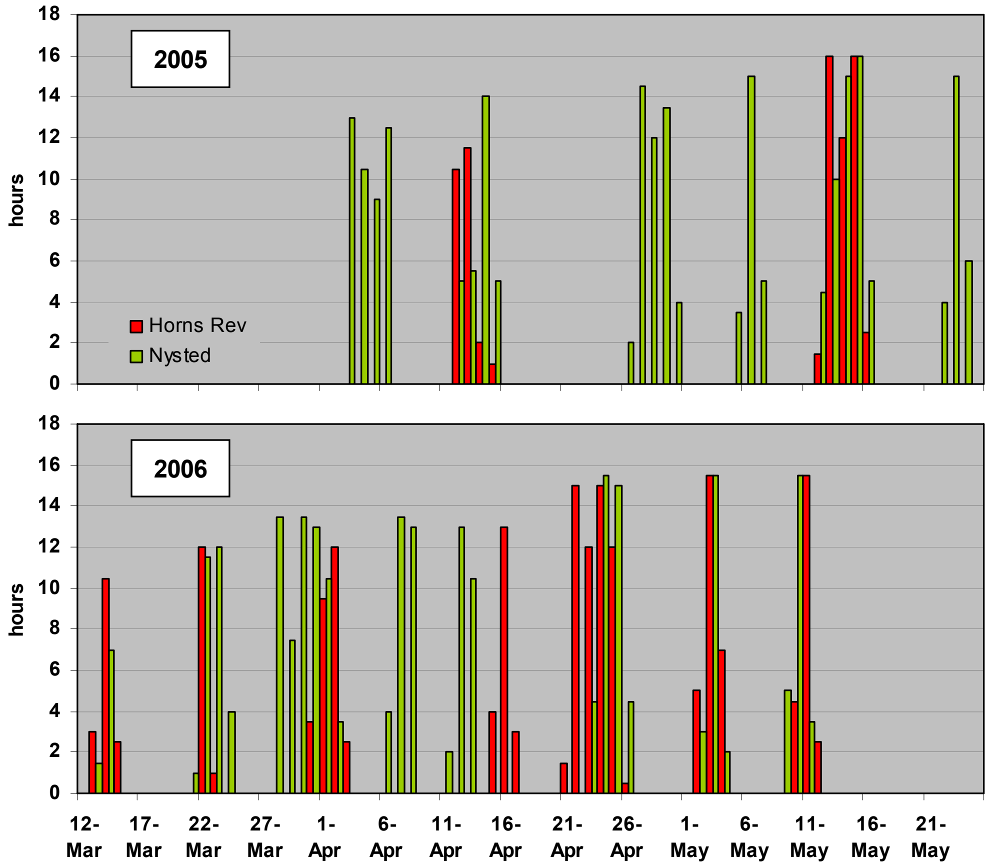


Fig. 2.14: Daytime covered by visual observations in Horns Rev and Nysted in spring 2005 and 2006.

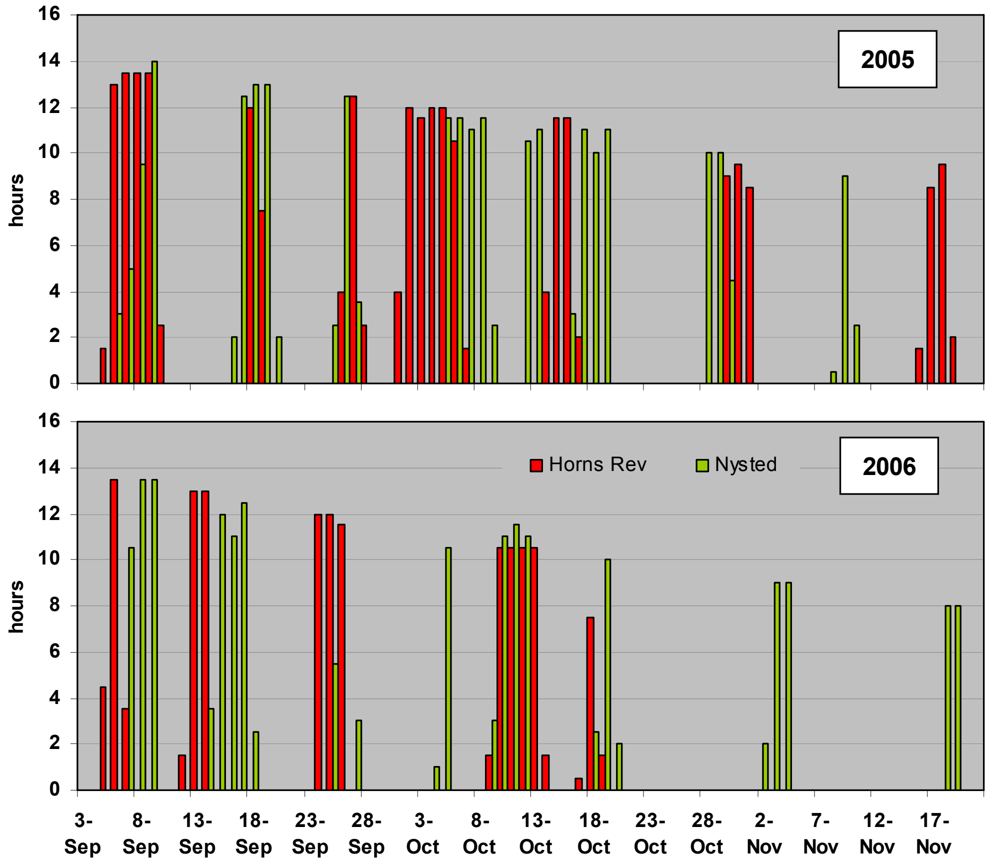


Fig. 2.15: Daytime covered by visual observations in Horns Rev and Nysted in autumn 2005 and 2006.

2.1.5. Acoustic observations

2.1.5.1. Presentation and analyses of data

During darkness (from after civil twilight in the evening until before civil twilight in the morning) acoustic observations were carried out by experienced observers. One observer registered every bird call during 10 minutes each within every half hour. Two of these acoustic observation units were at least five minutes apart from each other. The platforms used for acoustic observations were in both vessels the stern decks as they proved to be the most silent places on the vessel.
Acoustic observations yield species composition. Naturally, only those species which call during migration and migrate during night and only individuals close enough (distance, altitude) to be heard can be registered. The number of birds cannot be identified; instead, the number of calls reflects migration intensity and allows comparison between different nights.

2.1.5.2. Observation time

Acoustic observations were carried out during all nights at sea. In Horns Rev a total of 190 hours (24 nights) acoustic observations was carried out in spring (24,5 hours in 2005 and 165,5 hours in 2006). 405,5 hours (42 nights) were covered in autumn (241 hours in 2005 and 164,5 hours in 2006). In Nysted a total of 333,5 hours (45 nights) acoustic observations was carried out in spring (105,5 hours in 2005 and 228 hours in 2006) and a total of 537,5 hours (52 nights) in autumn (268 hours in 2005 and 269,5 hours in 2006).

2.2. Results

2.2.1. Radar observations – vertically rotating radar

2.2.1.1. Migration intensity and seasonal phenology

Migration intensity varies over the migration seasons. Two examples show how migration intensity can vary over different time periods.
In autumn 2005 at Horns Rev, we covered 7 observation periods between September 5th and November 19th. Migration clearly peaks around October 6th and October 15th, while during the other periods, it was generally low (Fig. 2.16).

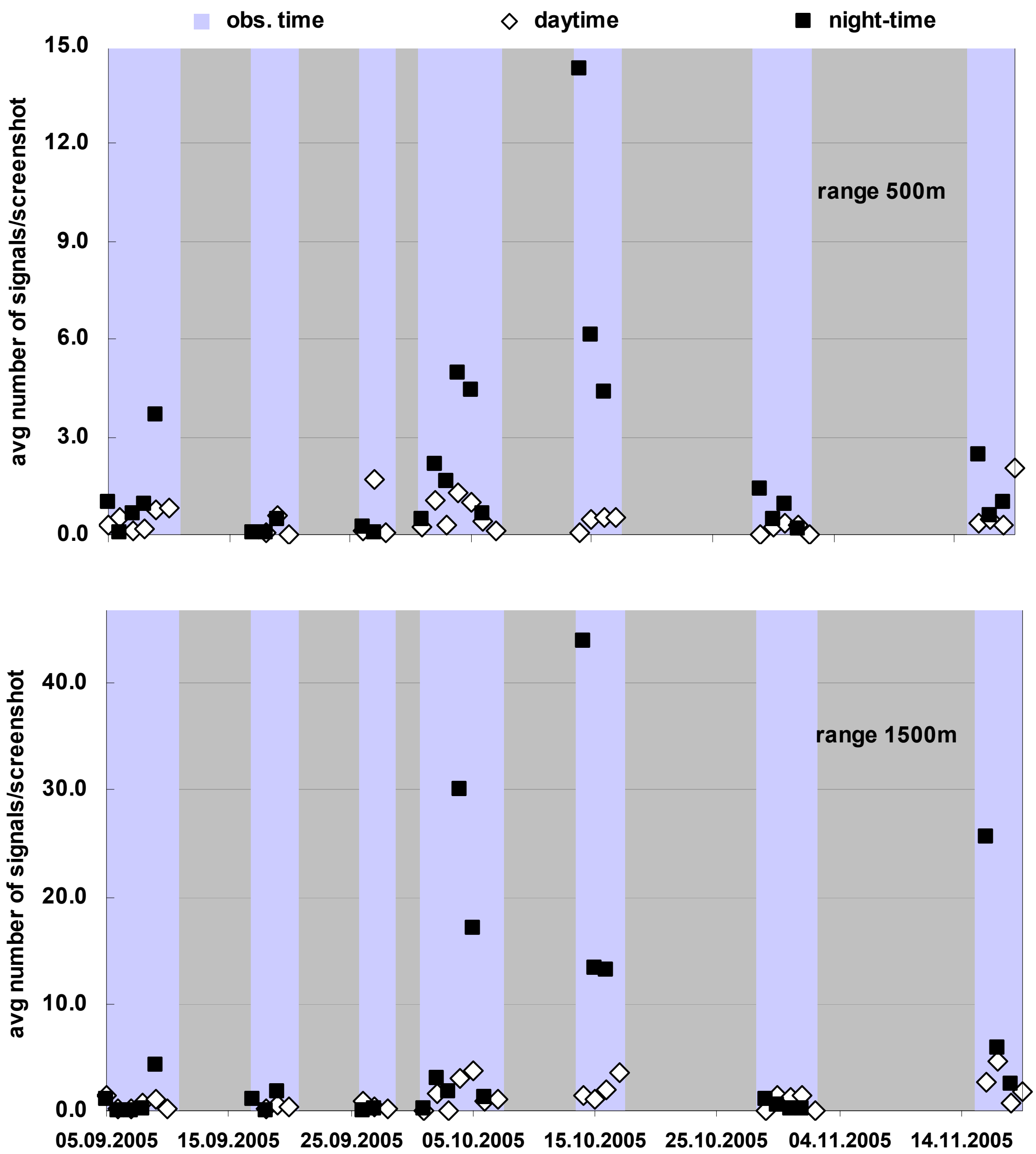


Fig. 2.16: Horns Rev - migration intensity during autumn 2005 for ranges 500 m and 1500 m. Observation periods in light blue, other periods in grey.

In spring 2006 in Nysted, for example, 8 observation periods are covered between March 13th and May 11th. There is low migration up to March 24th, and a clear migration peak in the period around April 1st. While migration intensity is low to moderate in mid-April, late April and May shows nights with moderate intensity again (Fig. 2.17).

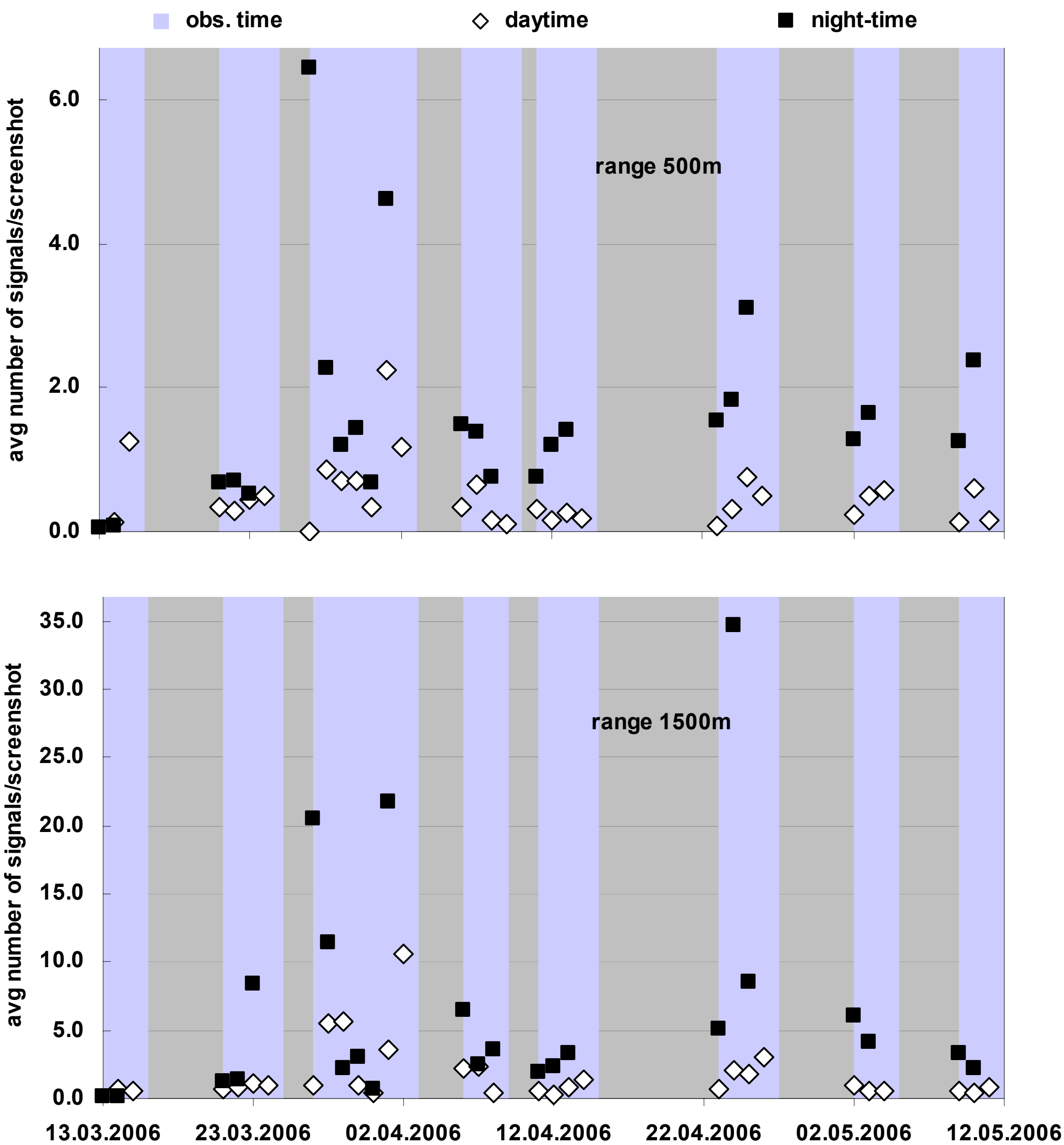


Fig. 2.17: Nysted - migration intensity during spring 2006 for ranges 500 m and 1500 m. Observation periods in light blue, other periods in grey.

In general, migration intensity is higher during night than during daytime and higher at Nysted than at Horns Rev (Fig. 2.18 and Fig. 2.19). Also, the number of signals per screenshot is higher at range 1500 m than at 500 m, even though exceptions apply which can be caused by different detection probability of the radar at different ranges.

Considering both years 2005 and 2006, the **migration phenology** described for the seasons is somewhat different in the two wind farms. At Horns Rev, autumn 2005 sticks out with highest migration intensity during day- and nighttime; during spring 2006, remarkable low intensities and only minor differences between day and night exist, but also the migration intensity for autumn 2006 is comparably low (Fig. 2.18). At Nysted, regularly high values during nighttime and the large differences between day and night indicate typical migration patterns (Fig. 2.19). Comparing Horns Rev with Nysted, it seems that at Nysted peak migration events have been covered in all seasons, while at Horns Rev generally low migration is registered during spring seasons and peak migration events are only apparent for autumn 2005.

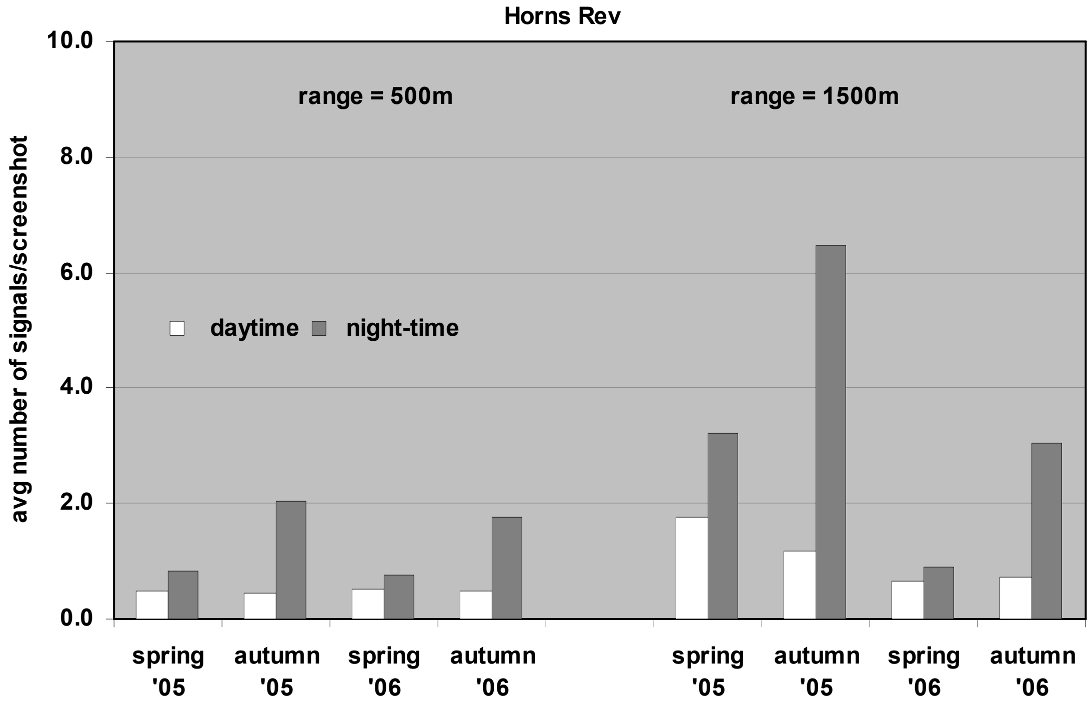


Fig. 2.18: Horns Rev - migration intensity during all seasons for ranges 500 m and 1500 m

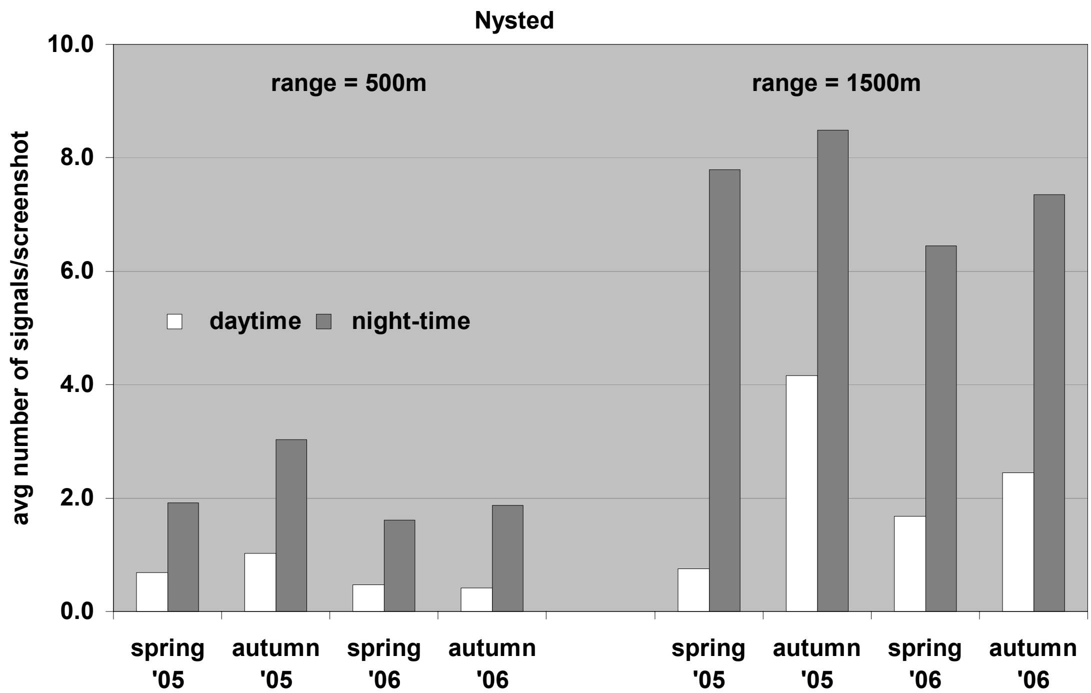


Fig. 2.19: Nysted - migration intensity during all seasons for ranges 500 m and 1500 m

2.2.1.2. Examples of diurnal phenology

The **diurnal migration phenology** describes the migration intensity during day- and night-time and follows certain patterns. Two examples shall illustrate this diurnal phenology at the offshore locations: To compare phenologies of different parameters and methods, the following figures show the radar results range 500 m and 1500 m at the top and at the bottom (see chapter 2.2.1.4 for more results) and the results of the night acoustic observations in the middle (see chapter 2.2.4 for more results); additional figures show the altitude distributions of the corresponding nights (see chapters 2.2.1.3 and 2.2.1.4 for more details).

Horns Rev in October 2005 (Fig. 2.20, Fig. 2.21): The evening sunset is around 16:30 with evening twilight around 17:05h, the morning twilight is around 05:20h, sunrise around 06:00h and two days before full moon (Oct. 17th, 2005). The wind came from ESE over the last days and turned to N during Oct 14th, back to E with beginning Oct 15th, temperatures relatively mild between 10 and 15° C. The ship anchored at the East side of the wind farm between the wind turbines 93 and 94 towards the northern end (Fig. 2.1). The first night is a peak migration night. On both radar ranges massive bird migration is registered, mainly in higher altitudes with a strong migration band at 600-900 m and a rather low proportion of birds migrating low. The onset of migration is around 17h in the lower altitudes, then around 19h in the higher altitudes, decreasing continuously from then on until it almost ceases around 3h in the morning. Bird calls of Songthrush, Redwing and Robin and a few other species had been registered mainly between 22h and 04h. The coming two nights show less migration on the radar, however, many bird calls. Signals are more evenly distributed over the altitude bands than during the first night. Clearly, night time migration is far more intense than daytime migration over this time interval.

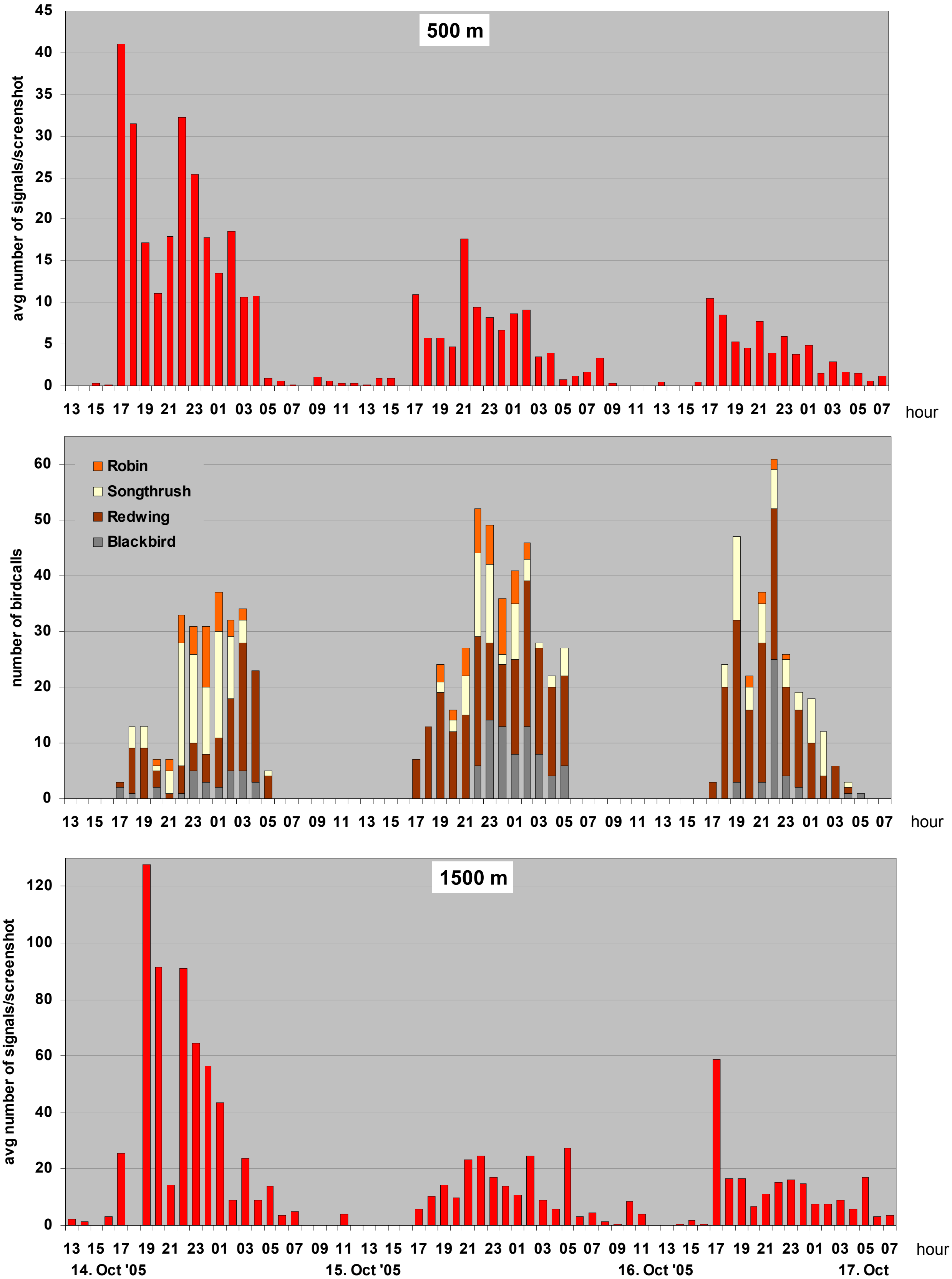


Fig. 2.20: Horns Rev - migration phenology October 14-17, 2005. Top and bottom are radar data, in the middle are the number of bird calls.

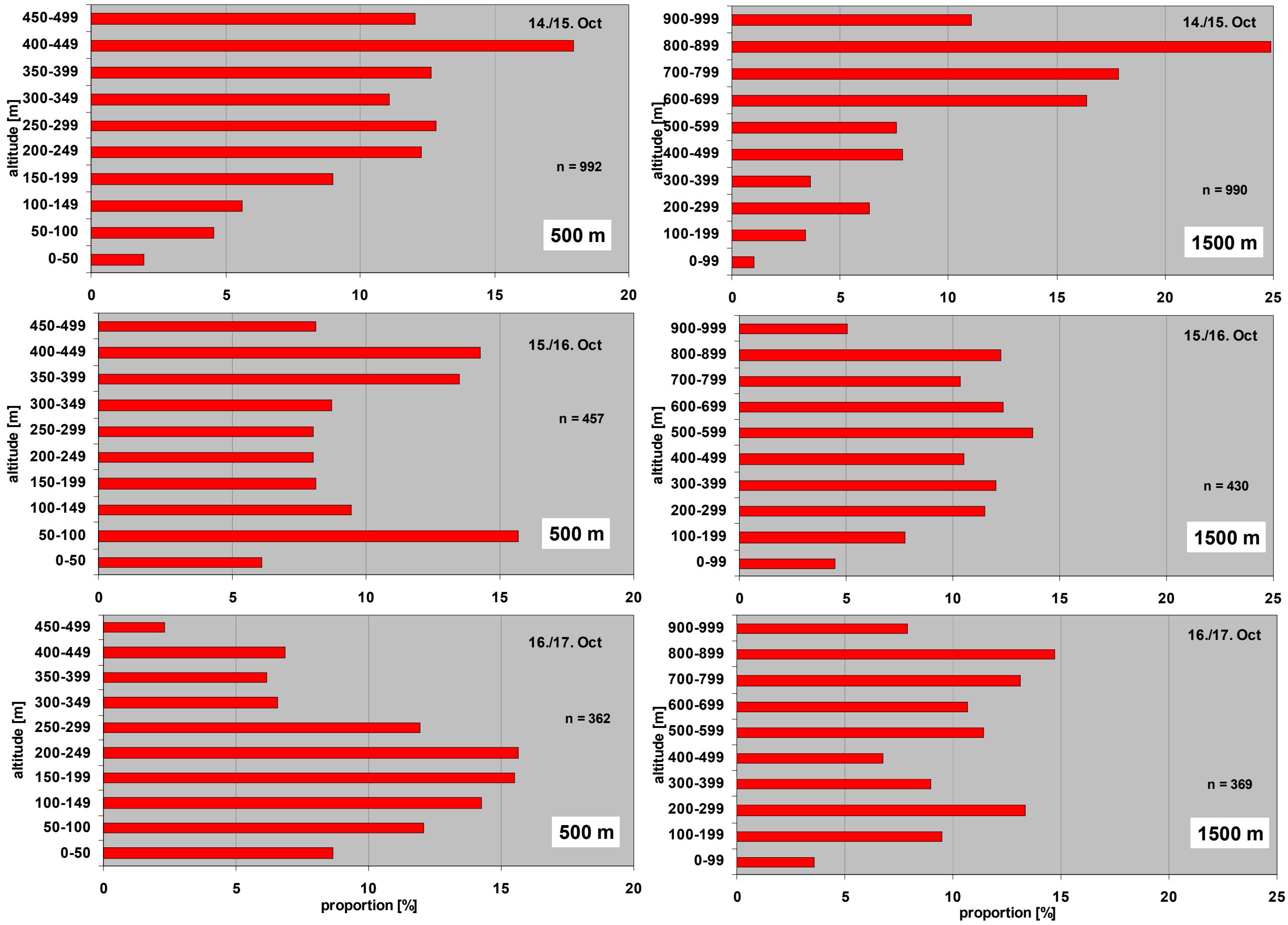


Fig. 2.21: Horns Rev – altitude distributions during three nights October 14-17, 2005. Left figures for range 500 m, right figures for range 1500 m.

Nysted October 2006 (Fig. 2.22 and Fig. 2.23): The evening sunset is around 16:30h with evening twilight around 17:06h, the morning twilight is around 04:55h, sunrise around 05:30h and it is two days after full moon (Oct. 7th, 2006). The wind came from WSW over the last days and turned to SE during Oct 9th daytime, however turning back to westerly directions during the following night. With the night beginning on Oct 10th, the wind turned towards E for the following days. Temperatures were relatively mild between 10 and 15° C. The ship anchored at the East side of the wind farm between the wind turbines H3 and H4 towards the northern end (Fig. 2.2).

At the 500 m range radar, both nights have comparable migration intensities, however, massive migration is shown on the 1500 m range especially during the first night; those signals seem to mainly occur in the altitude bands 600-1000 m and are thus not registered by the 500 m radar. Bird calls are registered, yet, their phenology deviates to some degree from the radar results. Main species is the Robin; its high-pitched flight calls can hardly be heard over larger distances – depending on environmental conditions like wind and other ambient noise; however, birds which are rather close will not appear on the radar.

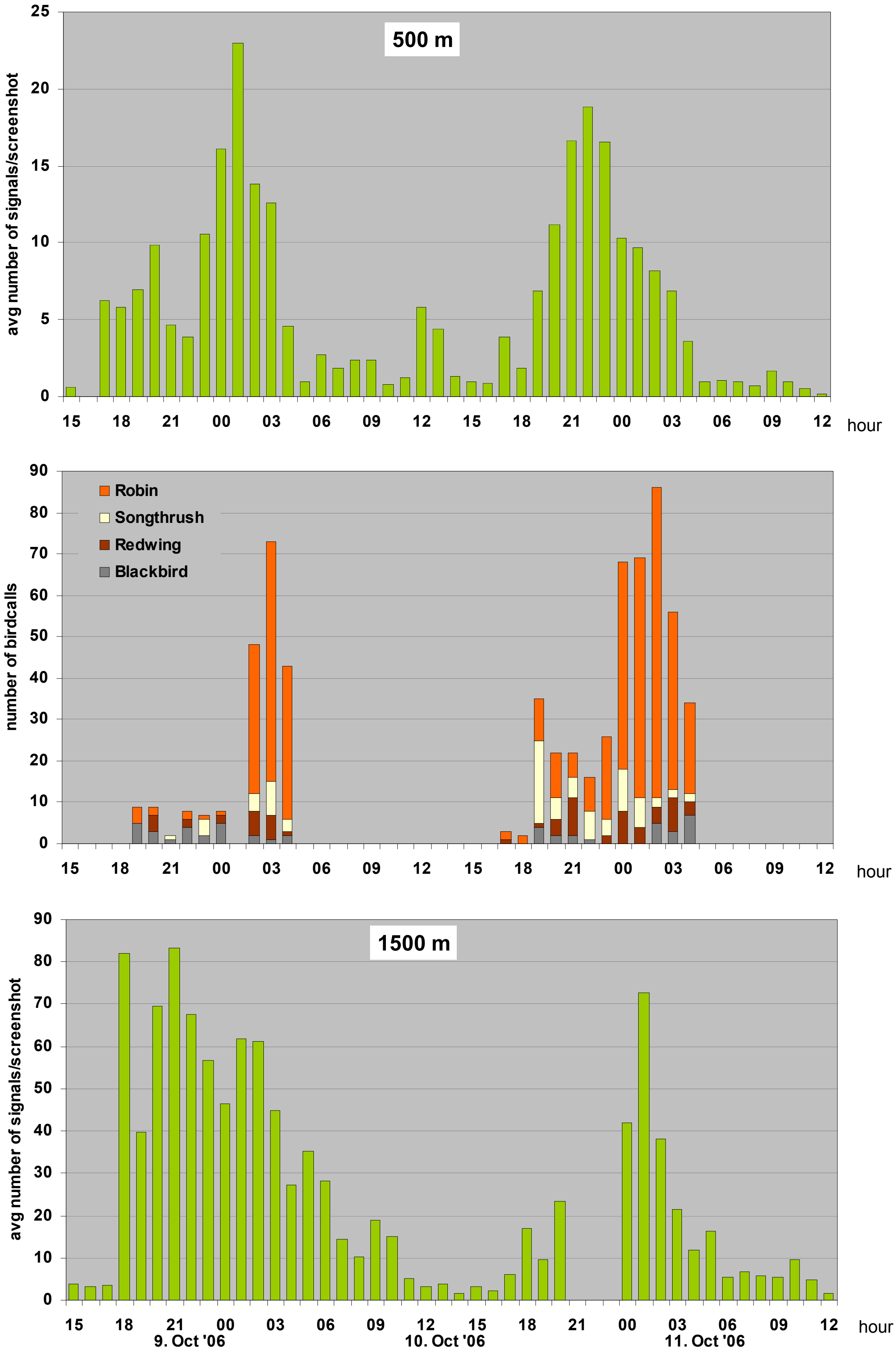


Fig. 2.22: Nysted - migration phenology October 9-11, 2006. Top and bottom are radar data, in the middle are the number of bird calls. Radar data 1500 m missing for Oct 10th, 21-23h.

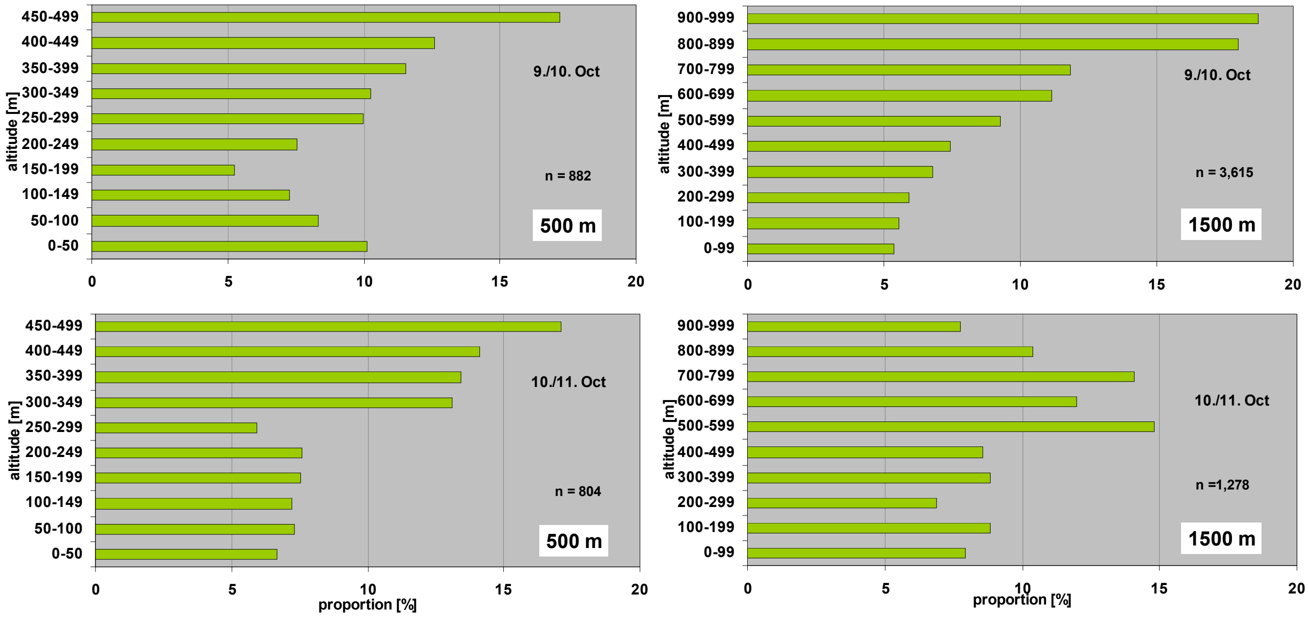


Fig. 2.23: Nysted – altitude distributions during two nights October 9-11, 2006. Left figures for range 500 m, right figures for range 1500 m.

Summary: Both examples demonstrate that even during periods of high and comparable migration intensity, the altitude distributions may considerably vary for different nights. They also show, that phenology results for both radar ranges do overlap in general, but maybe different if peak migration is above 500 m (Nysted). Radar results and bird calls show some synchronicity, but can well be different in intensity (Horns Rev) or phenology (Nysted) (e.g. Farnsworth et al. 2004), but can as well as be different (Horns Rev) somewhat synchronous with the bird call phenology. However, periods exist, when bird call results and radar results yet with subtle differences, the overlap of peak migration events based on radar results and acoustic observations.

Nysted: This example demonstrates the diurnal phenology of migration, the differences of the 500 m and 1500 m range results and again different altitude distributions during nights with comparable migration intensity.

2.2.1.3. Altitude distributions - general

To provide an overview, for each wind farm, radar data results are pooled under some categories; this helps to identify some common patterns, such as differences between seasons, years or day- and nighttime. For each range, the large figure represents data over the entire observation period, and the smaller figures represent data pooled for either years or seasons. In addition, day- and nighttime distributions are shown.

Horns Rev

At Horns Rev, a strong concentration during autumn is visible, with more than four times as many signals as during spring, in accordance with the migration intensity results (Chapter 2.2.1.1).

At the **500 m range**, a preference for the lowest altitude classes of 0-50 m and 50-100 m can be seen for most figures, most likely represent day-active birds; an exception is the year 2005. Altitude distributions at 100-500 m are rather regular, no clear patterns can be de-

picted (Fig. 2.24). Both at nighttime and daytime, the lower altitude class is dominating, and altitude distributions between 100-500 m are again more or less regular (Fig. 2.25).
At the altitude distributions using the **1500 m range -** meant to describe the migration situation overall - there are strong preferences for the altitudes > 800 m during the autumn seasons and in the year 2005 as well as in the data summarized over all. Data from the spring seasons as well as data for the entire year of 2006 show a more or less regular altitude distribution above 200 m, lacking a preference of the higher altitude categories (Fig. 2.26). Separation of night- and daytime signals for the 1500 m range clearly demonstrates, that during nighttime migration dominates beyond 400 m; during daytime, less signals overall exist; the altitude distribution above 200 m shows a pattern comparable, even though not so pronounced, to nighttime (Fig. 2.27).

Horns Rev - 500 m

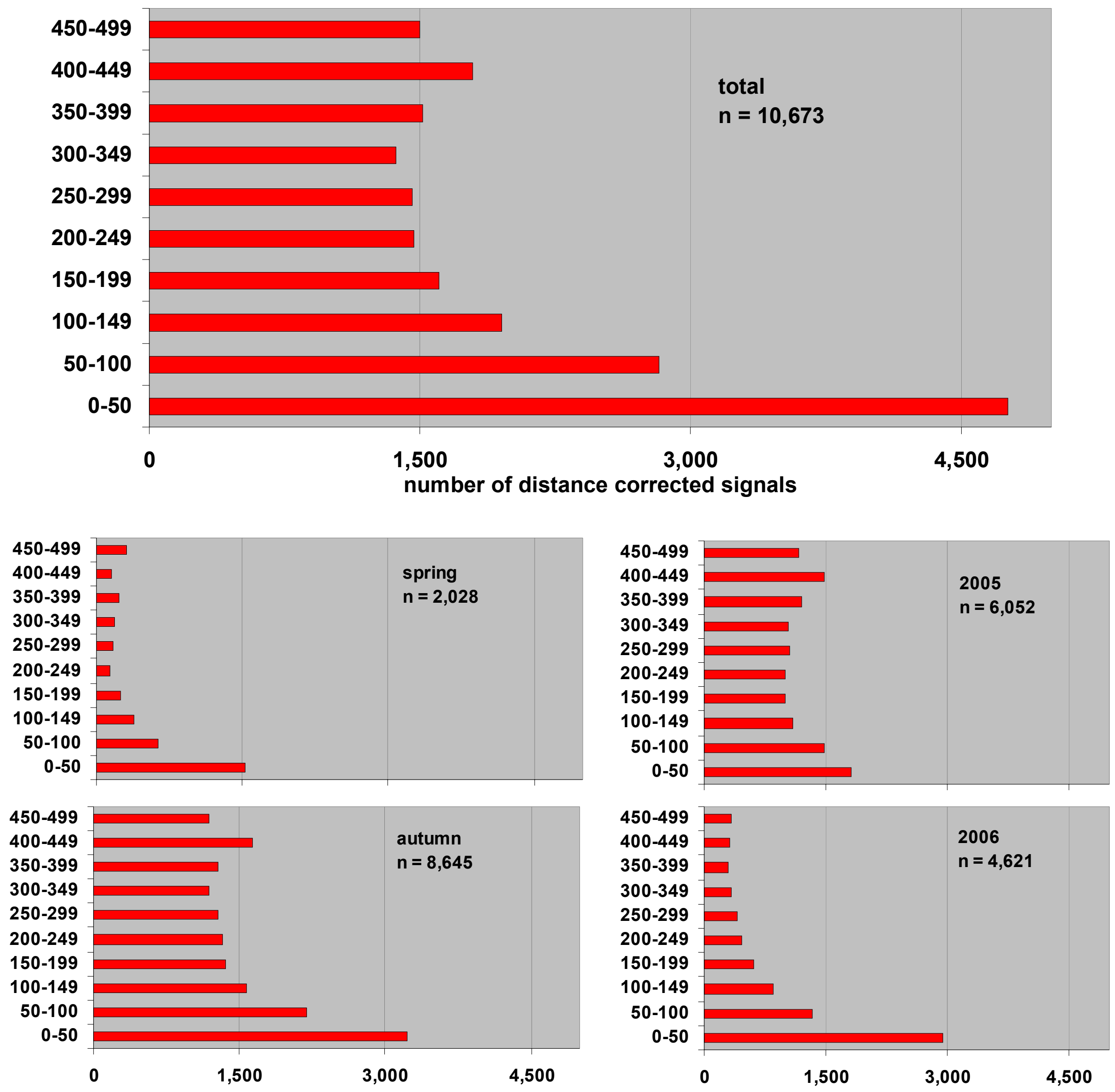


Fig. 2.24: Horns Rev: summaries of altitude distributions (number of distance corrected signals per altitude band, n for uncorrected signals), range 500 m. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

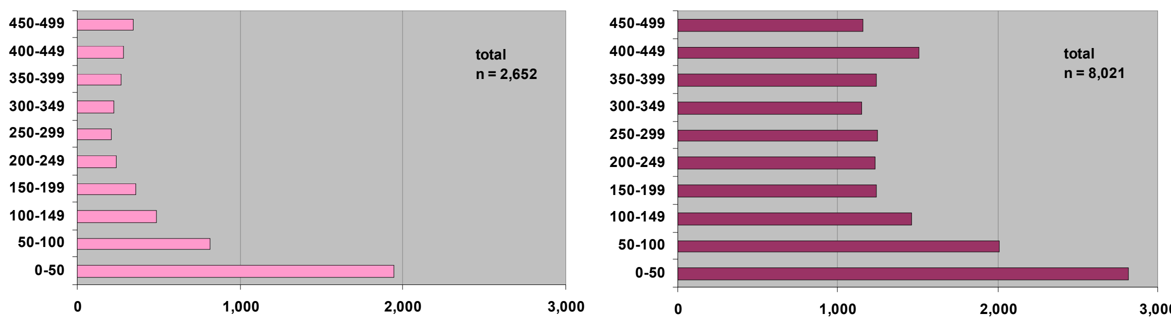


Fig. 2.25: Horns Rev – daytime (left) and nighttime (right): summaries of altitude distributions (number of distance corrected signals per altitude band, n for uncorrected signals), range 500 m. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

Horns Rev – 1500 m

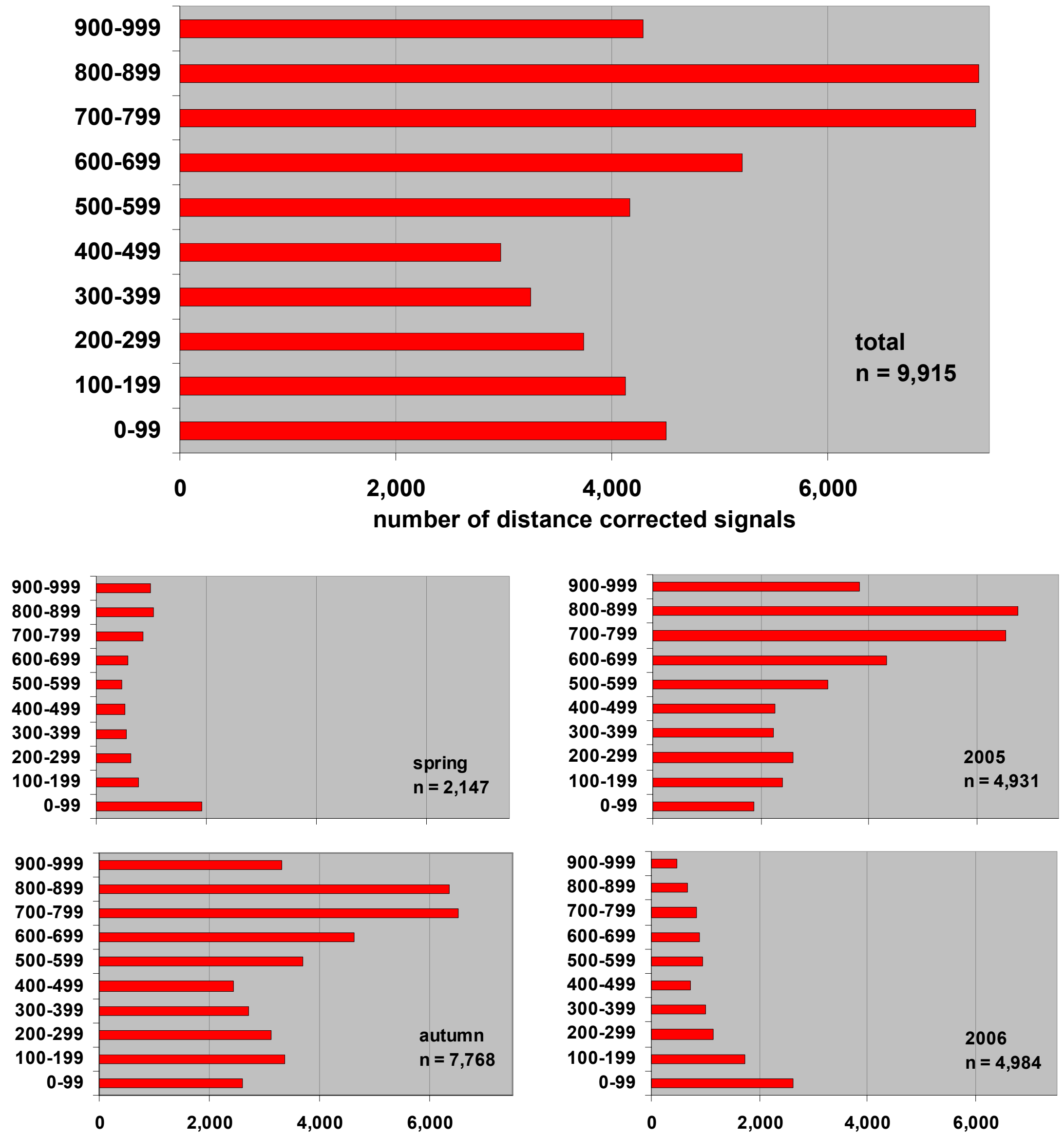


Fig. 2.26: Horns Rev: summaries of altitude distributions (number of distance corrected signals per altitude band, n for uncorrected signals), range 1500 m. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

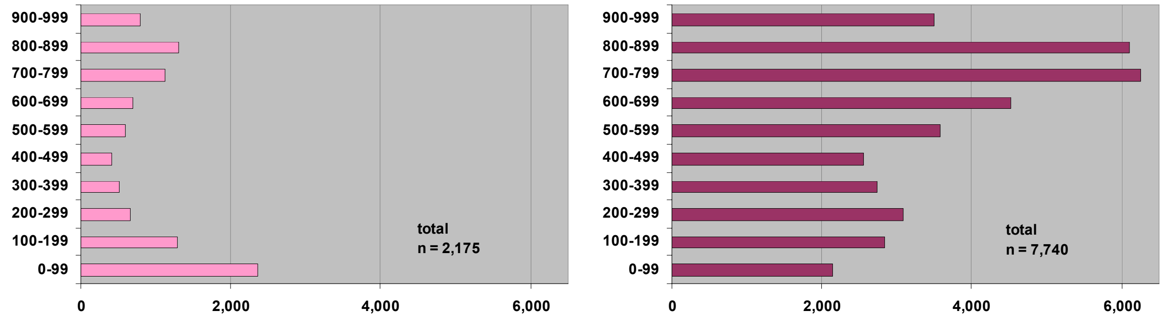


Fig. 2.27: Horns Rev – daytime (left) and nighttime (right): summaries of altitude distributions (number of distance corrected signals per altitude band, n for uncorrected signals), range 1500 m. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

Nysted

For Nysted, the autumn seasons yielded twice as much data as the spring seasons.

For the **500 m range**, a preference of the lower altitude categories, as seen in Horns Rev, is generally missing; differences between seasons or years are not obvious (Fig. 2.28). Differences between night- and daytime altitude distributions on the 500 m range are small, with some preferences for the lower altitudes during nighttime. Weak preferences for the categories < 100 m and > 300 m exist both during day- and nighttime (Fig. 2.29).

For the **1500 m range**, the altitude distributions of the summarized data are also rather regular; no clear preferences for the higher altitude bands are visible and differences between seasons or years are negligible (Fig. 2.30). In contrast, the differences between night- and daytime migration show, that a concentration at 700-900 m exists during nighttime, while at daytime only the lowest altitude band sticks out (Fig. 2.31).

Nysted - 500 m

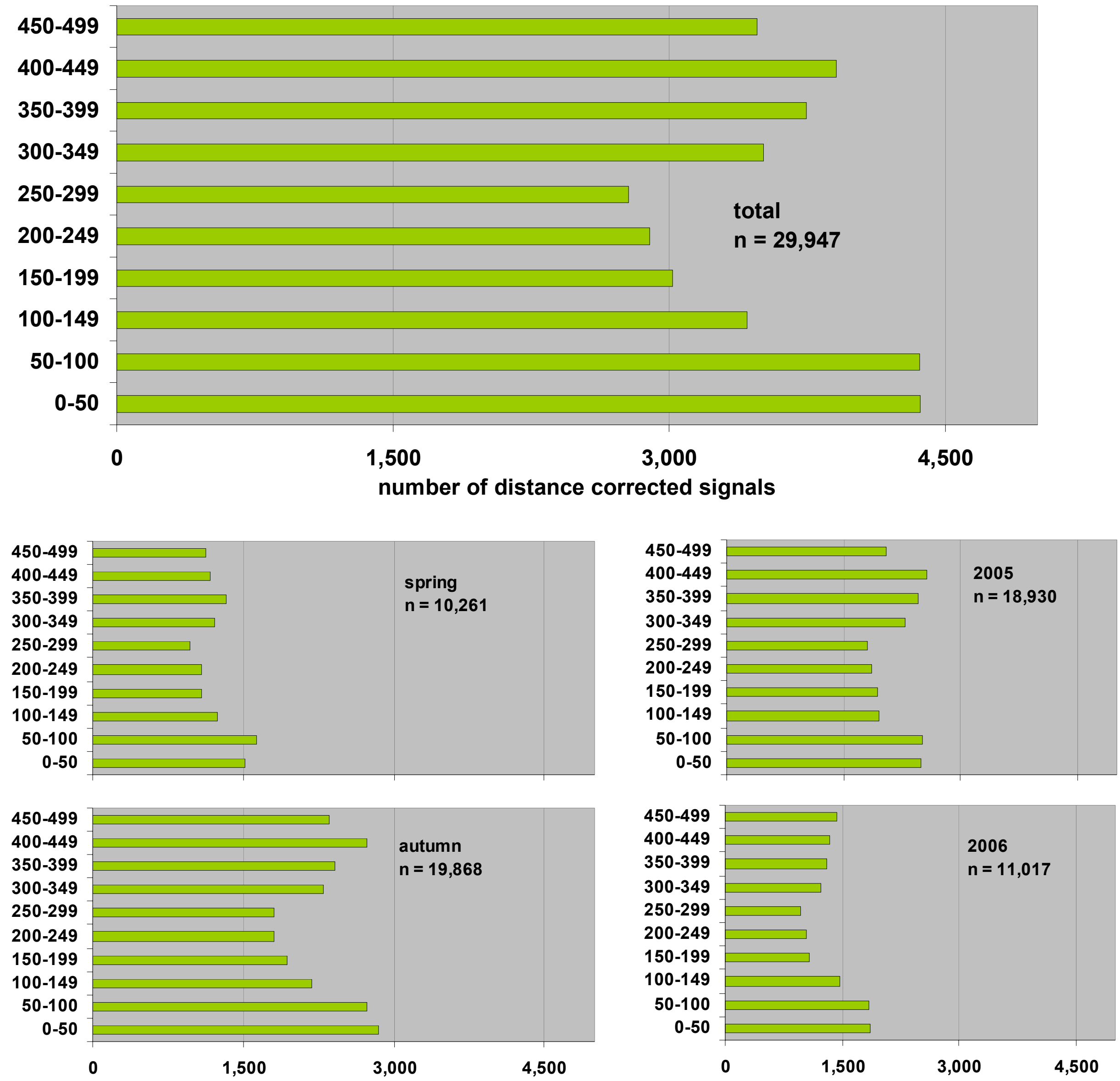


Fig. 2.28: Nysted: summaries of altitude distributions (number of distance corrected signals per altitude band, n for uncorrected signals), range 500 m. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

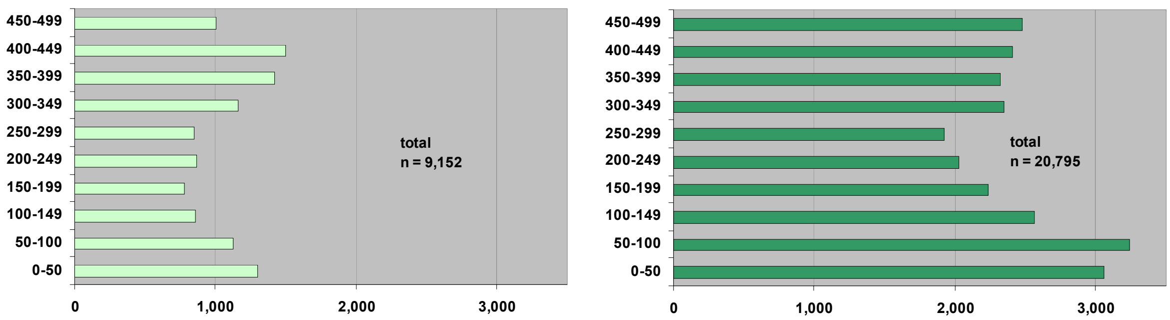


Fig. 2.29: Nysted – daytime (left) and nighttime (right): summaries of altitude distributions (number of distance corrected signals per altitude band, n for uncorrected signals), range 500 m. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

Nysted – 1500 m

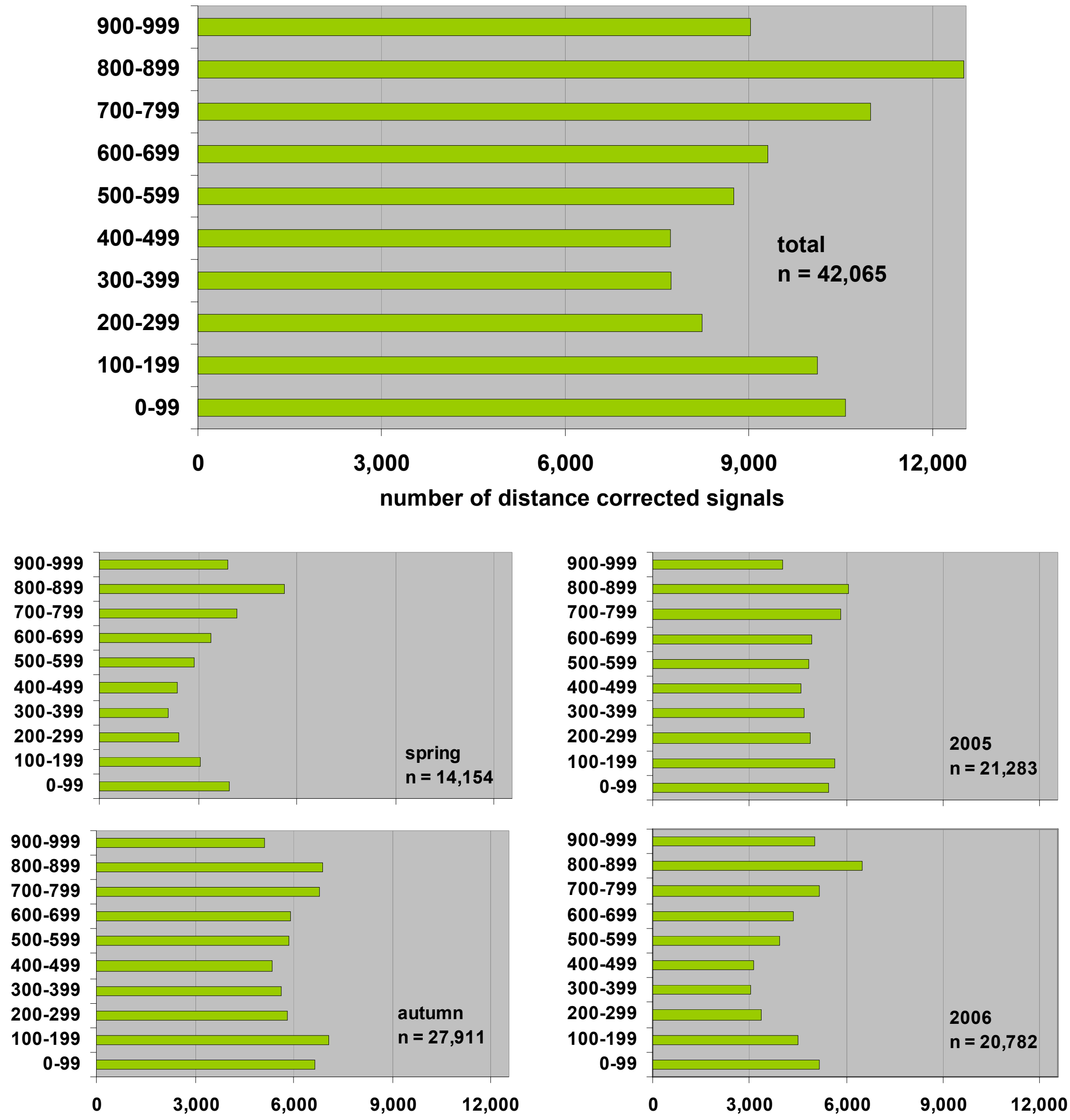


Fig. 2.30: Nysted: summaries of altitude distributions (number of distance corrected signals per altitude band, n for uncorrected signals), range 1500 m. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

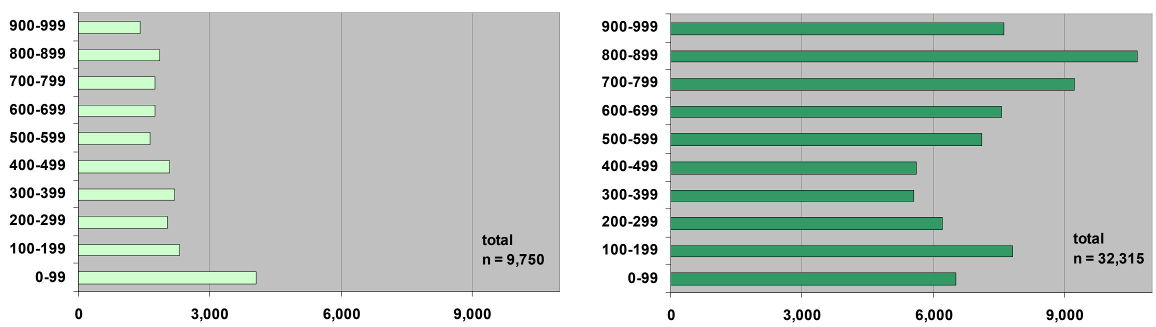


Fig. 2.31: Nysted – daytime (left) and nighttime (right): summaries of altitude distributions (number of distance corrected signals per altitude band, n for uncorrected signals), range 1500 m. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

2.2.1.4. Altitude distributions: Detailed analyses

To further describe altitude distributions as well as potential differences between inside and outside the wind farms, data are separated for seasons, for day- and nighttime and for periods with intensive and less intensive migration (for details see chapter 2.1.3).

The **500 m range** results help to describe differences in the lower altitude classes with regard to in- and outside the wind farm. The figures for the **1500 m range** are used to describe migration intensity as well as altitude distributions in general.

For all figures, the x-axes are scaled evenly within each season, to make comparisons easier. Data are presented as proportions [in%], i. e. not the number of signals, but the proportion of each altitude band in- or outside the wind farm with regard to the entire figure is given.

Horns Rev

In spring 2005, only few days of radar data were available (see chapters 2.1.2 and 2.1.3.3), allowing no representative results to be analysed.

For autumn 2005 (Fig. 2.32 and Fig. 2.33), considerably more signals exist for the nighttime than for the daytime data. For the 500 m range during night, an even distribution exists for all nights. During daytime, during intensive migration days, an avoidance of the wind farm area can only be seen for the lowest altitude category < 50 m. During periods with less migration, altitude distribution is biased towards the lower categories, and a tendency to avoid the wind farm area during daytime can be depicted for all three altitude classes < 150 m.

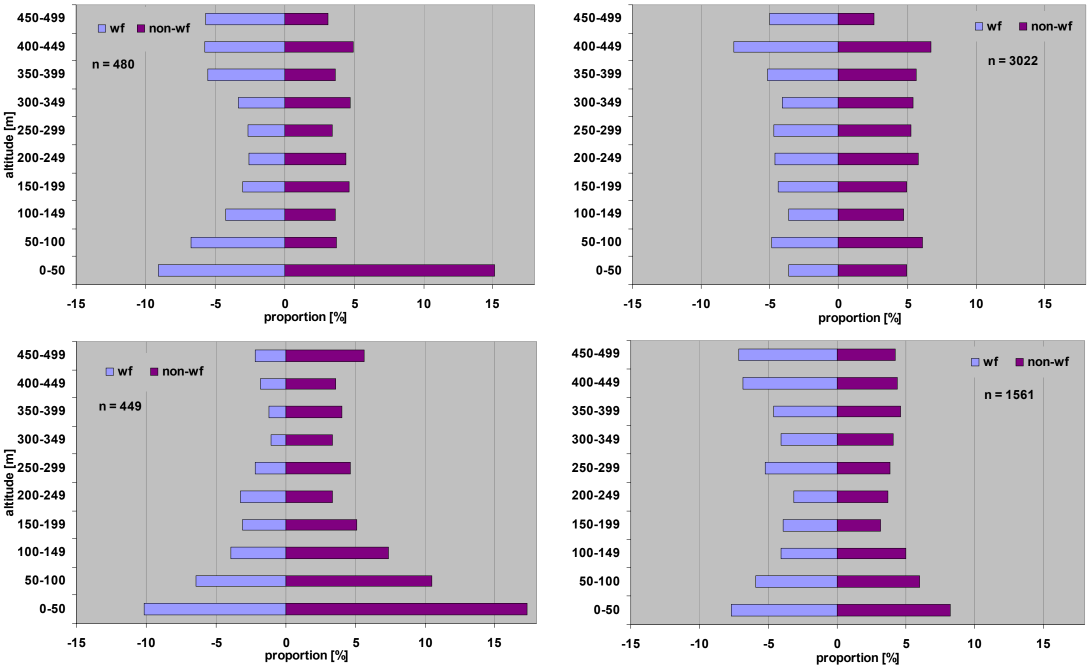


Fig. 2.32: Horns Rev – autumn 2005, altitude distribution inside (wf) and outside (non-wf), range 500 m. Top figures high, bottom low migration intensity. Left figures daytime, right nighttime.

For the 1500 m range, during days and especially nights of intensive migration, more signals are registered in the higher altitudes, suggesting migrating birds – most likely passerines - at those heights. During periods of less intensive migration, more daytime signals are found in the lower altitudes and nighttime data are more evenly distributed with some concentration still at 600-900 m.

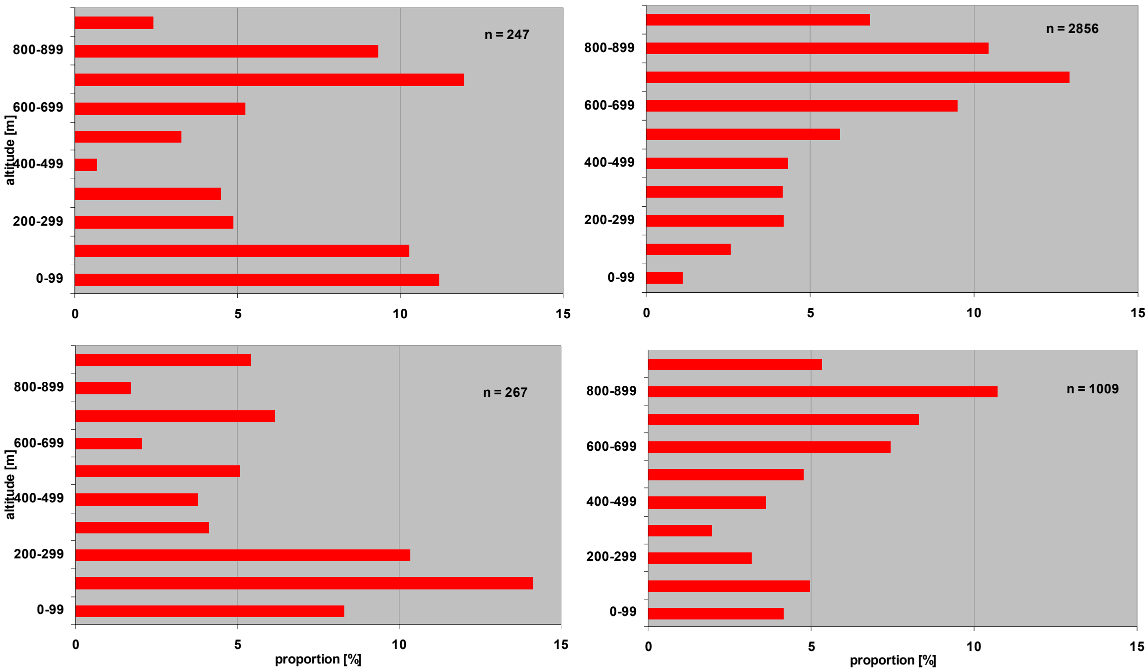


Fig. 2.33: Horns Rev – autumn 2005, altitude distribution of signals, range 1500 m. Top figures high, bottom low migration intensity. Left figures daytime, right nighttime.

For spring 2006 (Fig. 2.34 and Fig. 2.35), signal intensity is low throughout, differences between day- and nighttime are small, and differences between days with higher and lower migration intensity are also small. This suggests, that at Horns Rev, North Sea in spring 2006, there is only low migration intensity and there are no peak migration events expressed as high migration intensity during nighttime. Clearly, resident birds are found in the lower altitude categories in most occasions, showing some avoidance in the sample daytime during less intensive migration. An exception is the nighttime sample of 1500 m range for periods with higher migration, where the altitude distribution is more even.

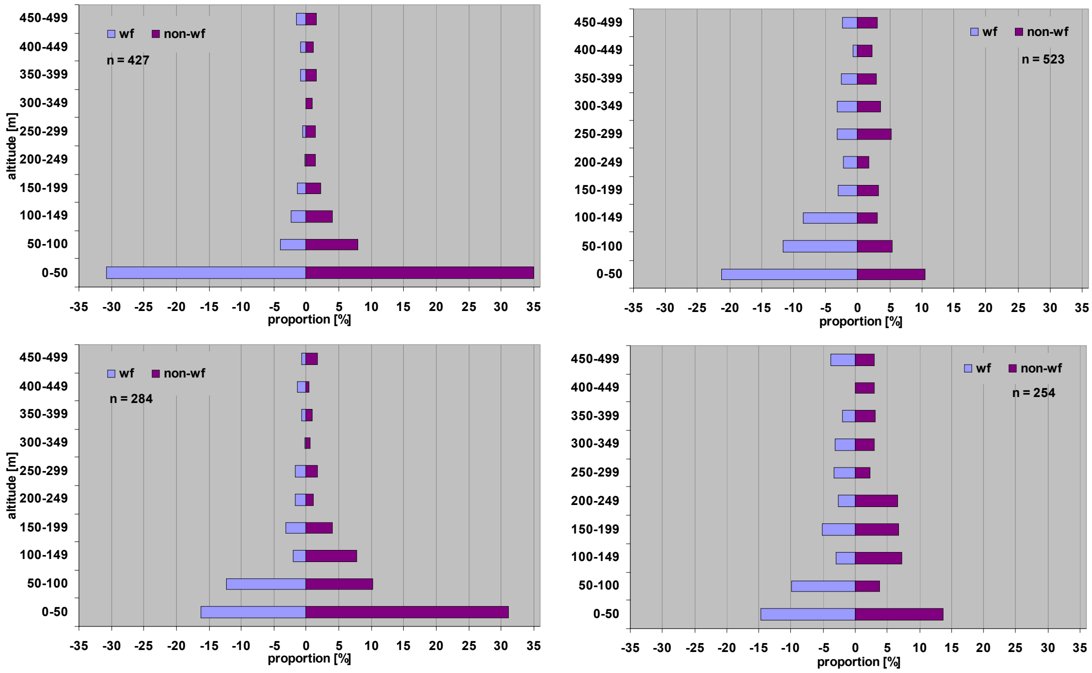


Fig. 2.34: Horns Rev – spring 2006, altitude distribution inside (wf) and outside (non-wf), range 500 m. Top figures high, bottom low migration intensity. Left figures daytime, right nighttime.

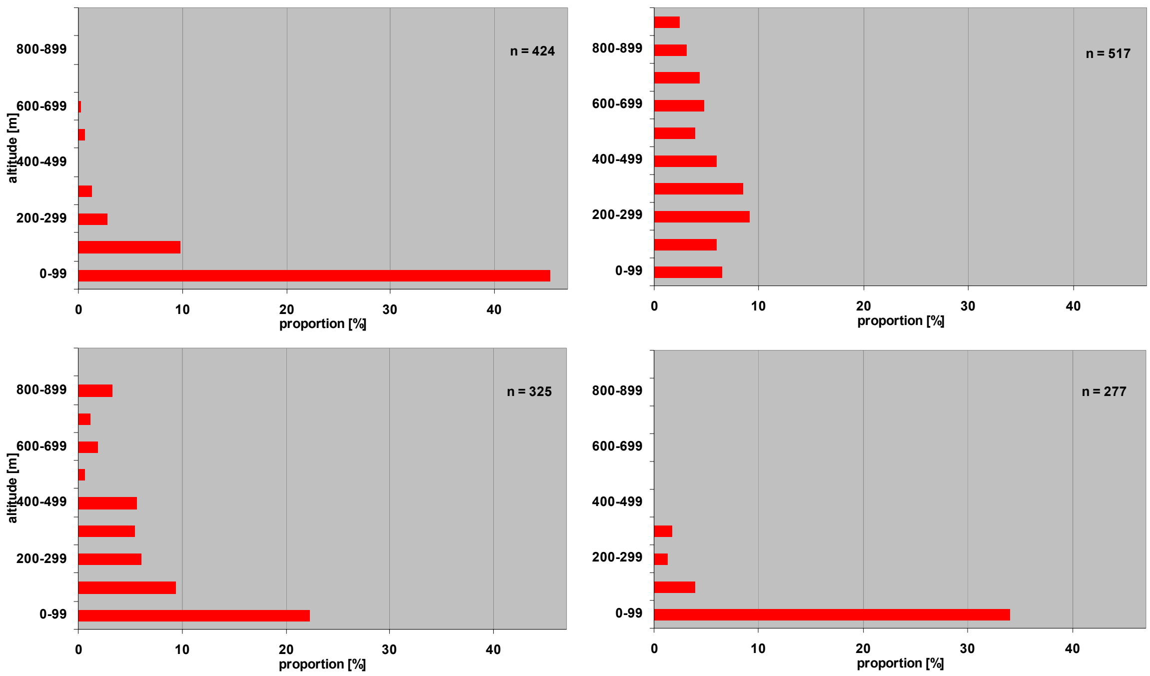


Fig. 2.35: Horns Rev – spring 2006, altitude distribution of signals, range 1500 m. Top figures high, bottom low migration intensity. Left figures daytime, right nighttime.

In Horns Rev in autumn 2006 (Fig. 2.36 and Fig. 2.37), patterns can be compared to autumn 2005, but are not as clear, potentially owing to an overall lower migration intensity. During daytime and high migration intensity, the 500 m range results show an avoidance of the wind farm area in the lowest altitude class. During low migration, only few data exist, which seem to show a preference for the wind farm area at the lowest altitudes.

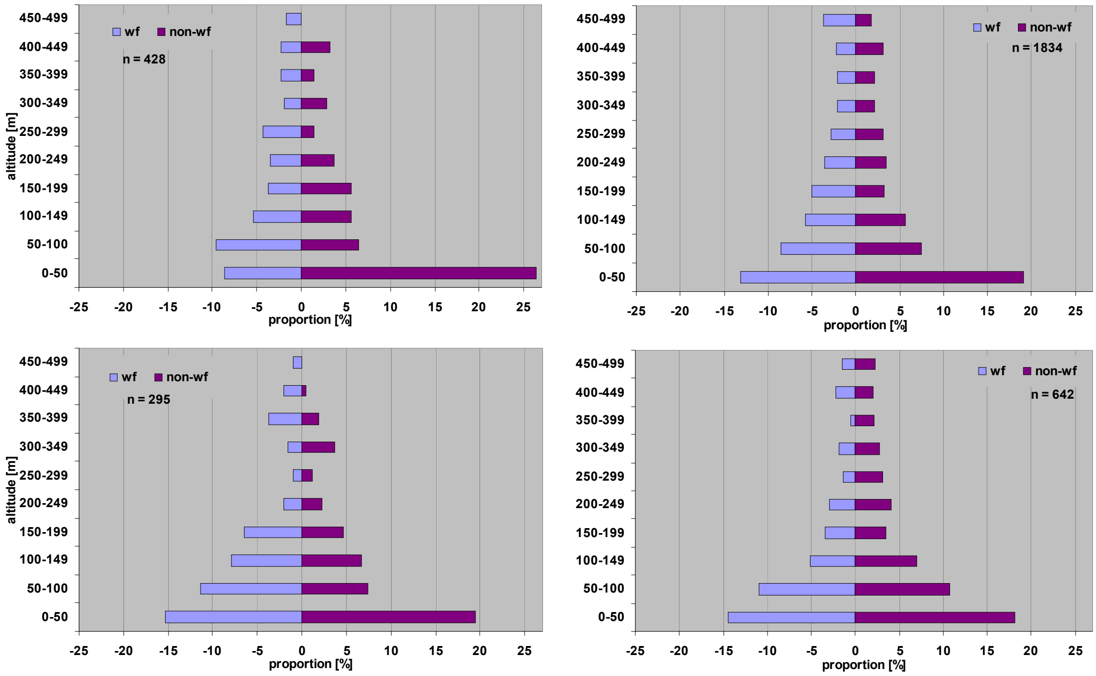


Fig. 2.36: Horns Rev – autumn 2006, altitude distribution inside (wf) and outside (non-wf), range 500 m. Top figures high, bottom low migration intensity. Left figures daytime, right nighttime.

Migration intensity during nighttime is considerably higher than during daytime, particularly during periods with a higher migration intensity, suggesting that at least some peak migration events have been covered during the observation periods. However, the altitude distributions are clearly biased towards the lower categories at both ranges.

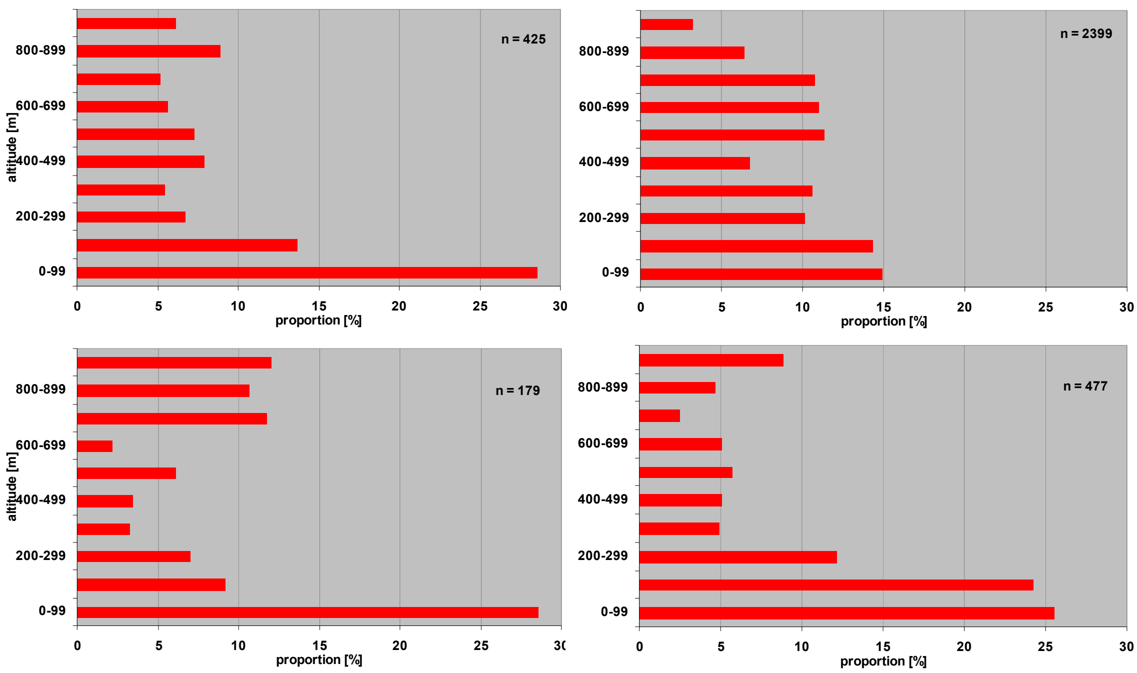


Fig. 2.37: Horns Rev – autumn 2006, altitude distribution of signals, range 1500 m. Top figures high, bottom low migration intensity. Left figures daytime, right nighttime.

Nysted

In Nysted, in spring 2005, some 80% of the signals have been registered during those five days with intensive migration. For the 500 m range, during daytime, altitude distribution is skewed towards the higher altitudes during intensive and towards the lower altitudes during less intensive migration. An avoidance of the wind farm area cannot be stated. During nighttime, only a slight upward shift in the altitude distribution pattern is visible during periods with high migration intensities.

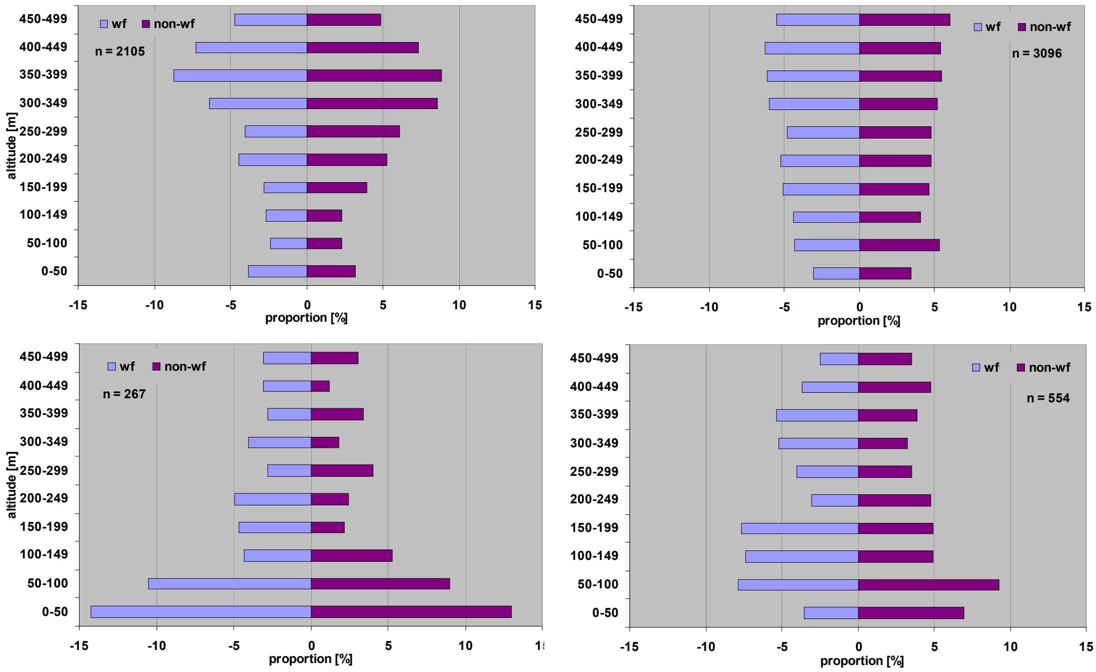


Fig. 2.38: Nysted – spring 2005, altitude distribution inside (wf) and outside (non-wf), range 500 m. Top figures high, bottom low migration intensity. Left figures daytime, right nighttime.

For the 1500 m range, during nighttime and intensive migration, a shift towards higher altitudes is apparent and a “migration band” at 600-900 m can be registered. At daytime, a clear preference for the lower altitudes can be seen during low intensity migration, while altitude distributions > 100 m show only weak patterns.

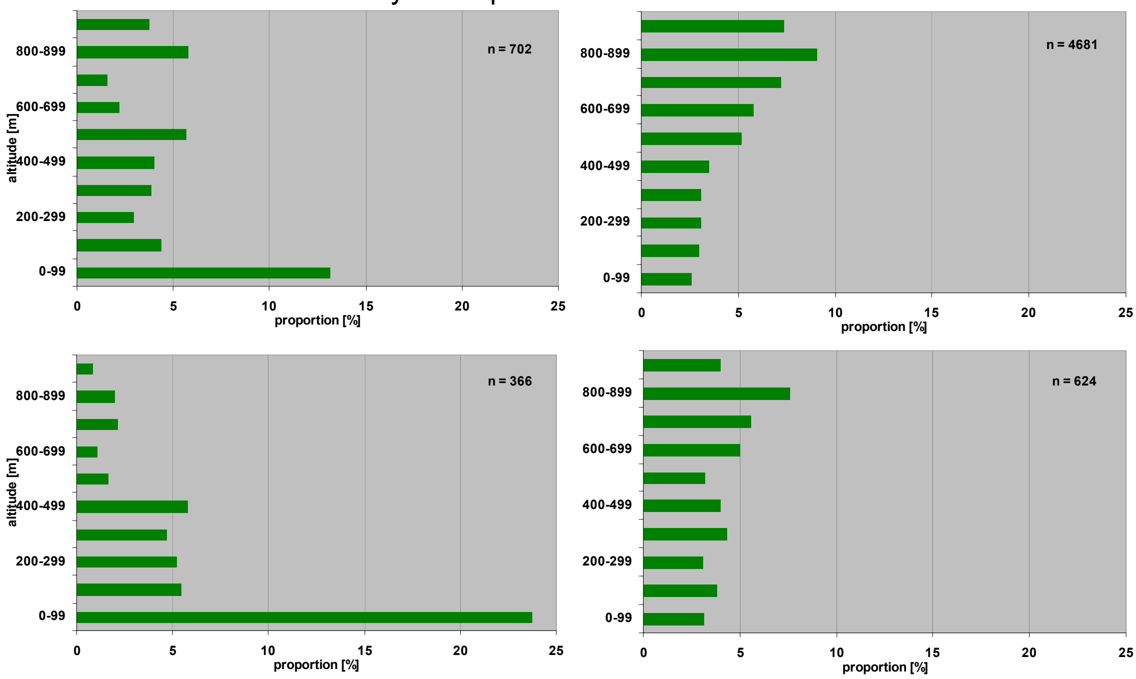


Fig. 2.39: Nysted – spring 2005, altitude distribution of signals, range 1500 m. Top figures high, bottom low migration intensity. Left figures daytime, right nighttime.

In Nysted, in autumn 2005, patterns of intensive migration exist, but are less clear, as there are many signals also during the “less intensive” periods (Fig. 2.40 and Fig. 2.41). During daytime at 500 m range, a preferred altitude of 300-450 m can be seen for the periods with intensive migration, but during nighttime differences in altitude distribution between intensive and less intensive migration periods are not apparent. In all periods an avoidance of the wind farm area in the low altitudes shows up.

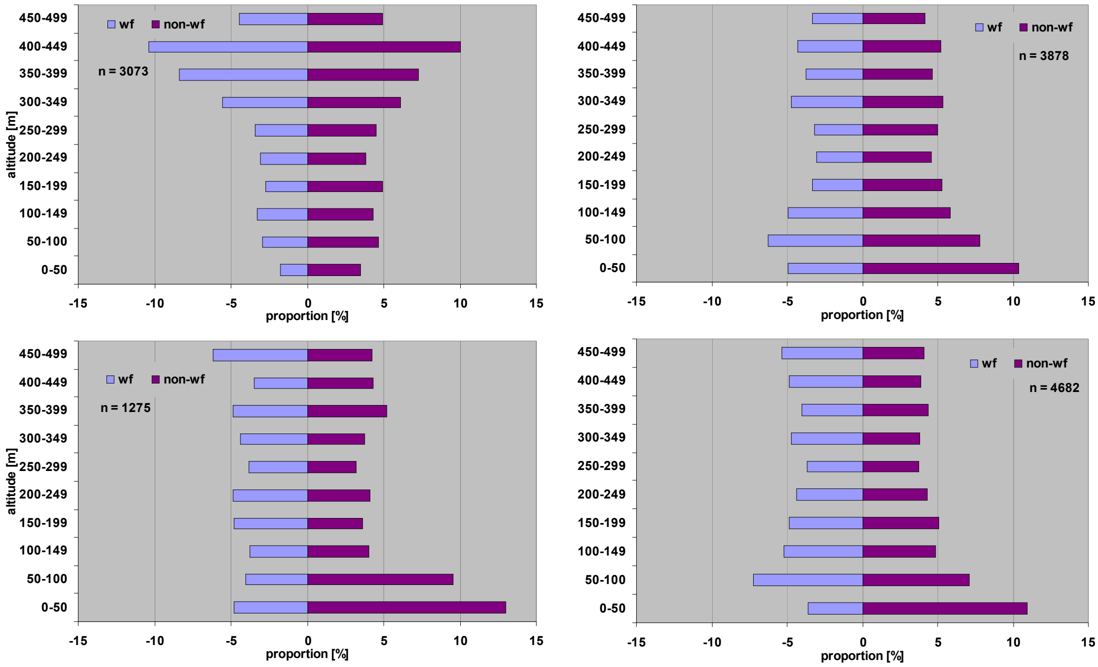


Fig. 2.40: Nysted – autumn 2005, altitude distribution of signals, range 500 m. Top figures high, bottom low migration intensity. Left figures daytime, right nighttime.

Altitude distribution during nighttime weakly depend on migration intensity. During periods of intense migration, a preference of altitudes above 500 m shows up during nighttime; during daytime, however, a preference of the altitude band 300-500 m can be registered.

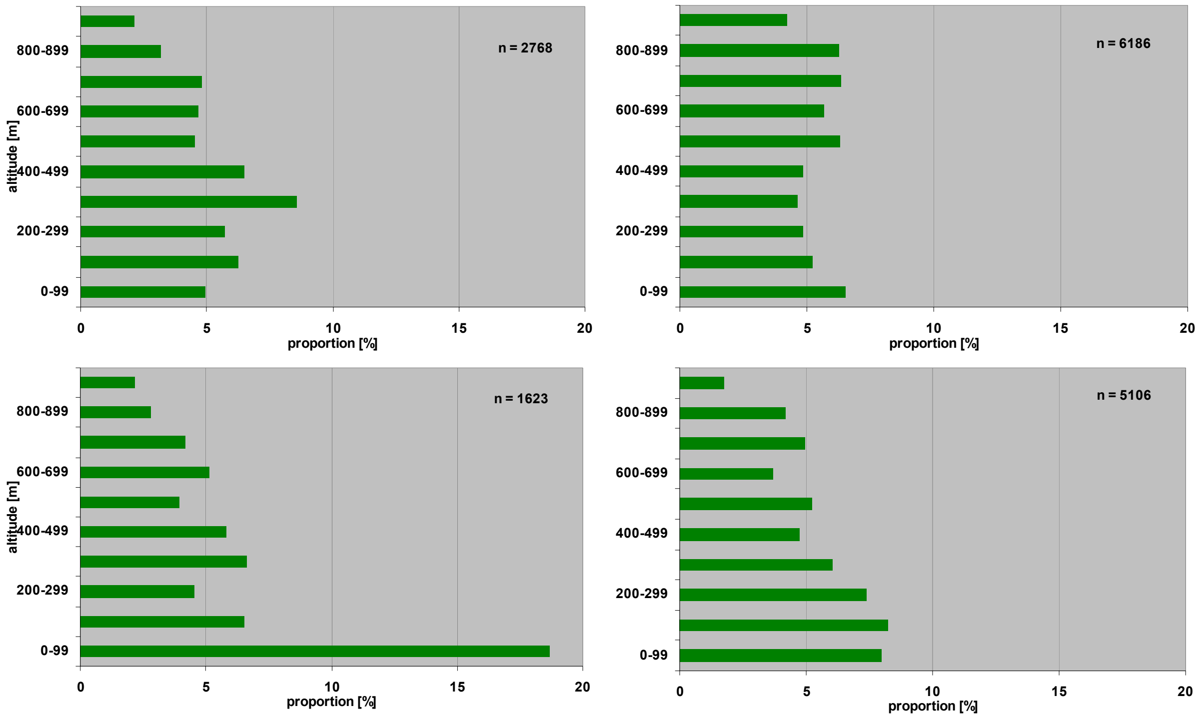


Fig. 2.41: Nysted – autumn 2005, altitude distribution of signals, range 1500 m. Top figures high, bottom low migration intensity. Left figures daytime, right nighttime.

In Nysted, in spring 2006, results of the 500 m range show only small differences between the periods of high and low migration intensity (Fig. 2.42 and Fig. 2.43). Also, differences between day- and nighttime are hardly visible, even though considerably more signals had been recorded during nighttime.

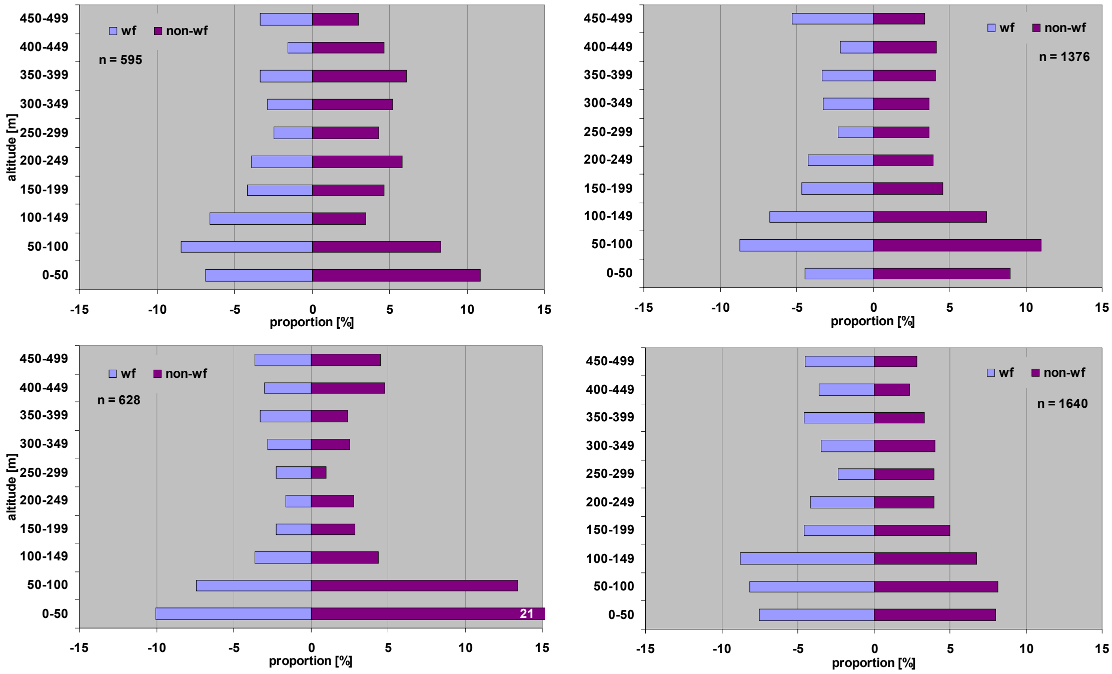


Fig. 2.42: Nysted – spring 2006, altitude distribution inside (wf) and outside (non-wf), range 500 m. Top figures high, bottom low migration intensity. Left figures daytime, right nighttime.

The results of the 1500 m range, however, show a clear preference for the higher altitudes during periods of intensive migration, in particular during nighttime. During periods of low migration and particularly during daytime, signals in low altitudes are dominating, as in the 500 m range.

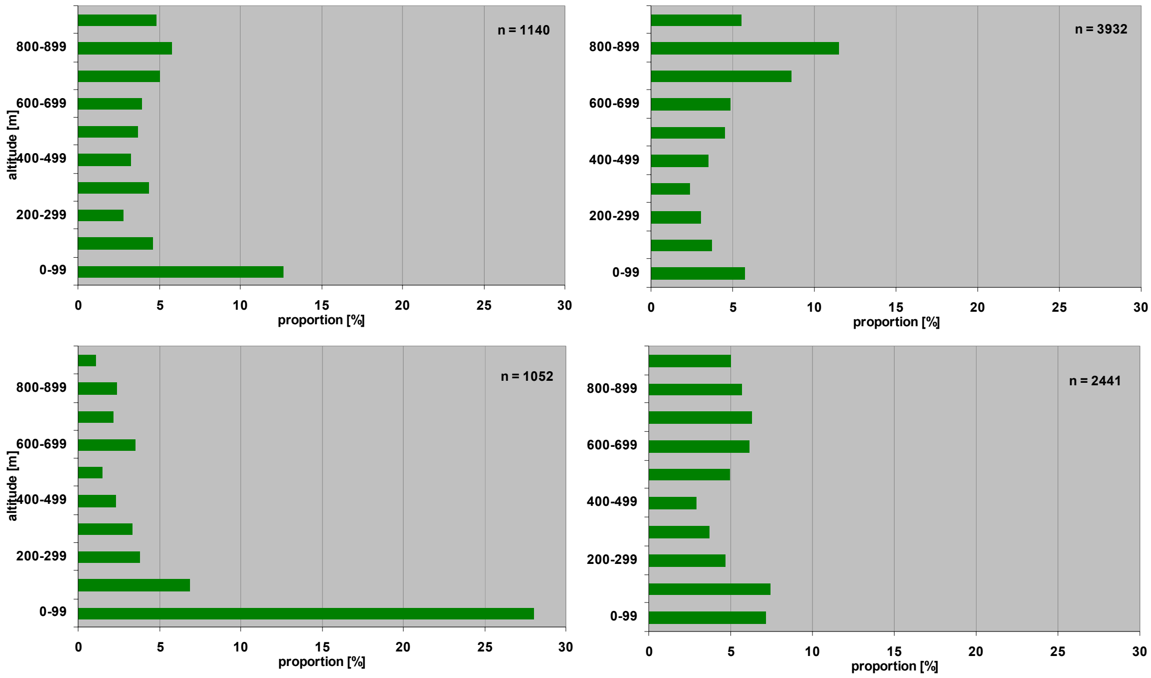


Fig. 2.43: Nysted – spring 2006, altitude distribution of signals, range 1500 m. Top figures high, bottom low migration intensity. Left figures daytime, right nighttime. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

In Nysted, during autumn 2006, patterns of mass migration events can be seen (Fig. 2.44 and Fig. 2.45). During the periods of intensive migration, high numbers of signals exist during nighttime. The 500 m range results indicate a bias for the higher altitudes during intensive migration both day and night, and during day and less intensive migration, the low altitudes are preferred. All periods show a slight avoidance of the wind farm area at the 500 m range in the lower altitude bands.

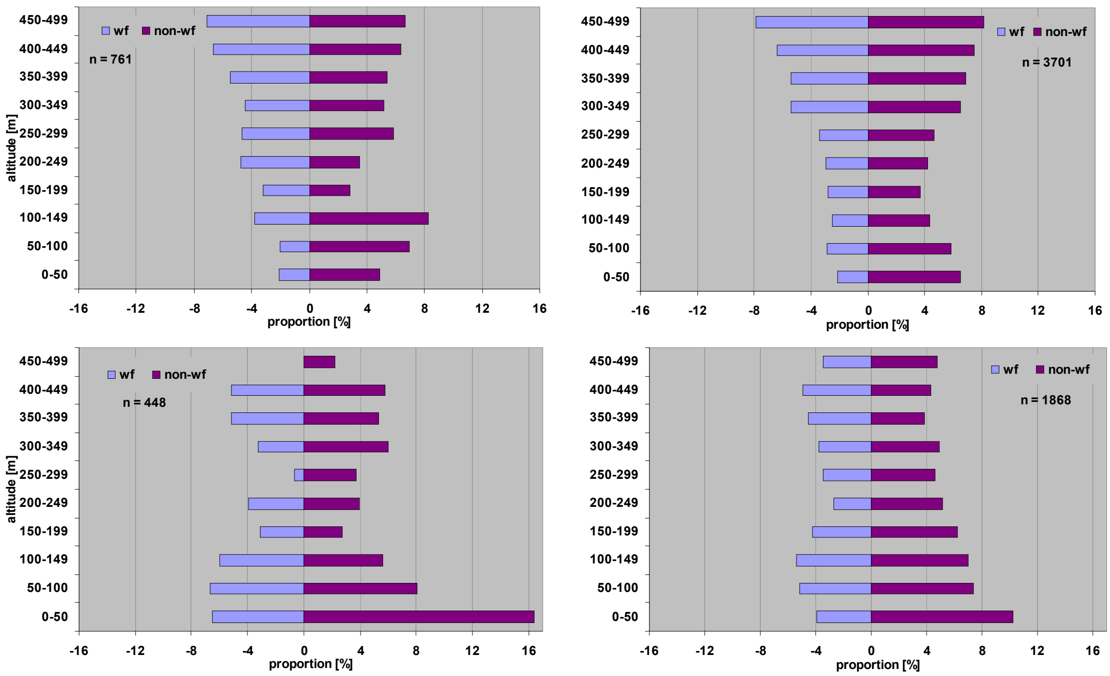


Fig. 2.44: Nysted – autumn 2006, altitude distribution inside (wf) and outside (non-wf), range 500 m. Top figures high, bottom low migration intensity. Left figures daytime, right nighttime.

The 1500 m range during intensive migration shows a large proportion of signals above 600 m day and night, while during less intensive migration, the lower altitudes are preferred.

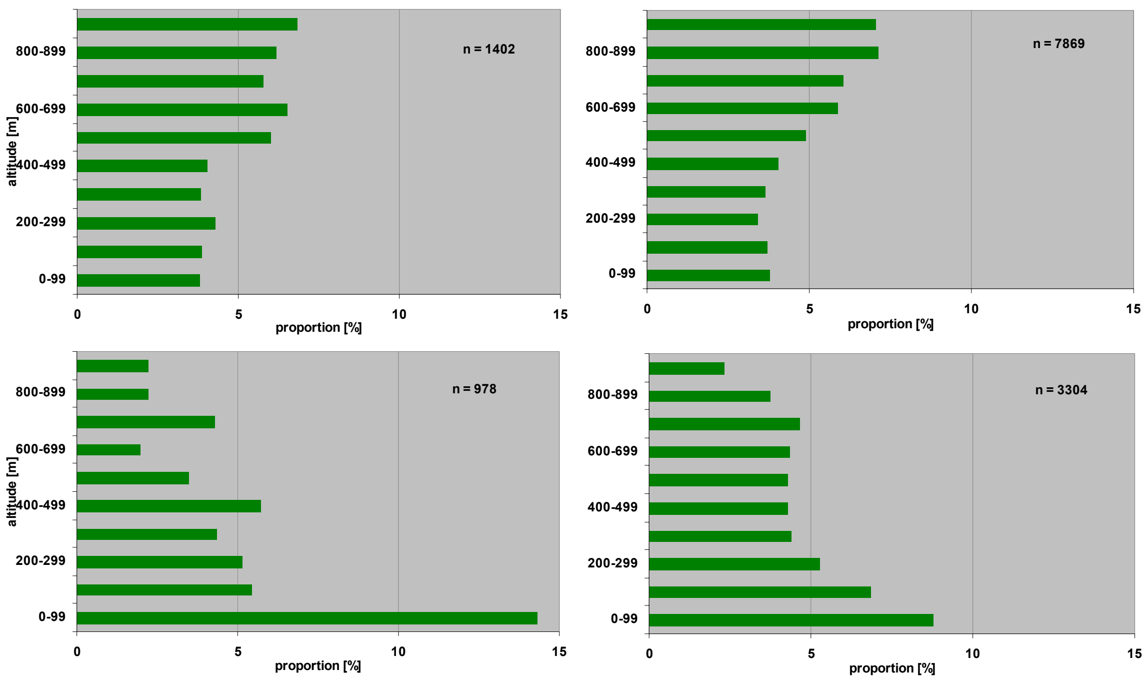


Fig. 2.45: Nysted – autumn 2006, altitude distribution of signals, range 1500 m. Top figures high, bottom low migration intensity. Left figures daytime, right nighttime.

Summary: Differences between inside and outside wind farms

The detailed altitude distributions separated for wind farms, seasons, day and night and for periods of high and low migration intensity show a tendency that at lower altitudes an avoidance of the wind farm does occur preferably during daytime (daytime active birds like ducks, cormorant, gulls and terns) and often during time of low migration intensity, thus during periods when resident numbers of birds like gulls and cormorants dominate the species distribution.

With regard to **avoidance** as indirectly registered from altitude distributions, the vertical dividing line for potential collision risk is 200m, meaning that birds flying below 200 m are at risk with regard because they are considered to be close to the wind turbines, while birds flying above 200 m are not at risk; 200 m was also chosen to allow for some "blur" / inaccuracies with regard to the radar measurements, caused by disturbance or ship movements (see chapter 2.1.3.2). To summarize results of the more detailed altitude distributions (see above), signals below 200 m are used to look at their proportions inside (in red) and outside (in pink) the wind farm, separated for seasons, night- and daytime and periods of low and high migration (Fig. 2.46, Fig. 2.47). To account for "areas directly hidden by the turbines", we added 5.4% to the sum of signals on the wind farm side (see Tab. 2.18 in chapter 2.3.1.5). It must be noted that no information from the vertical radar is available whether birds fly towards a wind turbine or between rows.

In 10 out of 28 situations, the differences in the proportions of signals < 200 m inside compared to outside are very small, and represent more or less 50% on either side. Apparently more signals are registered outside the wind farms in 15 out of 28 combinations, while in only 3 occasions more signals are registered inside the wind farm. As differences are this small, no clear patterns appear in the data. There is a slight tendency, that at daytime, more signals are registered outside the wind farm. Most other combinations do not suggest conclusive results. For instance, nighttime periods of mass migration occurred at Horns Rev during autumn 2005, at Nysted during all seasons; while at Horns Rev less signals are registered outside in periods of intensive migration compared to those of low migration (compare left to right bars in the respective seasons), the opposite is true for the data from Nysted.

Consequently, the tendencies described above might apply for certain combinations of factors when e.g. day active birds prevail. However, it is questionable whether the overall weak differences in the pooled data are true results of avoidance. The high variability of the data seems to override minor differences; in addition, potential artefacts owing to method limitations exist (see discussion in chapters 2.3.1.5 and 2.3.2).

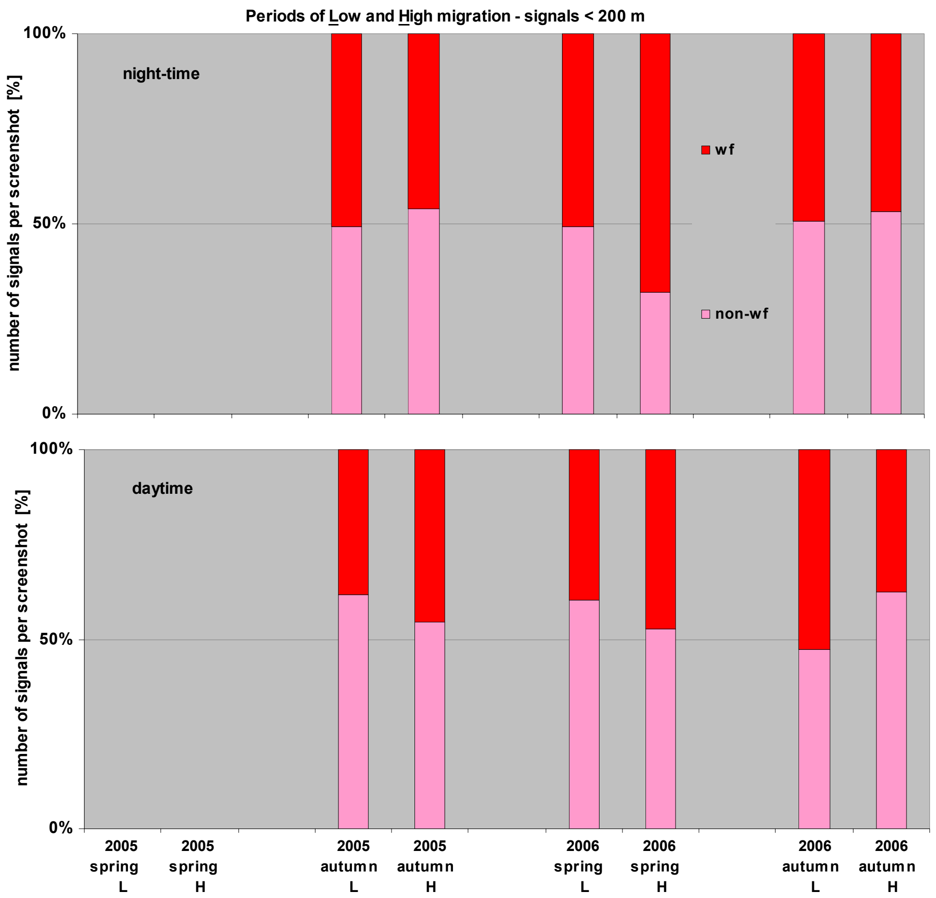


Fig. 2.46: Horns Rev – proportions of signals < 200 m inside (wf) and outside (non-wf) the wind farms for all seasons during periods of low and high migration intensity - range 500 m.

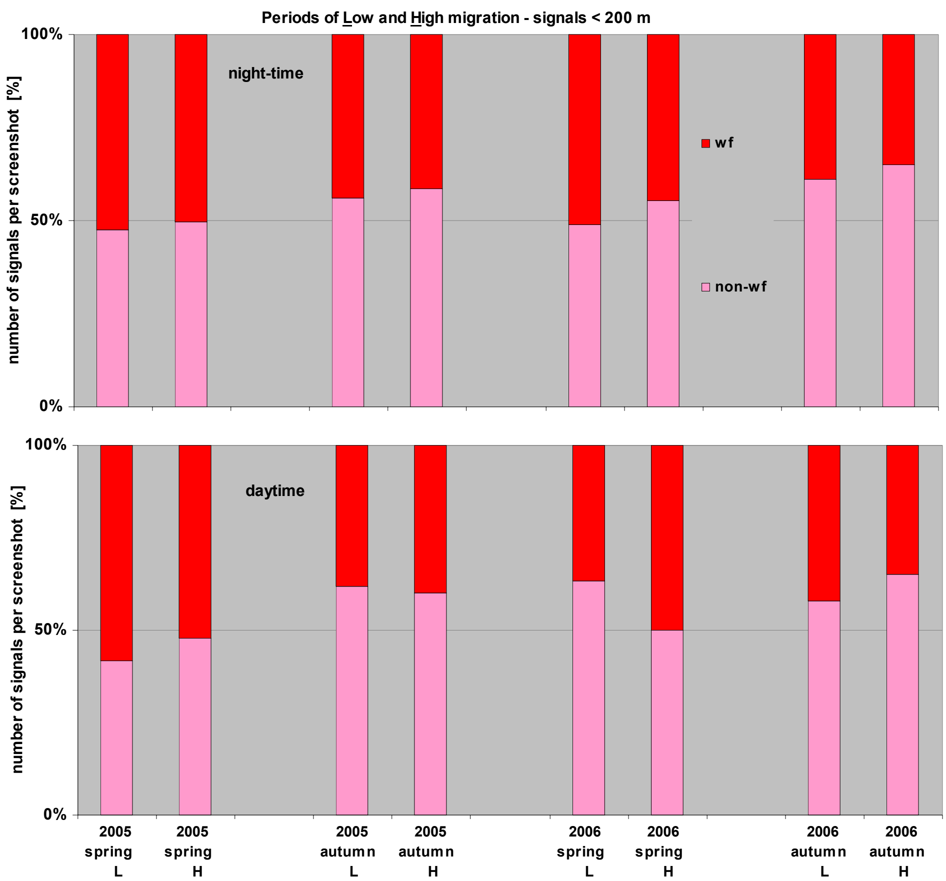


Fig. 2.47: Nysted – proportions of signals < 200 m inside (wf) and outside (non-wf) the wind farms for all seasons during periods of low and high migration intensity - range 500 m..

Summary: Altitude distributions

To summarize results of the more detailed altitude distributions (see above), data are pooled in larger altitude bands 0-200 m (wind farm influenced), 200-500 m (wind farm uninfluenced) and 500-1000 m (representing truly migrating individuals).

In general, altitude distributions show a high variability. If separated for day- and nighttime and for periods with and without intensive migration, some patterns can be registered. During the observation period mass migration events (passerine mass migration) have occurred at Nysted probably during all seasons (Fig. 2.50), but in Horns Rev only during autumn 2005 (Fig. 2.48.

For **Horns Rev**, the highest migration peak could be observed during autumn 2005, followed by autumn 2006 (Fig. 2.48). Typical for mass migration, during autumn 2005 a high number of signals is registered above 500 m; in autumn 2006 these results are not as pronounced. Daytime numbers during autumn seasons and all numbers during spring seasons (spring 2005 not considered due to lack of data) are very low and effects in the altitude distributions are not that obvious.

During autumn 2005, the season at Horns Rev with the highest migration intensity and peak, large proportions of signals are registered > 500 m and – compared to the other seasons - the smallest proportions of signals are registered below 200 m and during this season the proportions of signals below 200 m is again lower during the intensive migration periods (Fig. 2.49). Results of spring 2006 and autumn 2006, seasons with a generally lower migration intensity, are different: Overall, a higher proportion of signals are registered in the lower altitudes, yet during nighttime again, the proportions of low flying birds are lower during intensive migration periods. Daytime data show different proportional distributions and most likely represent a mixture of resident and migrating birds.

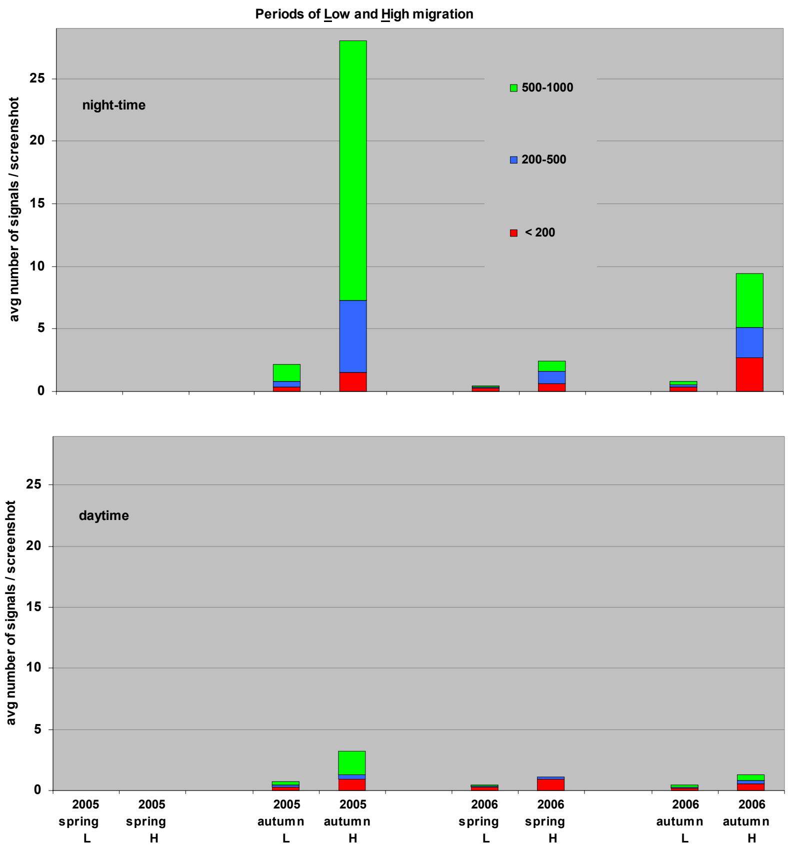


Fig. 2.48: Horns Rev – migration intensity at selected altitude bands (average number of signals per screenshot) during periods of **L**ow and **H**igh migration intensity - range 1500 m.

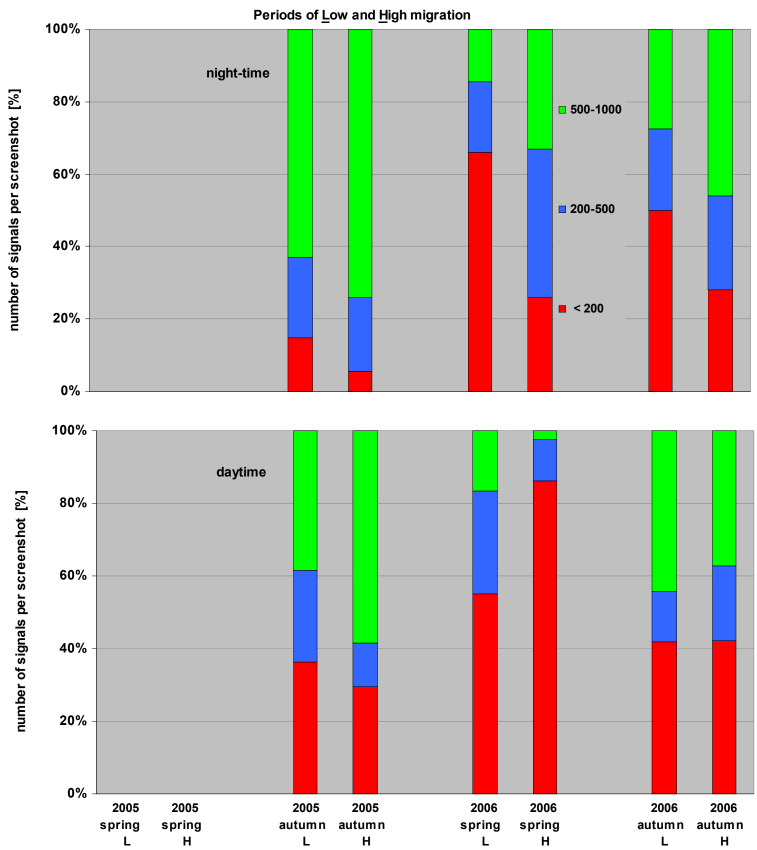


Fig. 2.49: Horns Rev – migration intensity at selected altitude bands (% of the average number of signals per screenshot) during periods of **L**ow and **H**igh migration intensity - range 1500 m.

For **Nysted**, migration peaks occurred during all seasons; thus - except for autumn 2005 nighttime – average signal numbers per screenshot are regularly higher than at Horns Rev (Fig. 2.50). Separation between the five days with intensive migration from those with less intensive migration (Fig. 2.51 - compare left with right bars per season) is clearly pronounced during night- and to a lesser extent during daytime. For all seasons at day- and nighttime, the proportion of birds migrating below 200 m decreases during periods of high migration intensity. In most cases, altitudes above 500 m are preferred during periods of intensive migration; for autumn 2005, a season with a continuous high migration, differences between periods of low and high migration intensities are not as pronounced (Fig. 2.51).

These findings show that at Nysted altitude distributions are more regular across all seasons. In contrast, results from Horns Rev are similar for the one season with migration peaks, that is autumn 2005, but less predictable in all other seasons.

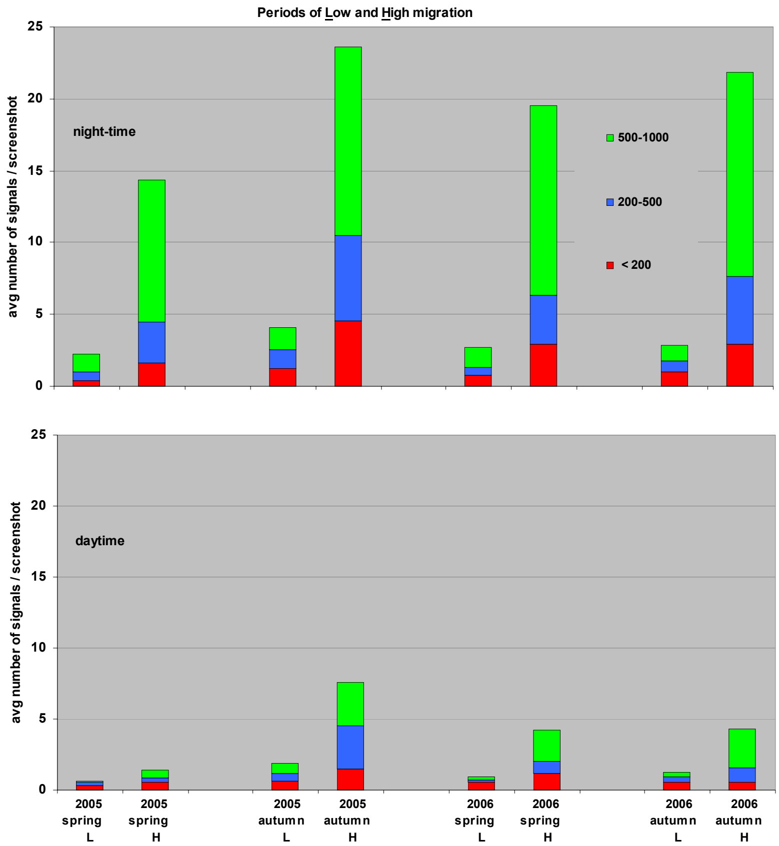


Fig. 2.50: Nysted – migration intensity at selected altitude bands (average number of signals per screenshot) during periods of Low and High migration intensity - range 1500 m.

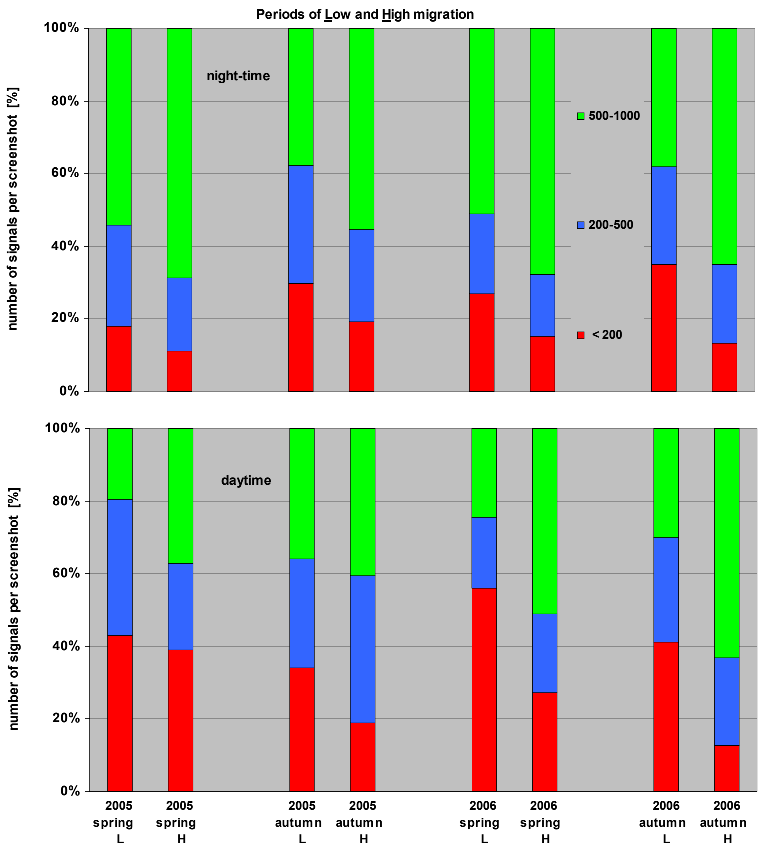


Fig. 2.51: Nysted – migration intensity at selected altitude bands (% of the average number of signals per screenshot) during periods of Low and High migration intensity - range 1500 m.

2.2.1.5. Reactions of birds to the wind farms – vertical plane

Methodological aspects

Results of manual tracking have been registered and stored into a databank just like the screenshot-signals, with the additional feature, that a track consists of a straight line or a series of connected straight lines (Fig. 2.52).

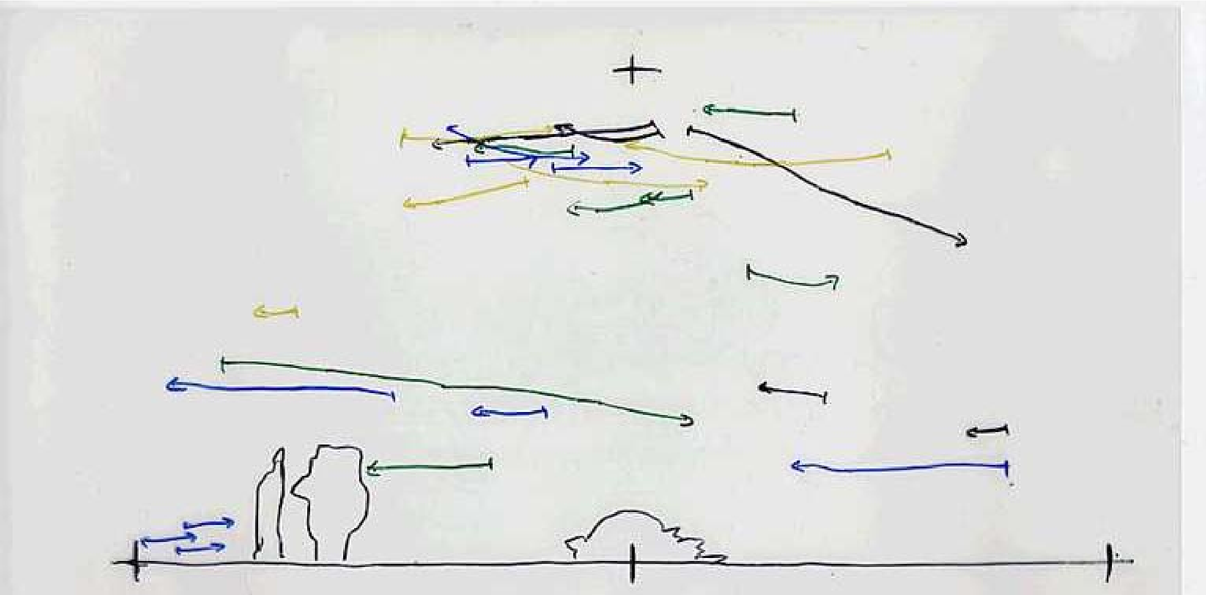


Fig. 2.52: Example of an overhead transparency with manually tracked signals / paths on the radar screen (Sep 18th, 2006, Nysted, range 500 m). Wind turbines with their associated disturbances sketched on the left side; different colours are from different observation periods; some tracks descending from left to right, most tracks with "no altitude change" (see text).

Clearly, a track on a screen produced by a vertically turned radar does not give a direct picture of a birds path; if a bird flies exactly parallel to the rotating t-bar-antenna of the radar, its track is recorded across the entire screen, however, short lateral movements would not be visible. If a bird flies at some angle to the rotating t-bar it will produce a shorter track; of this track, the lateral direction is unknown, consequently the angle of either a decrease or increase in altitude is unknown. A bird flying exactly perpendicular to the rotation plane/layer will produce only a spot signal without a track if it does not de- or increase altitude (see Fig. 2.5). However, the gross direction of the signals movement can be assessed and has been used to categorize signals moving towards or away from the wind farm. In consequence, with the current approach an increase or decrease can only be recorded as an altitude change, not as an inclination angle. An overall quality control exists, since of all radar data only situations during correct alignment of the vertical radar parallel to the expected bird migration are kept for analyses (see chapter 2.1.3). Following additional quality control measures are applied to avoid mis- or over-interpretation of the manually tracked data:

1) only tracks with an apparent "length" of > 100 m (≙ 25 mm on the radar screen) are considered. This assures, that the direction of the birds path is correctly assessed, however, it reduces the data from 21.486 tracked signals to 11.966 tracked signals;
2) an altitude change is defined by the change in altitude between the first and the last appearance of a signal on the screen, regardless whether it is a straight line or a combination of several straight lines;

3) an altitude change must be at least > 20 m (≙ 5 mm on the radar screen), otherwise it is by definition “no altitude change”.

Tracks were sorted into six categories under two top categories according to their movement with regard to the wind farm (Fig. 2.53, Tab. 2.8). As in all radar analyses, the area between the ship and the wind farm is defined as “wind farm side” (Fig. 2.12).

Under the top category of “tracks flying towards the wind farm” fall three categories:

1) “tracks outside, flying towards”;

2) “tracks crossing in” – i. e. tracks cross from the “non wind farm side” to the “wind farm side” and

3) “tracks inside, flying further in”.

Under the top category “tracks flying away from the wind farm” categories 4-6 are listed, named likewise.

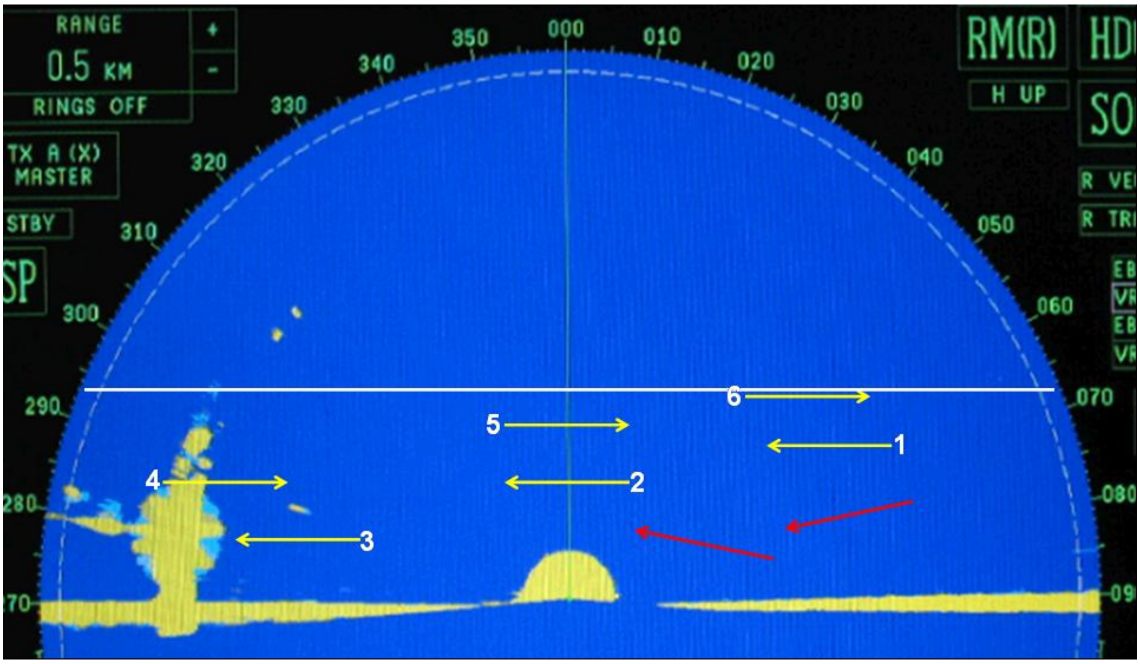


Fig. 2.53: Manually tracked signals / paths on the radar screen – range 500 m. Wind farm on the left side; numbered yellow arrows illustrating the six categories (see text and Tab. 2.8); red arrows representing minimum altitude difference of 25-30 m; white line at 200 m altitude.

Results

The majority of signals (81% below 200 m, 77% at 200-500 m) belongs to the three categories of “tracks flying towards” the wind farm. Even though the number of tracked paths is much lower during day- than during nighttime, the proportion of “tracks flying towards” is practically the same. This supports the assumption, that the observation position is correctly chosen, to register birds on their main migration route potentially entering the wind farm. However, considering tracked paths, the main flight and migration direction does not differ between day- and nighttime, opposite to the suspicion, that large numbers of gulls, cormorants and other resident (non-migrating) birds would influence this proportion.

Tab. 2.8: Manually tracked signals: results for six categories of tracks at two altitude classes (n = 11.966).

	altitude band 0-200 m		altitude band 200-500 m	
Track category	**no of signals**	**in%**	**no of signals**	**in%**
1) tracks outside, flying towards	2.744	41%	1.477	28%
2) tracks crossing in	613	9%	1.517	29%
3) tracks inside, flying further in	2.123	31%	1.027	20%
Total tracks flying towards:	**5.480**	**81%**	**4.021**	**77%**
4) tracks inside, flying out	512	8%	431	8%
5) tracks crossing out	148	2%	453	9%
6) tracks outside, flying away from	633	9%	288	6%
Total tracks flying towards:	**1.293**	**19%**	**1.172**	**23%**
Total	**6.773**		**5.193**	

Tracks of the six categories were split into three groups: 1 and 2) “ascending” and “descending”, if the altitude differences between start- and end-position is > 20 m, 3) “none”, if the altitude difference is < 20 m (Tab. 2.9). Results are separated for day- and nighttime and for signals registered below 200 m considered to be flying within an altitude affected by the wind farm (Fig. 2.54, Fig. 2.55) and those at 200-500 m considered to be above and unaffected by the wind farm (Fig. 2.56, Fig. 2.57).

Of all the tracks, the vast majority does not show any change of altitude (81% for signals < 200 m, 71% for signals at 200-500 m). Even though data are pooled across all seasons and both wind farms, the data basis for some of the figures is rather thin (n < 500).

Of the tracks at the altitude of < 200 m – considered to be affected by the wind farm - differences of altitude changes (ascend, descend) between the top categories “flying towards” (1 to 3) and “flying away from” (4 to 6) are small. However, for the categories 2 and 3, most likely to show vertical avoidance, 12% (290 of 2388) of the tracks ascend during nighttime; and only 5.6% (43 of 759) during daytime. In comparison, for the same categories, but above the wind farm at 200-500m, only 6.5% (215 or 3291) ascend during nighttime, and again 6.7% (49 of 730) during daytime. Tracks of the categories 4, 5 and 6 “flying away from”, however overall less frequent, show comparable proportions ascending (22.5%, 22.1% and 7.5% at < 200 m, 23.1%, 11.2% and 4.8% at 200-500 m). Thus, while the tracks approaching the wind farm seem to show a stronger vertical avoidance below 200 m than above 200 m, the categories “leaving or flying away from the wind farm” show overall higher proportions of “ascending” tracks, yet both, for below and above 200 m, respectively.

The proportion of descending tracks below 200 m is in all cases smaller than the proportion of ascending tracks, with the exception of signals “outside, flying away from (6)”, yet with a overall rather low numbers. The still considerable number of descending tracks can be interpreted as an attraction to the wind farm, caused possibly by the illumination.

Summary: Only small proportions of the manually tracked paths “flying towards” show vertical avoidance reactions. Those proportions are not distinctly different for the “non-affected” altitudes above 200-500 m and also not different for signals “moving away from” the wind farm. Thus, altitude changes exist for all signals moving “towards” or “away from” or “below” or “above” the wind farms, but cannot be solely attributed to signals likely to be affected (flying towards below turbine height).

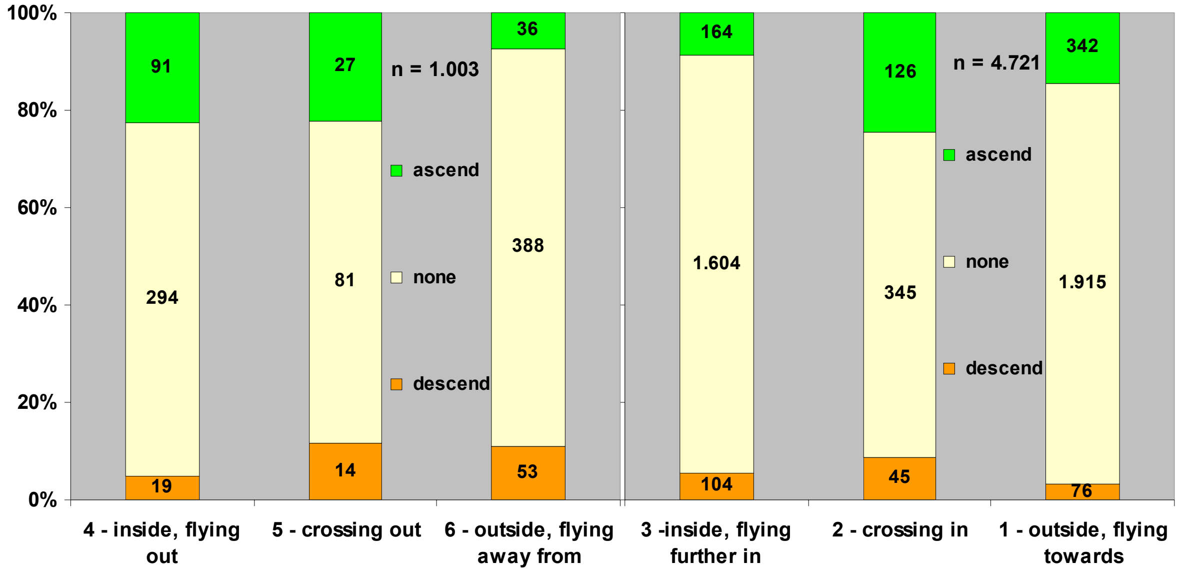


Fig. 2.54: Altitude changes of six categories of manually tracked signals; nighttime, signals < 200 m. Left: signals moving towards the wind farm, right: signals moving away from the wind farm.

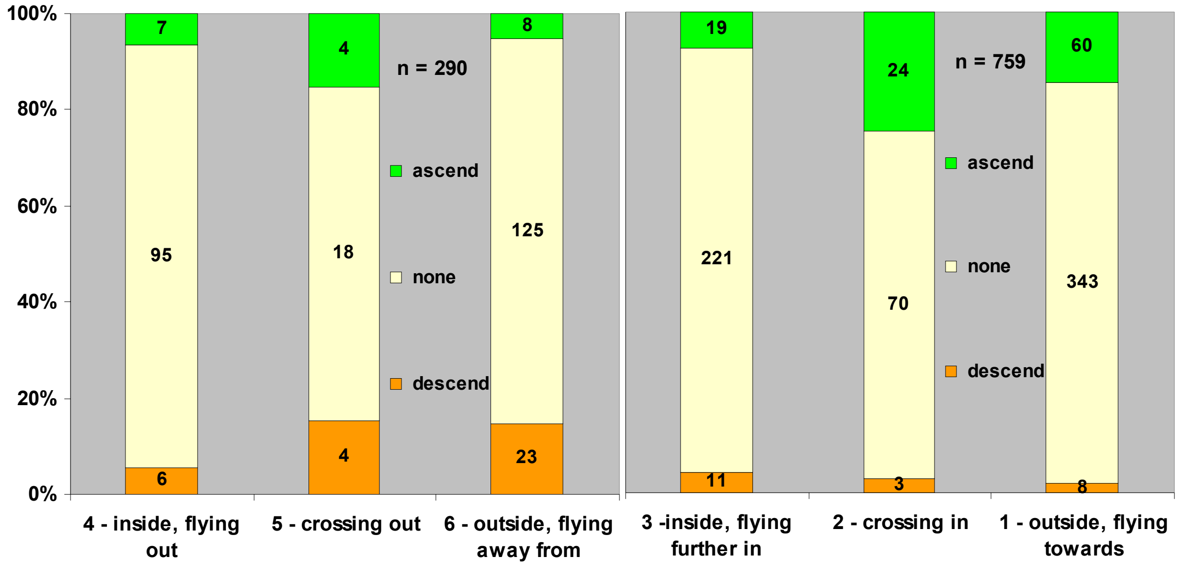


Fig. 2.55: Altitude changes of six categories of manually tracked signals. Daytime, signals below 200 m. Top figure represents signals moving towards, bottom figure signals moving away from the wind farm.

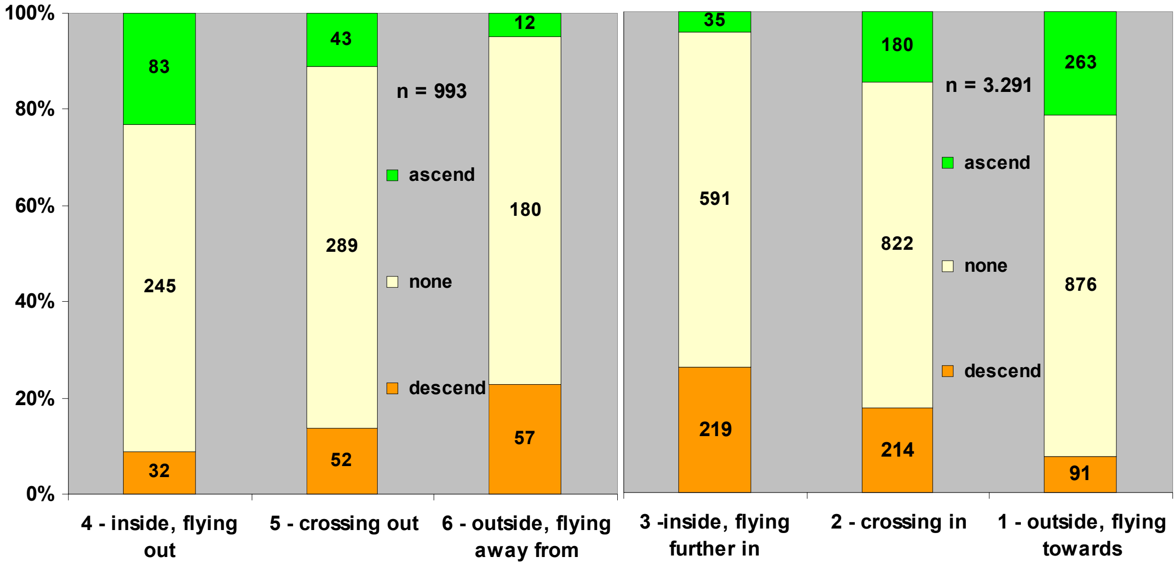


Fig. 2.56: Altitude changes of six categories of manually tracked signals. Nighttime, signals 200-500 m. Top figure represents signals moving towards, bottom figure signals moving away from the wind farm.

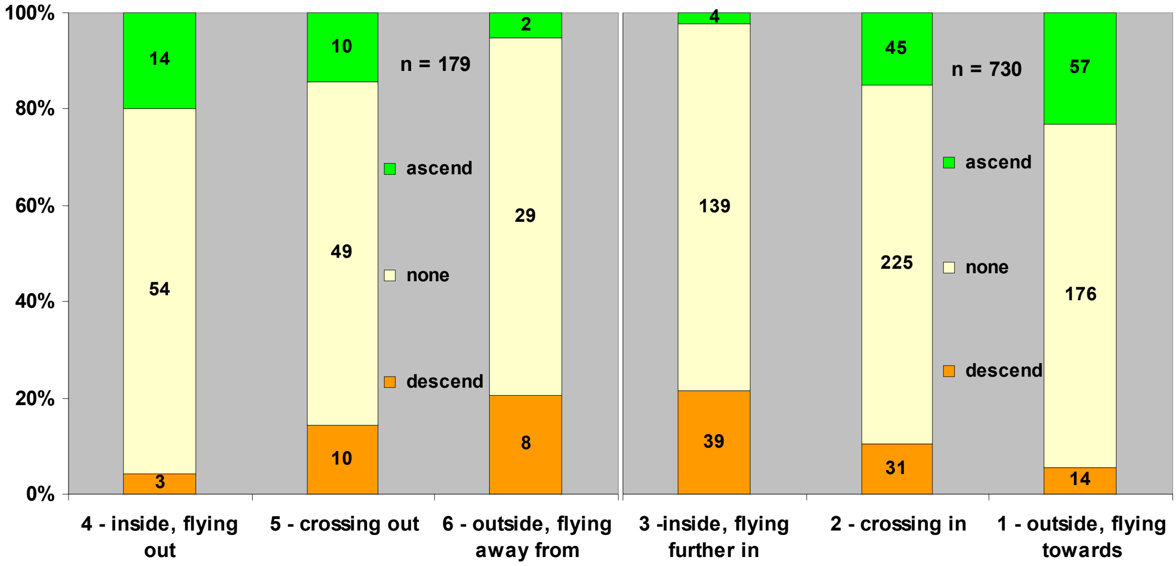


Fig. 2.57: Altitude changes of six categories of manually tracked signals. Daytime, signals 200-500 m. Top figure represents signals moving towards, bottom figure signals moving away from the wind farm.

Tab. 2.9: Altitude changes of six categories of tracked signals, separated for day- and nighttime and for altitude classes “< 200 m” and “200-500 m” (n = 11.966).

bird tracks below 200 m - nighttime - n = 5724						
	descend	ascend	none	descend	ascend	none
track category	absolute numbers			in% of category		
1) outside, flying towards	76	342	1915	3,3	14,7	82,1
2) crossing in	45	126	345	8,7	24,4	66,9
3) inside, flying further in	104	164	1604	5,6	8,8	85,7
"flying towards wind farm"	**225**	**632**	**3864**	**4,8**	**13,4**	**81,8**
4) inside, flying out	19	91	294	4,7	22,5	72,8
5) crossing out	14	27	81	11,5	22,1	66,4
6) outside, flying away from	53	36	388	11,1	7,5	81,3
"flying away from wind farm"	**86**	**154**	**763**	**8,6**	**15,4**	**76,1**
bird tracks below 200 m - day-time - n = 1049						
	descend	ascend	none	descend	ascend	none
track category	absolute numbers			in% of category		
1) outside, flying towards	8	60	343	1,9	14,6	83,5
2) crossing in	3	24	70	3,1	24,7	72,2
3) inside, flying further in	11	19	221	4,4	7,6	88,0
"flying towards wind farm"	**22**	**103**	**634**	**2,9**	**13,6**	**83,5**
4) inside, flying out	6	7	95	5,6	6,5	88,0
5) crossing out	4	4	18	15,4	15,4	69,2
6) outside, flying away from	23	8	125	14,7	5,1	80,1
"flying away from wind farm"	**33**	**19**	**238**	**11,4**	**6,6**	**82,1**
bird tracks 200-500 m - nighttime - n = 4284						
	descend	ascend	none	descend	ascend	none
track category	absolute numbers			in% of category		
1) outside, flying towards	91	263	876	7,4	21,4	71,2
2) crossing in	214	180	822	17,6	14,8	67,6
3) inside, flying further in	219	35	591	25,9	4,1	69,9
"flying towards wind farm"	**524**	**478**	**2289**	**15,9**	**14,5**	**69,6**
4) inside, flying out	32	83	245	8,9	23,1	68,1
5) crossing out	52	43	289	13,5	11,2	75,3
6) outside, flying away from	57	12	180	22,9	4,8	72,3
"flying away from wind farm"	**141**	**138**	**714**	**14,2**	**13,9**	**71,9**
bird tracks 200-500 m - day-time - n = 909						
	descend	ascend	none	descend	ascend	none
track category	absolute numbers			in% of category		
1) outside, flying towards	14	57	176	5,7	23,1	71,3
2) crossing in	31	45	225	10,3	15,0	74,8
3) inside, flying further in	39	4	139	21,4	2,2	76,4
"flying towards wind farm"	**84**	**106**	**540**	**11,5**	**14,5**	**74,0**
4) inside, flying out	3	14	54	4,2	19,7	76,1
5) crossing out	10	10	49	14,5	14,5	71,0
6) outside, flying away from	8	2	29	20,5	5,1	74,4
"flying away from wind farm"	**21**	**26**	**132**	**11,7**	**14,5**	**73,7**

2.2.2. Radar observations – horizontally rotating radar

Migration intensity and / or flux rates are not given for the horizontal radar results, since only a selection of some 5-8% of the observation periods was available (Chapter 2.1.3), strongly biased towards dry and calm weather.

2.2.2.1. Number and direction of tracks

Since no effort was made to manually track signals, the potential track lengths of the signals are a function of flight speed, rotation speed of the antenna (24 rpm) and visibility of trails on the radar screen.

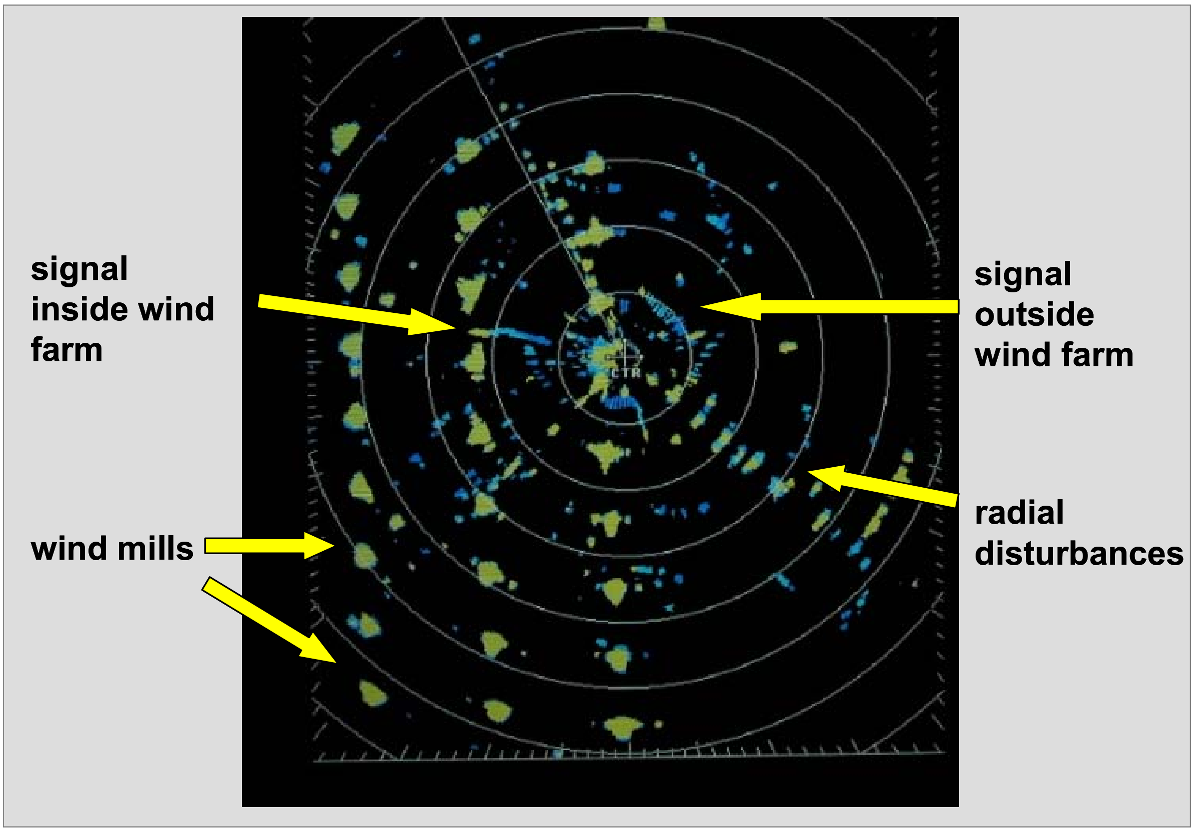


Fig. 2.58: Example of horizontal radar screenshot (Nysted, 3. November 2006).

More screenshots were available for analysis from Nysted in the Baltic Sea and considerably more screenshots could be sampled during daytime than during nighttime (Fig. 2.59 and Tab. 2.10).

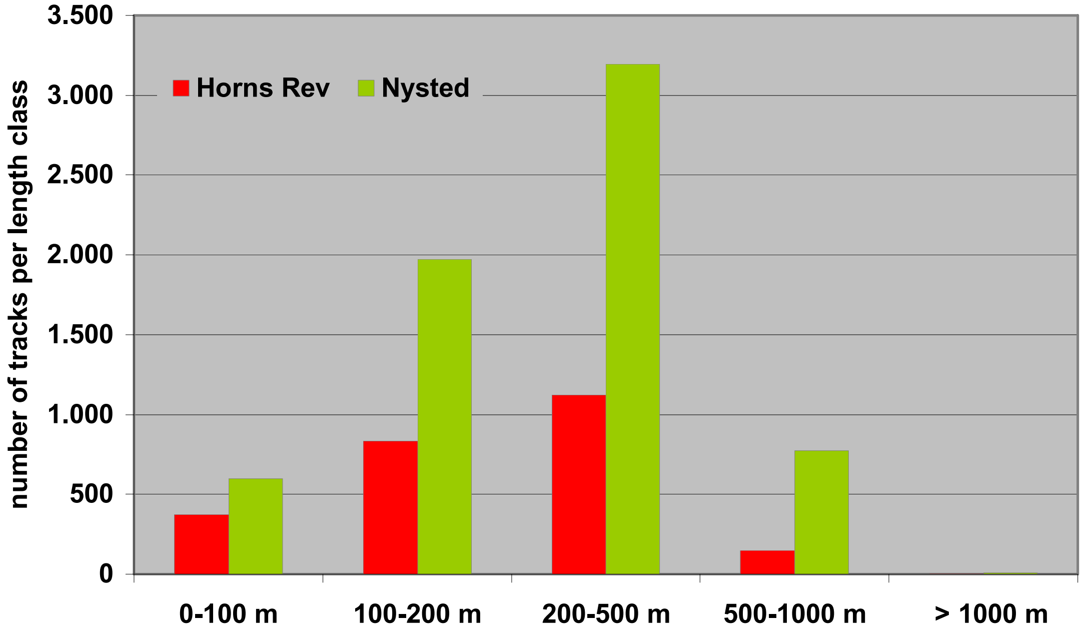


Fig. 2.59: Number of tracks per length classes in Horns Rev and Nysted 2006 (n = 9.027).

Tab. 2.10: Average track length of horizontal radar signals (n = 9.027).

Area	all	n	day	n	night	n
Total	274 m (+/- 173 m)	9,027	279 m (+/- 174 m)	6.479	260 m (+/- 168 m)	2.548
Nysted	284 m (+/- 174 m)	6.550	291 m (+/- 177 m)	4.562	268 m (+/- 177 m)	1.988
Horns Rev	245 m (+/- 158 m)	2.477	251 m (+/- 166 m)	1.917	227 m (+/- 127 m)	560

For further analyses tracks were grouped / categorized according to their direction in relation to the first row of the wind farm. Tracks "flying towards" included all directions between directly towards up to an angle of 45° to either side; the categories "flying away from" and "flying more or less parallel" were defined accordingly (Fig. 2.60). An example plot of all tracks recorded during a certain time interval can be seen in Fig. 2.61.

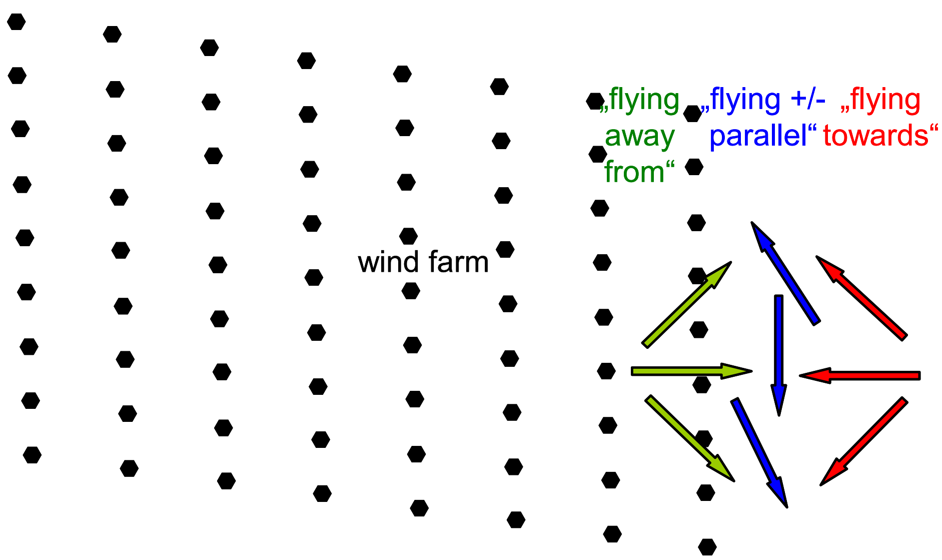


Fig. 2.60: Explanation of track categories

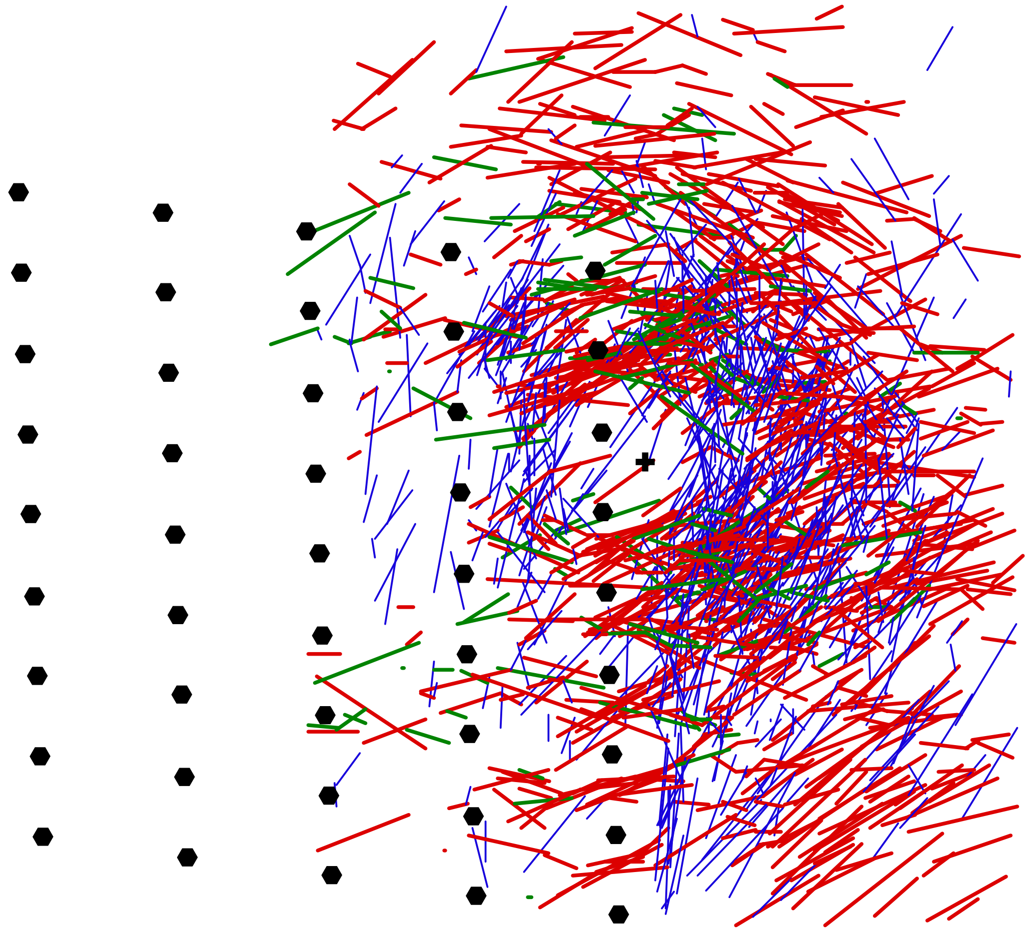


Fig. 2.61: Horizontal radar, categorized tracks, example Nysted 10. October 2006, east side.
Red – tracks moving towards the wind farm, green – tracks moving away from the wind farm, blue – tracks moving more or less parallel to the wind farm (n = 1.693).

Tab. 2.11: Track categories registered at Horns Rev and Nysted in 2006 (n = 9.027).

wind farm considered	**track categories**								
	all			**day**			**night**		
	towards	away from	+/- parallel	towards	away from	+/- parallel	towards	away from	+/- parallel
Total	3.180	1.471	4.376	2.111	1.049	3.319	1.069	422	1.057
Nysted	2.693	779	3.078	1.725	563	2.274	968	216	804
Horns Rev	487	692	1.298	386	486	1.045	101	206	253

During daytime, most tracks fall into the category “more or less parallel” to the wind farm, followed by the category “towards” and “away from”, representing resident birds and most likely waterbirds. During nighttime, almost equal numbers of signals are moving “towards” or “more or less parallel”, representing night-active migrants.

2.2.2.2. Inside vs. outside the wind farm

Tracks are assigned to “inside” or “outside” the wind farm, if its actual signal is “inside” or “outside” the wind farm (“inside” includes per definition signals between the ship and the wind farm) with tracks crossing the line between inside and outside excluded from the analyses.

As visually apparent in the example (Fig. 2.61), less tracks are registered inside the wind farm than outside. While many signals seem to be "crossing" into the wind farm, the density of signals inside the wind farm strongly decreases after the first row and more or less disappears after the second row of wind turbines. This is consistent throughout all different positions at the different seasons.

This impression would suggest, that birds strongly avoid the wind farm. To analyse this situation the three categories assessed separately (Fig. 2.62).

1) For signals "moving more or less parallel", 76% (Nysted) and 78% (Horns Rev) are outside the wind farm. Thus, an avoidance seems to exist expressed by less signals inside than outside the wind farm.

2) For signals "moving towards", 76% (Nysted) and 69% (Horns Rev) are outside the wind farm. Since those signals by way of their direction should inevitably enter the wind farm, this can only be explained, if those signals should either show a lateral avoidance apparent by the angle or the systematic deflection of angles of approaching signals (see below in chapter 2.2.2.3) or a vertical avoidance of steeply ascending signals (see chapter 2.2.1.5). However, neither lateral nor vertical avoidance reactions could be proven with the methods applied. A third option would be that birds flying towards the wind farm land on the water, however, this seems to be less likely both for migrating or for resident birds.

3) For signals "moving away from", still 62% (Nysted) and 59% (Horns Rev) are outside the wind farm. In theory, differences between inside and outside should be small, since it is very unlikely, that signals sort of "appear" outside the wind farm, that is steeply descend or fly up from the water surface.

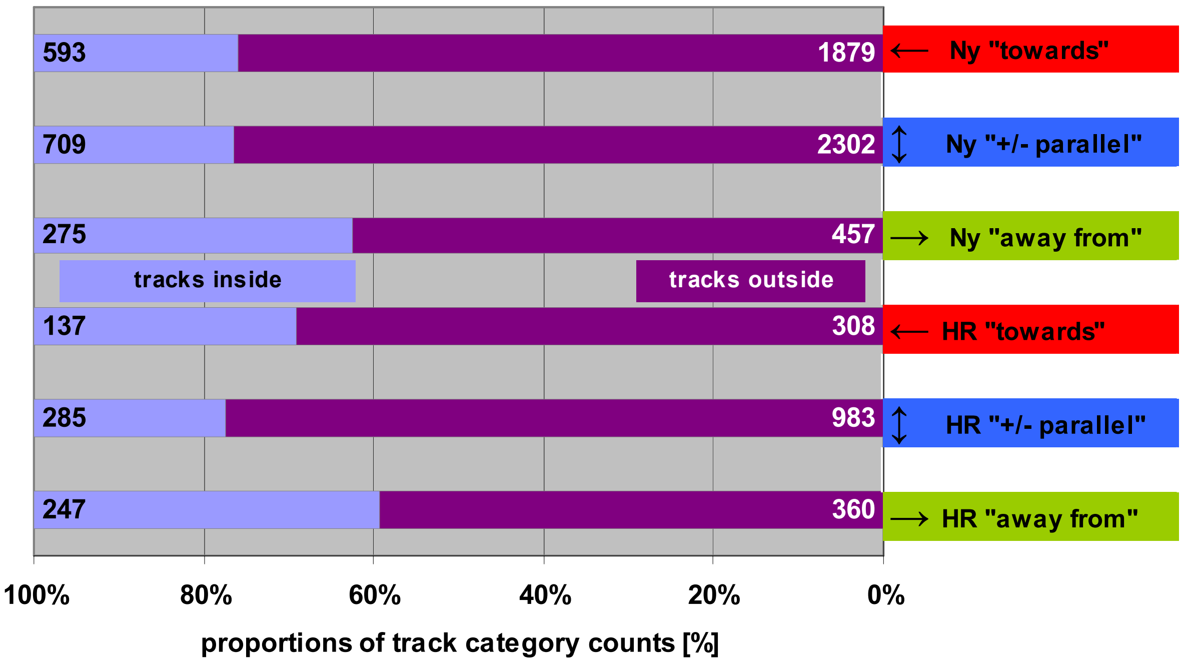


Fig. 2.62: Horizontal radar, tracks moving "towards", "away from" or "+/- parallel" to the wind farm, counted inside and outside the wind farm, as proportions of total counts [%] (n = 8.535).

2.2.2.3. Reactions of birds to the wind farms – horizontal plane

Reactions of birds to the turbines or the entire wind farm could may become apparent on the horizontal radar. Tracks approaching the wind farm would be bending away from the wind farm; this has been shown during Danish investigations (Petersen et al. 2006). An alternative way of looking at potential reactions / lateral avoidance is to analyse the angles of tracks "moving towards" at different distances from the wind farm. For this, four 500 m wide bands have been defined at the side where birds are expected to approach the wind farm. To analyse the "relative angle" of signals approaching the wind farm, track angles are standardized in relation to the wind farm for each ship position (west, east of south of the wind farm). A track moving directly towards the wind farm has a "standardized" angle of 0°. If the track points to the right while approaching the wind farm, its angle is between +1° and +90°, if it points to the left, it is between -1° and -90°. A lateral avoidance would exist, if the average of the absolute angles of approaching signals would increase with decreasing distance from the wind farm (Fig. 2.63.

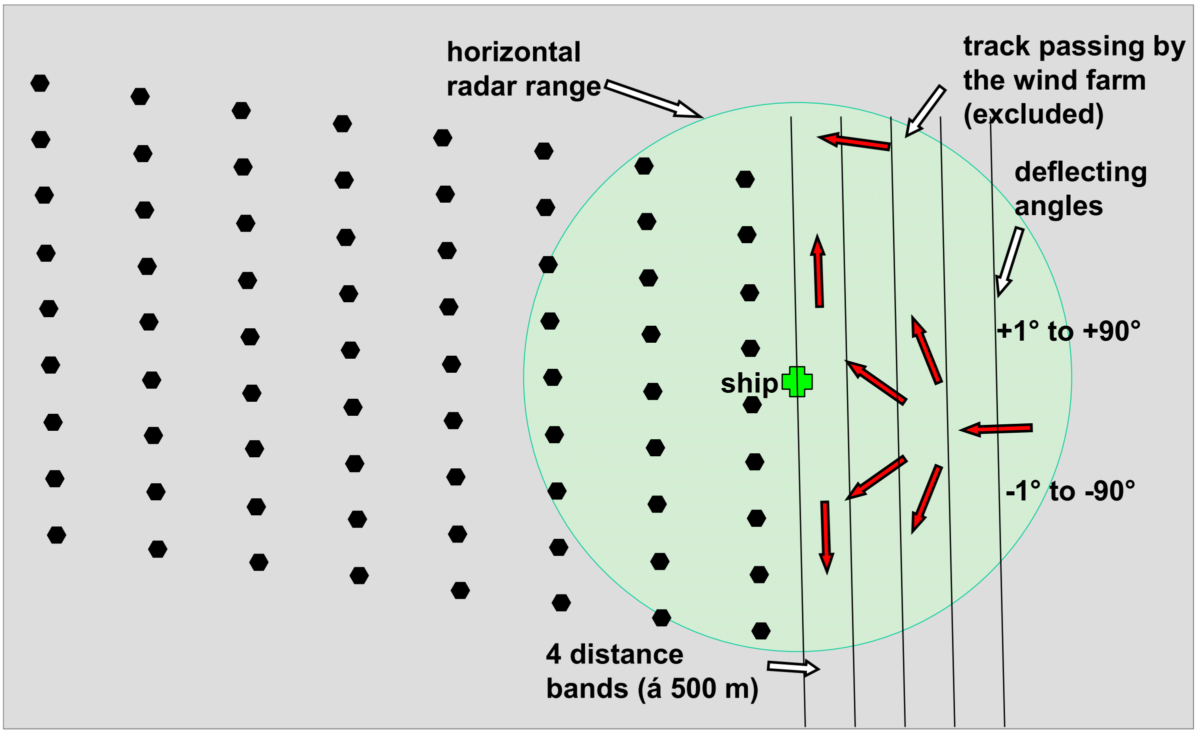


Fig. 2.63: Horizontal radar, schematic presentation of tracks approaching the wind farm from the east, deflecting angles and 4 distance bands.

3,543 "approaching" tracks (753 at Horns Rev, 2,790 at Nysted) exist outside the wind farms within the four distance bands, excluding those, which pass by the wind farm (Tab. 2.12).

Tab. 2.12: Number of approaching tracks outside the wind farms for the different positions (n = 4.012).

Wind farm	season	position	number of approaching tracks outside the wind farm (excluding those passing by the wind farm)
Horns Rev	spring	South	65
		West	500
	autumn	South	13
		East	175
Nysted	spring	South	214
		West	**1.467**
	autumn	**East**	**1.109**

Since bird species composition and behaviour might be different during different seasons, day or night, wind farms and positions, data are treated separately (Tab. 2.13).

Sufficient data for this type of analysis is not available for Horns Rev, but for Nysted in spring at the western side and in autumn at the eastern side (e. g. Fig. 2.61).

Tab. 2.13: Mean angles of approaching tracks outside the wind farms for two positions at Nysted 2006 (n = 2.576). Deviation describes the orientation of the approaching track; D/N = day / night.

Nysted West		Band 0 to 500 m			Band 500 to 1000 m			Band 1000 to 1500 m			Band 1500 to 2000 m		
deviation	D/N	mean	st. dev.	N	mean	st. dev.	N	mean	st. dev.	N	mean	st. dev.	N
north	D	**-48.7**	27.7	115	**-47.7**	26.5	112	**-47.3**	25.0	114	**-44.9**	25.3	52
north	N	**-41.1**	28.5	78	**-46.5**	27.2	119	**-44.5**	25.0	80	**-51.9**	20.1	29
south	D	**38.1**	25.1	116	**42.0**	26.1	194	**43.4**	25.2	135	**45.4**	25.8	77
south	N	**34.6**	26.5	64	**35.6**	26.7	106	**29.2**	23.8	46	**23.2**	24.5	18
deviation expressed in absolute values													
	D	**43.4**	27.0	231	**44.0**	26.5	307	**44.5**	25.6	253	**44.9**	25.8	130
	N	**37.4**	28.0	145	**41.0**	27.6	227	**38.9**	25.7	126	**40.1**	26.4	48
Nysted East		Band 0 to 500 m			Band 500 to 1000 m			Band 1000 to 1500 m			Band 1500 to 2000 m		
deviation	D /N	mean	st. dev.	N	mean	st. dev.	N	mean	st. dev.	N	mean	st. dev.	N
south	D	**-49.3**	23.0	202	**-45.7**	22.3	211	**-42.3**	23.0	125	**-33.9**	21.4	50
south	N	**-49.9**	26.7	89	**-50.5**	25.7	87	**-43.5**	24.6	39	**-53.4**	21.3	12
north	D	**29.7**	25.6	44	**30.0**	25.3	49	**35.9**	27.4	45	**27.7**	23.6	19
north	N	**25.4**	24.9	52	**40.0**	28.1	41	**35.7**	25.8	29	**48.2**	20.9	10
deviation expressed in absolute values													
	D	**45.6**	24.8	247	**42.7**	23.7	260	**40.1**	24.6	172	**32.2**	22.2	69
	N	**40.6**	28.7	142	**46.8**	27.1	129	**40.2**	25.4	68	**51.1**	21.3	22

Angles do not differ nor increase with decreasing distance to the wind farm. A tendency can be seen for Nysted West during night, where averaged track angles show a lateral avoidance to the South from +23.2° within the distance band “1,500-2,000 m” to +34.6° within the band “0-500m”, or for Nysted East during daytime changing from -33.9° to -49.3°, also showing a deviation towards the South. Yet, variation (standard deviations) of these results is too high to yield any significance, and contrasting examples exist, where the deviation decreases with decreasing distance to the wind farm, e.g. at Nysted East during nighttime.

2.2.3. Visual observations

2.2.3.1. Species composition

During visual observations in the **Horns Rev** wind farm area in 2005 and 2006 a total of 96 bird species could be identified. 61 of these could be seen flying inside the wind farm and over the wind farm area (above turbine height), respectively. For the rest of the species this could not be proven during this survey.

Besides typical coastal waterbirds such as gulls, sea-ducks or geese several pelagic species were recorded in Horns Rev (Fulmar, Gannet, Kittiwake) as well as a wide range of migrating songbirds. Important families among the latter were pipits and wagtails (Motacillidae), thrushes and related (Turdidae) and finches (Fringillidae).

While Fulmar was observed only in spring in most other taxa more species were recorded in autumn (e.g. geese, waders, songbirds). The total of species observed in spring is 57, for autumn-recorded species it is 89.

A list of species recorded in Horns Rev wind farm area plus additional information about their occurrence is given in Tab. 2.14.

In **Nysted** wind farm area in 2005 and 2006 a total of 114 bird species was observed, 73 of which were also recorded inside/above the wind farm area.

The species composition was dominated by a wide range of non-pelagic waterbirds and migrating songbirds. Furthermore a considerable number of (migrating) bird of prey species was recorded. Seven species of geese were observed in the area (six indigenous plus one introduced species) as well as 16 duck species, 14 raptor species and 44 songbird species.

A list of species recorded in Nysted wind farm area plus additional information about their occurrence is given in Tab. 2.15.

Not surprisingly, the species composition in both areas differed. Strongly pelagic species (e.g. tubenoses, gannets) occur only occasionally in the Baltic Sea whereas they are regular inhabitants of the North Sea. Under certain circumstances they come fairly close to the coastline and thus can be seen in the Horns Rev wind farm area.

In Horns Rev the number of wader species is considerably higher than in Nysted. Swans were only observed in Nysted.

Tab. 2.14: 96 bird species were identified in Horns Rev wind farm area during visual observations in 2005 and 2006. 61 of these were also recorded inside (or above) the wind farm area (species in bold print). **x** = recorded; **–** = not recorded.

	spring	autumn		spring	autumn
Red-throated Diver	x	x	**Razorbill**	x	x
unidentified Grebe	-	x	Little Auk	-	x
Fulmar	x	-	**Feral Pigeon**	x	-
Gannet	x	x	**Wood Pigeon**	x	x
Great Cormorant	x	x	Collared Dove	x	-
Grey Heron	x	x	**Short-eared Owl**	x	x
Brent Goose	-	x	**Skylark**	x	x
Pink-footed Goose	-	x	**Shore Lark**	-	x
White-fronted Goose	-	x	**Barn Swallow**	x	x
Greylag Goose	x	x	**House Martin**	x	-
Wigeon	-	x	Tawny Pipit	-	x
Teal	x	-	**Tree Pipit**	-	x
Common Eider	x	x	**Meadow Pipit**	x	x
Common Scoter	x	x	Red-throated Pipit	-	x
Velvet Scoter	x	x	**Rock Pipit**	-	x
Marsh Harrier	-	x	**Blue-headed Wagtail**	x	x
Sparrowhawk	x	x	**Grey Wagtail**	-	x
Red Kite	-	x	**White Wagtail**	x	x
Merlin	x	x	**Wren**	x	x
Peregrine Falcon	-	x	Dunnock	x	x
Kestrel	-	x	**Robin**	x	x
Oystercatcher	x	x	Black Redstart	x	-
Ringed Plover	-	x	**Common Redstart**	x	x
Grey Plover	-	x	Wheatear	x	x
Golden Plover	-	x	**Blackbird**	x	x
Lapwing	x	x	Fieldfare	x	x
Whimbrel	x	-	**Songthrush**	x	x
Curlew	-	x	**Redwing**	-	x
Bar-tailed Godwit	-	x	Blackcap	-	x
Woodcock	x	x	Chiffchaff	x	x
Common Snipe	-	x	Willow Warbler	x	x
Redshank	x	x	Goldcrest	x	x
Turnstone	-	x	Blue Tit	-	x
Dunlin	-	x	Great Tit	-	x
Arctic Skua	x	x	**Jackdaw**	x	x
Long-tailed Skua	-	x	**Starling**	x	x
Little Gull	x	x	Tree Sparrow	-	x
Sabine's Gull	-	x	**Chaffinch**	x	x
Black-headed Gull	x	x	**Brambling**	x	x
Common Gull	x	x	**Greenfinch**	x	x
Lesser Black-backed Gull	x	x	**Siskin**	-	x
Herring Gull	x	x	**Linnet**	x	x
Great Black-backed Gull	x	x	**Redpoll**	-	x
Kittiwake	x	x	Lapland Bunting	-	x
Sandwich Tern	x	x	Snow Bunting	-	x
Common Tern	x	x	Yellowhammer	-	x
Arctic Tern	x	x	**Reed Bunting**	-	x
Little Tern	-	x			
Guillemot	-	x	**total**	**57**	**89**

Tab. 2.15: 114 bird species were identified in Nysted wind farm area during visual observations in 2005 and 2006. 73 of these were also recorded inside (or above) the wind farm area (species in bold print). x = recorded; – = not recorded.

	spring	autumn		spring	autumn
Red-throated Diver	x	x	Curlew	x	x
Black-throated Diver	x	x	Green Sandpiper	x	-
Crested Grebe	x	-	**Dunlin**	-	x
Red-necked Grebe	x	-	Arctic Skua	-	x
Great Cormorant	x	x	**Little Gull**	x	x
Grey Heron	x	x	**Black-headed Gull**	x	x
Mute Swan	x	x	**Common Gull**	x	x
Whooper Swan	x	x	**Lesser Black-backed Gull**	x	x
Brent Goose	x	x	**Herring Gull**	x	x
Barnacle Goose	x	x	**Caspian Gull**	x	-
Canada Goose	x	x	**Great Black-backed Gull**	x	x
Bean Goose	x	-	Caspian Tern	-	x
Pink-footed Goose	-	x	**Sandwich Tern**	x	x
White-fronted Goose	x	x	Common Tern	x	x
Greylag Goose	x	x	**Arctic Tern**	x	x
Shelduck	x	-	unidentified Auk	x	-
Gadwall	-	x	**Feral Pigeon**	x	-
Wigeon	x	x	**Wood Pigeon**	x	x
Teal	x	x	**Short-eared Owl**	-	x
Mallard	x	x	**Swift**	x	-
Pintail	x	x	**Wood Lark**	-	x
Shoveler	x	-	**Skylark**	x	x
Tufted Duck	x	-	**Shore Lark**	x	x
Scaup	x	-	Sand Martin	x	x
Common Eider	x	x	**Barn Swallow**	x	x
Long-tailed Duck	x	x	House Martin	x	x
Common Scoter	x	x	Tree Pipit	x	x
Velvet Scoter	x	-	**Meadow Pipit**	x	x
Goldeneye	x	-	**Rock Pipit**	x	x
Goosander	x	x	**Blue-headed Wagtail**	x	x
Red-breasted Merganser	x	x	Grey Wagtail	-	x
Osprey	-	x	**White Wagtail**	x	x
Honey Buzzard	x	x	**Wren**	x	x
Hen Harrier	x	x	Dunnock	x	-
Montagu's Harrier	-	x	Common Redstart	x	-
Marsh Harrier	x	x	**Robin**	-	x
Goshawk	-	x	**Black Bird**	x	x
Sparrowhawk	x	x	**Fieldfare**	-	x
Red Kite	-	x	**Songthrush**	-	x
Rough-legged Buzzard	-	x	**Redwing**	-	x
Common Buzzard	x	x	Chiffchaff	x	-
Merlin	x	x	Willow Warbler	x	-
Hobby	x	-	Goldcrest	x	x
Peregrine Falcon	x	x	Red-breasted Flycatcher	-	x
Kestrel	x	x	Long-tailed Tit	-	x
Crane	x	-	Coal Tit	-	x
Oystercatcher	x	-	**Blue Tit**	x	x
Grey Plover	-	x	**Great Tit**	x	x
Golden Plover	x	-	**Jackdaw**	x	x
Whimbrel	x	-	**Rook**	x	x

	spring	autumn		spring	autumn
Carrion Crow	x	x	**Greenfinch**	x	x
Raven	-	x	Goldfinch	x	x
Starling	x	x	**Siskin**	x	x
House Sparrow	x	-	**Linnet**	x	x
Tree Sparrow	-	x	**Twite**	-	x
Chaffinch	x	x	Redpoll	-	x
Brambling	x	x	Reed Bunting	x	x
			total	**89**	**90**

The composition of bird taxa recorded in **Horns Rev** during standard transect counts in 2005 and 2006 is presented in Fig. 2.64.

The pie charts show percentages, hence the size of the slices depends on the number of all observations. For example it might be the case that one taxon formed a proportion of 10% in spring and 15% in autumn. That does not necessarily mean that the number of observations in autumn was higher. The opposite could have been the case.

Gulls (except Little Gull) formed the largest proportion with more than a third of the standard transect counts in both seasons. Little Gull was very prominent on migration in spring when it made up more than 20% of the records but hardly appeared at all in autumn.

Common Scoter is a species characteristic for the area and hence was always present though it formed a reasonably higher proportion in spring when it made up almost one fourth.

While passerines formed the second largest fraction in autumn (also more than one third), they were far less important in spring.

Another group with an unequal appearance were terns. Terns were the fourth largest fraction in spring, but not prominent in autumn. This was clearly due to the fact that tern's spring migration was entirely covered by the survey period whereas in autumn a large part of terns had already left southwards before the survey period started.

Cormorants and geese occurred only in autumn in reasonable fractions but still didn't exceed 5%.

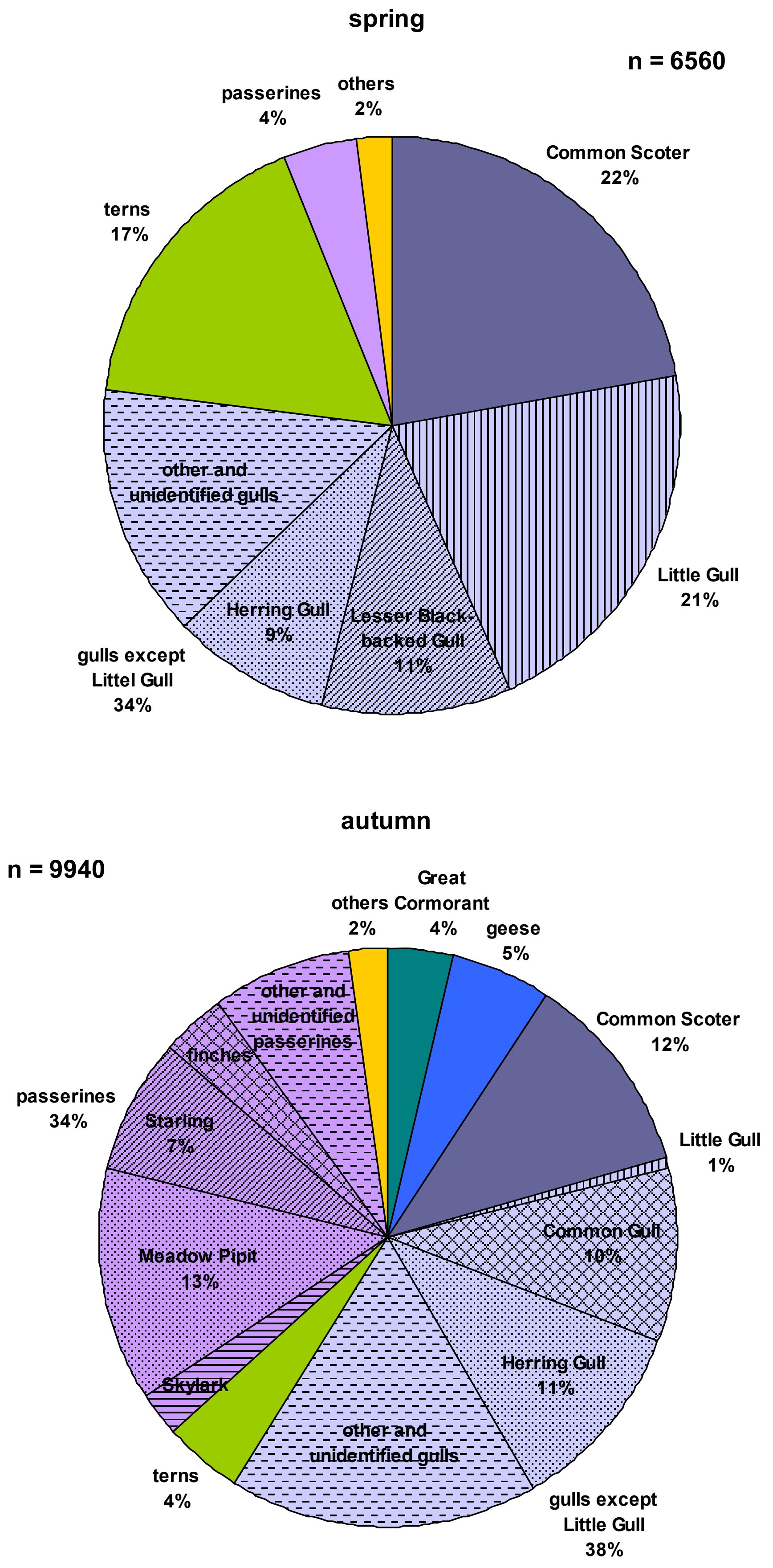


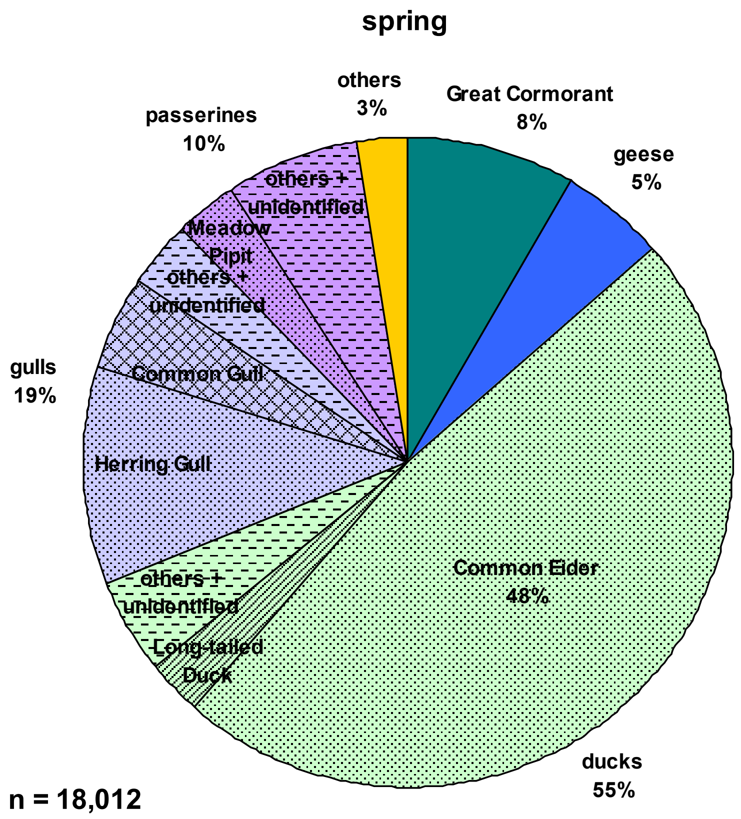
Fig. 2.64: Species composition in percent from transect count results in Horns Rev wind farm area during spring (top) and autumn (bottom) in 2005 and 2006.

In **Nysted** species composition in autumn was characterised by huge feeding associations of Great Cormorants (Fig. 2.65). More than half of all standard transect counts was formed by Cormorants in autumn while during spring that species made up only 8%.

The otherwise most important taxon was ducks, namely Common Eider. In spring ducks made up more than a half (Common Eider almost one half) and in autumn despite the Cormorant's relevant numbers still more than one quarter (almost all of them being Common Eiders).

Gulls formed 19% in spring and shrank to 4% in autumn, clearly an arithmetical effect due to Cormorant's numbers.

Passerines formed comparable proportions in spring and autumn (roughly 10%) and geese low proportions in both seasons (5%). However, due to the different total numbers this means that both taxa were recorded in larger numbers in autumn than in spring.



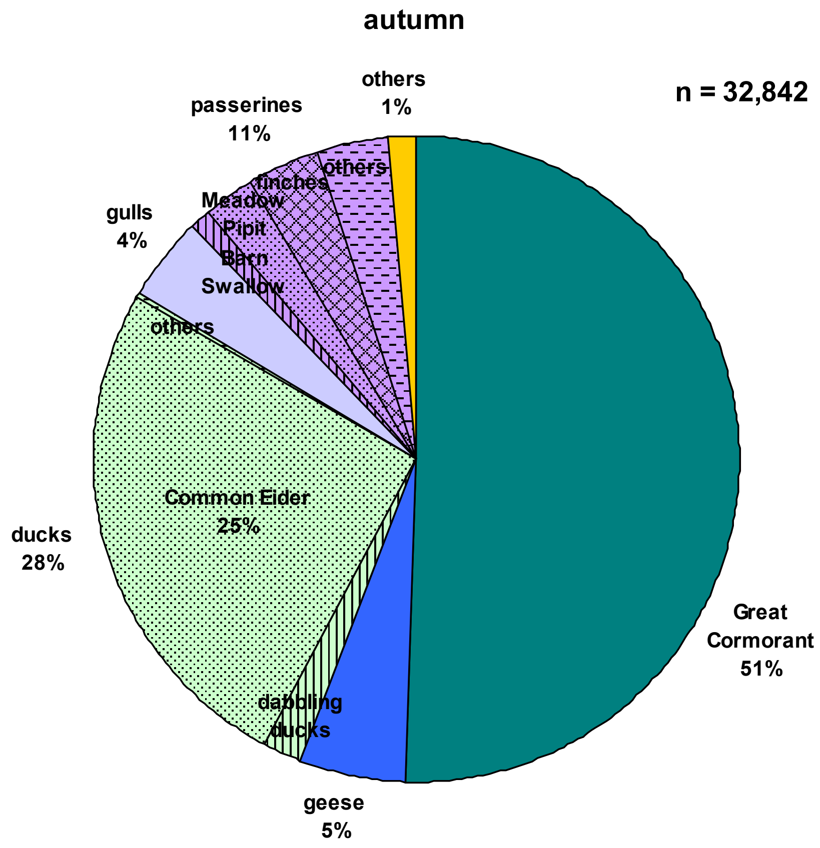


Fig. 2.65: Species composition in percent from transect count results in Nysted wind farm area during spring (top) and autumn (bottom) in 2005 and 2006. Note: in the autumn diagram the fractions “others” in ducks and passerines include the unidentified birds of each group, too.

2.2.3.2. Spatial distribution

Altitude distributions inside and outside the wind farm (distance class A, see Fig. 2.12), were analysed for all species with sufficient datasets available. These were the waterbirds being resident in or migrating through the investigation areas in considerable numbers during the observation periods. Taxa of general interest or concern with poor data for a thorough statistical approach are treated in a rather descriptive way. Taxa which occurred in a few individuals only are not dealt with in this section, but are still listed in Tab. 2.14 and Tab. 2.15.

Horns Rev wind farm

Divers Gaviidae

During standard transect counts 36 divers were observed. All identified individuals were Red-throated Divers *Gavia stellata*. Only two records date from spring. Four out of all 36 birds flew inside the wind farm (two in 5-30 m altitude and two within rotor range) while 28 flew outside. The remaining four individuals flew within the 300 m transect (distance zone B) and hence were not allocated inside or outside. Six birds were tracked, including three of those flying inside the wind farm. Only one of the tracked individuals showed an obvious reaction but still entered the wind farm.

Flight altitudes ranged from water surface to turbine height (plus one individual flying above turbine height). Most birds flew below the rotor swept altitude range (17). Numbers recorded close to the sea surface and within the rotor range were similar (ten and eight respectively).

Gannet *Sula bassana*

66 Gannets were recorded during standard transect counts. Only two of them flew inside the wind farm, at an altitude of 0 – 5 m and 30 – 110 m respectively. Numbers in spring and autumn were alike (34 and 32 respectively). General altitude distribution is shown in Fig. 2.66. Gannets were observed foraging in the area.

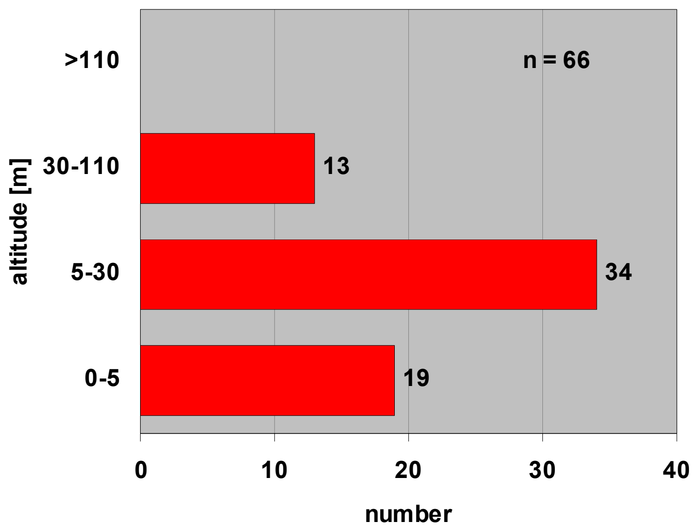


Fig. 2.66: Altitude distribution of Gannets recorded during standard transect counts in Horns Rev wind farm area in 2005 and 2006 (n = 66; 2 birds inside wind farm, 64 birds outside).

Great Cormorant *Phalacrocorax carbo*

In Horns Rev most Cormorants were observed in autumn (90). Only 14 records date from spring. These low numbers of Cormorants are most likely non-resident birds on migration. All altitude classes were used. Owing to this low number of observations results were not statistically tested. If observations from distance class B (between 30 and 300 m) are included 286 birds could be tracked. 252 of these (12 flocks/single birds) showed an obvious reaction towards the turbines (see chapter 2.2.3.3).

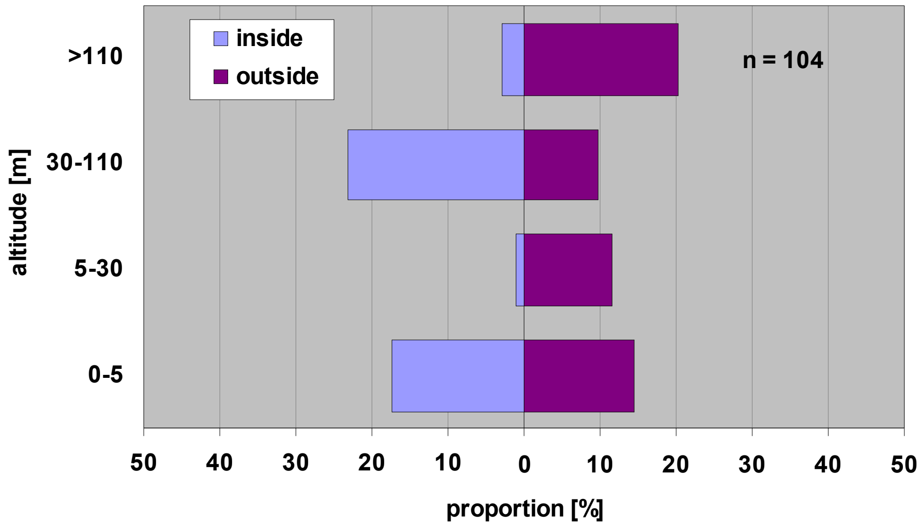


Fig. 2.67: Spatial distribution of Cormorants recorded during standard transect counts in Horns Rev wind farm area in 2005 and 2006 (n = 104).

Geese Anserini

Most of all goose records were made outside the wind farm area. Those few touching the wind farm area flew almost completely above turbine height. However, the goose dataset is too slim to undergo statistical procedures.

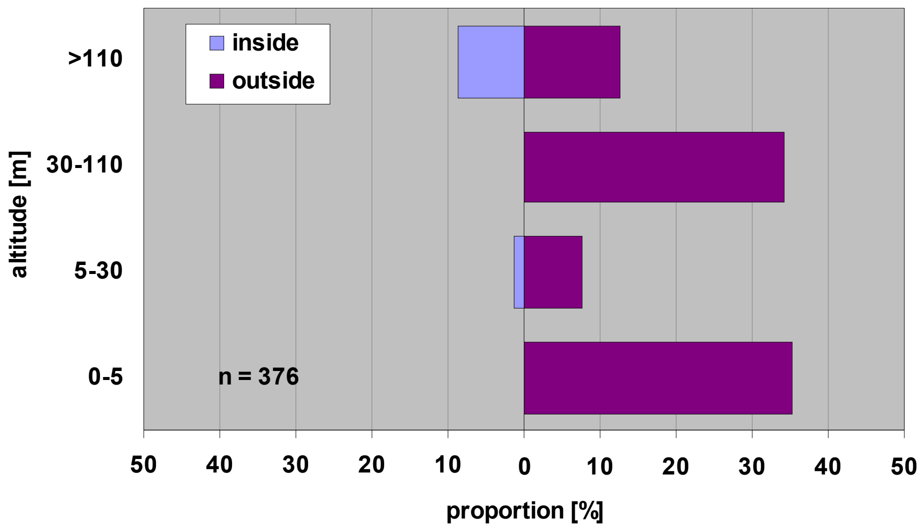


Fig. 2.68: Spatial distribution of geese recorded during standard transect counts in Horns Rev wind farm area in 2005 and 2006 (n = 376).

Common Scoter *Melanitta nigra*

One of the most numerous groups in Horns Rev area is the Common Scoter. During standard transect counts 2300 Common Scoters were recorded 349 of which flew inside and 1951 outside the wind farm.

The diagram in Fig. 2.69 shows the altitude distribution inside and outside the wind farm.

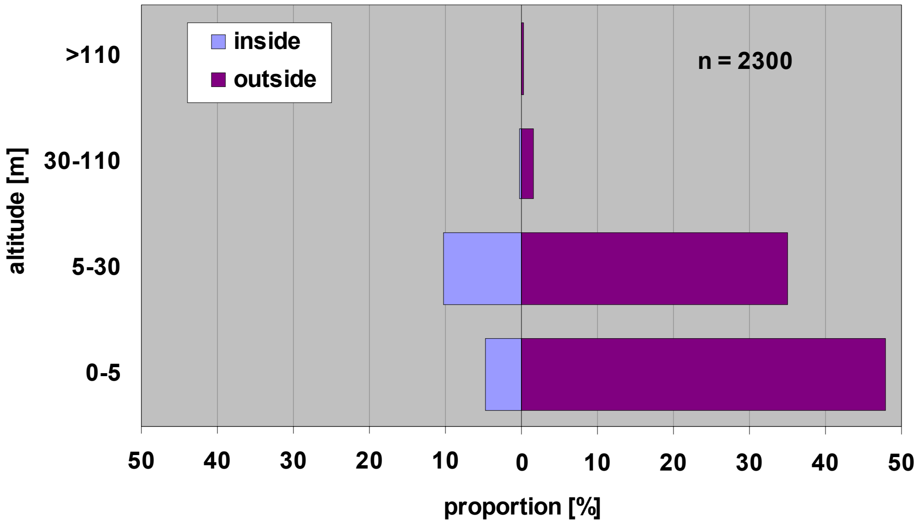


Fig. 2.69: Spatial distribution of Common Scoters recorded during standard transect counts in Horns Rev wind farm area in 2005 and 2006 (n = 2300).

Common Scoters prefer flying at altitudes lower than 30 m in general. Besides they obviously avoid to enter the wind farm area: a comparison of the numerical distribution in all observation intervals with Common Scoters (247) reveals a significant difference in occurrence of this species inside and outside the wind farm (GLM: $n = 247$; $p < 0.001$). Yet, the birds observed within the wind farm did not show a different altitude distribution from those flying outside (ANOVA for 2 LMERs: $p = 0.05027$).

Although we used only four altitude bands of different width we can show the relation between wind and flying altitude well for Common Scoter. Fig. 2.70 shows a clear tendency of a preference for lower flight altitudes with a decreasing TWC, expressing increasing headwind. This tendency proves valid independently of season and the presence of wind turbines.

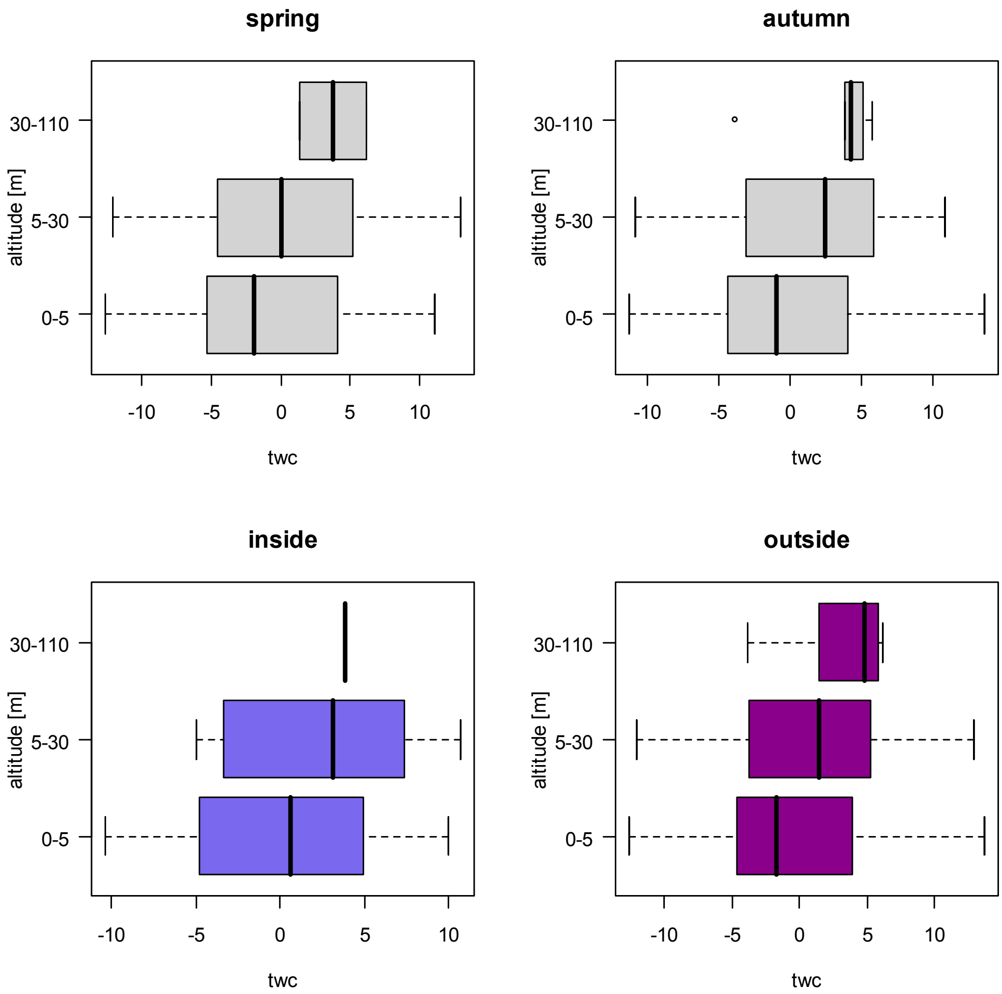


Fig. 2.70: Relation between flying altitude and tailwind component (TWC) in Common Scoters at Horns Rev wind farm area. Boxes show the first and the third quartile; the bold line shows the median; whiskers show the minimum/maximum value and 1.5 times the interquartile range respectively, whichever is the smaller. In the latter case outliers are plotted individually. n = 1887.

Waders Charadrii

61 waders were recorded in Horns Rev during standard transect counts, 14 in spring and 47 in autumn (distance class B included). Nine species were observed. All altitude bands were covered, the lowest a bit more pronounced than the others. Waders occurred inside the wind farm. Among tracked individuals (15) no obvious reactions towards the wind turbines could be observed.

Little Gull *Larus minutus*

1187 Little Gulls could be observed in standard transect counts, 327 inside and 860 outside the wind farm. Fig. 2.71 shows the percental distribution for each height class and transect side.

Generally the abundance decreases continuously with increasing altitude class. There was no record from above turbine height.

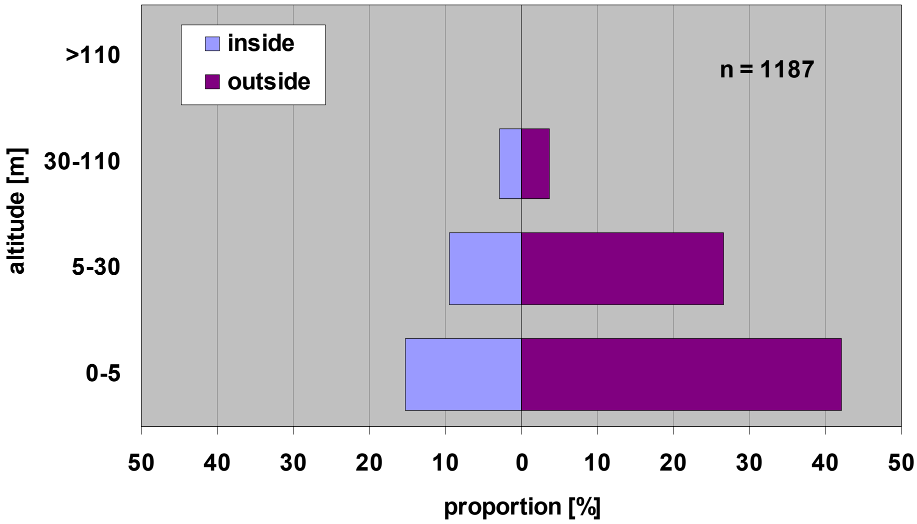


Fig. 2.71: Spatial distribution of Little Gulls recorded during standard transect counts in Horns Rev wind farm area in 2005 and 2006 (n = 1187).

Little Gulls avoid the wind farm. For the comparison of the numerical distribution inside and outside the wind farm all 77 observation intervals in which Little Gulls occurred were included. Significantly less Little Gulls were present inside the wind farm than outside (GLM: n = 77; p = 0.00777).

Although altitude distributions look superficially similar on either side they differ significantly (ANOVA for 2 LMERs: p = 0.00559).

Gulls Laridae (except Little Gull)

All other gull species were pooled as gulls except Little Gull. For simplification they are just treated as "gulls" below. The biggest fraction was made up by Herring Gulls. The second most abundant species were Common Gull and Lesser Black-backed Gull (similar numbers). Great Black-backed Gull, Black-headed Gull and Kittiwake were recorded less frequent. A considerable number of gulls could not be identified to species level but was still included in the taxon gulls.

Gulls formed the largest group at Horns Rev: a total of 3090 was observed during standard transect counts. Additionally gulls were the taxon showing least difference in numbers between inside and outside the wind farm. But still: only 984 birds were recorded inside compared to 2106 outside. The spatial distribution (Fig. 2.72) shows a clear preference of altitudes below rotor range. The second most preferred height class inside the wind farm was the rotor range while outside the wind farm it was just above sea surface. Only a small percentage flew above turbine height.

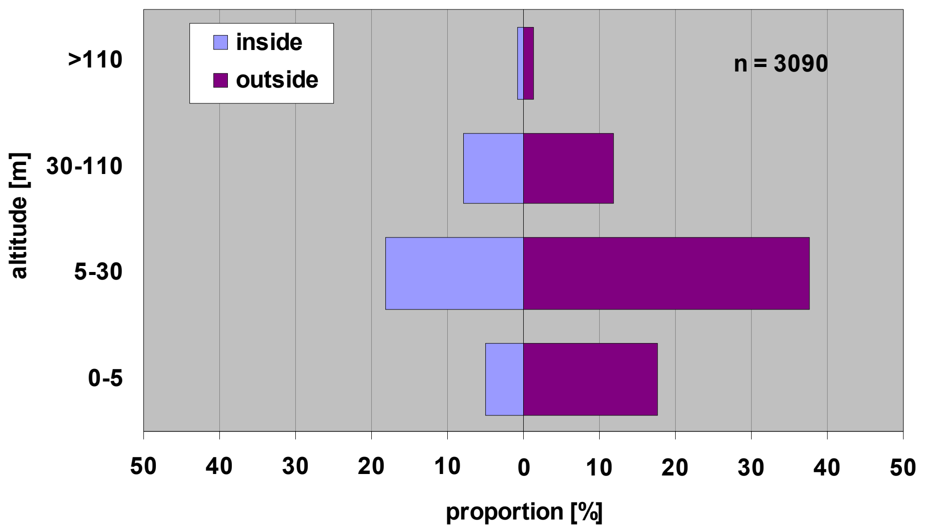


Fig. 2.72: Spatial distribution of gulls (except Little Gulls) recorded during standard transect counts in Horns Rev wind farm area in 2005 and 2006 (n = 3090).

Gull numbers differed significantly between inside and outside the wind farm in 781 gull-positive observation intervals (GLM: n = 781; $p < 0.001$).

Altitude distribution varied significantly between both sides (ANOVA for 2 LMERs: $p < 0.001$).

Terns Sternidae

All terns observed in the investigation area – namely the three species Sandwich Tern *Sterna sandvicensis*, Common Tern *S. hirundo* and Arctic Tern *S. paradisaea* – were pooled as one group.

Standard transect counts yielded a total of 855 terns 207 of which flew inside the wind farm and 648 outside. Fig. 2.73 shows a general preference of lower altitudes. However, inside the wind farm only a minor percentage flew just above the water. No individuals were recorded above turbine height. Terns clearly avoid the wind farm: the inside-outside difference of the counts is significant (GLM: n = 190; $p < 0.001$).

Altitude distribution on each side is differing (ANOVA for 2 LMERs: $p < 0.001$).

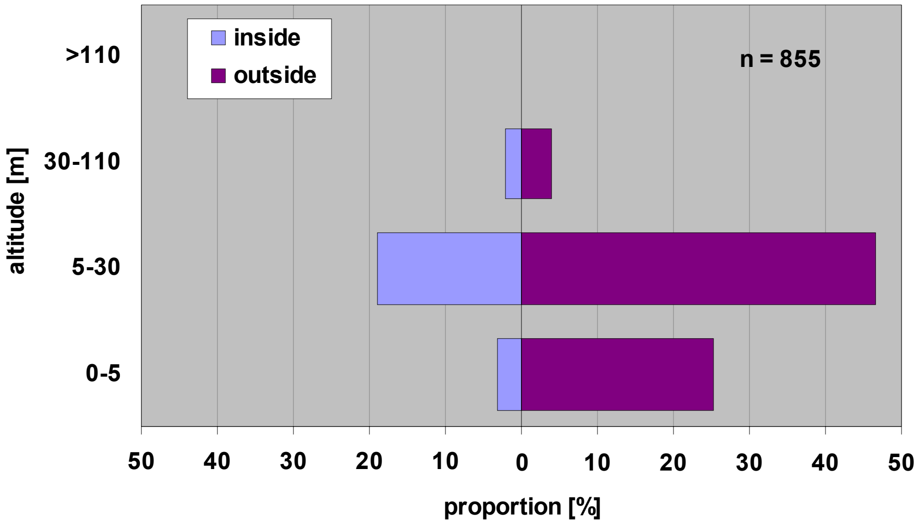


Fig. 2.73: Spatial distribution of terns recorded during standard transect counts in Horns Rev wind farm area in 2005 and 2006 (n = 3090).

Songbirds Passeri

When songbirds are examined alone, corvids are excluded from that group because they are much easier to spot than other songbirds due to their larger body size especially when flying at considerable distances. So, the likelihood for corvids to be recorded might have been considerably higher at any distance than for all other songbirds. The term “songbirds” is meant as “songbirds without corvids”.

It is also important to realise that for this treatment only songbirds recorded within the distance class B (30 to 300 m) were included with regard to their smaller body size and hence a very low detectability beyond that range. The consequence is that the two samples (transect sectors) to be compared are much closer to each other (60 m instead of 600 m for class A birds) and the birds from the wind farm side of the transect do rather fly between the ship and the wind farm than inside the wind farm like in the other cases (see Fig. 2.12). Hence the notation “wf side” and “non-wf side” (instead of “inside” and “outside”).

Fig. 2.74 shows the spatial distribution of songbirds within 30 to 300 m (class B) on each side. The side distribution looks very similar. Since those birds are actually not inside or outside the wind farm respectively (cf. the methods chapter) a further statistical approach was dropped. With regard to altitude distribution songbirds show a preference of lower flight altitudes (below rotor range) and decreasing numbers with increasing height and just above the water.

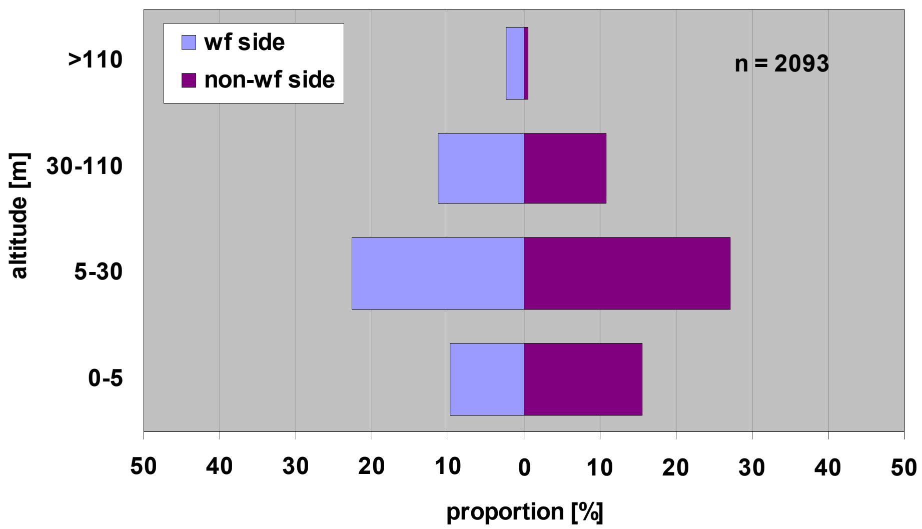


Fig. 2.74: Spatial distribution of songbirds except corvids recorded during standard transect counts in Horns Rev wind farm area in 2005 and 2006 (n = 2093).

Meadow Pipit *Anthus pratensis*

To present a species example for songbirds the spatial distribution of Meadow Pipit is shown in Fig. 2.75. Meadow Pipits made up more than one third of songbirds in Horns Rev in autumn and overall. The distribution (which includes only 31 spring records) reflects largely the situation for all songbirds. Compared to all songbirds the altitude below rotor range is slightly larger and there were no Meadow Pipits seen above turbine height at all.

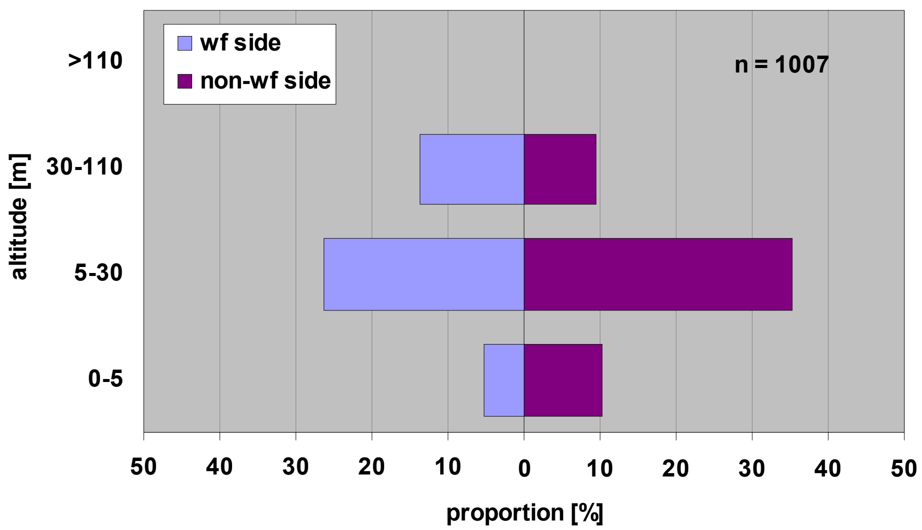


Fig. 2.75: Spatial distribution of Meadow Pipits recorded during standard transect counts in Horns Rev wind farm area in 2005 and 2006 (n = 1007).

Starling *Sturnus vulgaris*

The Starling is an example of another songbird distribution. On wind farm side the numbers are similar in all altitudes while on non-windfarm side higher altitudes seem to be preferred.

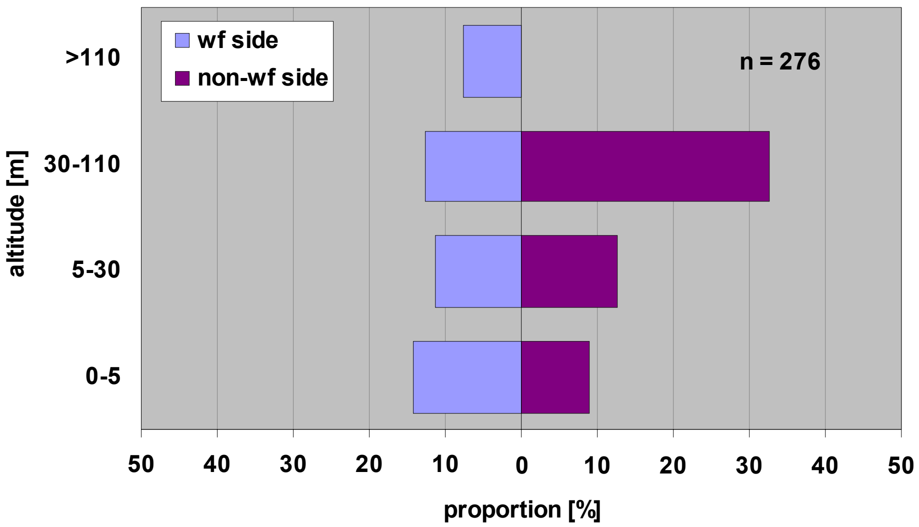


Fig. 2.76: Spatial distribution of Starlings recorded during standard transect counts in Horns Rev wind farm area in 2005 and 2006 (n = 276).

Nysted wind farm

Divers Gaviidae

In Nysted a total of 25 divers was recorded during standard transect counts. Identified species were Red-throated Diver (3 ind.) and Black-throated Diver *Gavia arctica* (1 ind.). Only four records date from autumn. 5 individuals flew inside/above the wind farm, 9 outside, the remaining 11 were within 300 m from the vessel and therefore not allocated. 6 birds were tracked. Three of them flew into/came out of the wind farm and the other three did not touch the wind farm area at all. None of them showed any obvious reaction to the turbines. There is only one above turbine height record (wind farm area). All other altitudes were used frequently: 0 – 5 m: 7 ind.; 5 – 30 m: 10 ind.; 30 – 110 m: 7 ind.. These numbers comprise the wind farm, too (2 birds in rotor range).

Great Cormorant *Phalacrocorax carbo*

A special case under several aspects was the Great Cormorant in Nysted wind farm area. It was the species with the by far largest individual number recorded during standard transect counts in the entire study. 17,037 birds could be observed, 11,154 inside and 5883 outside the wind farm. It was the only species occurring in a larger number inside than outside.

Almost 95% of all records are from the lowest altitude class just above water surface, over 60% inside and over 30% outside. Fig. 2.77 illustrates the distribution pattern.

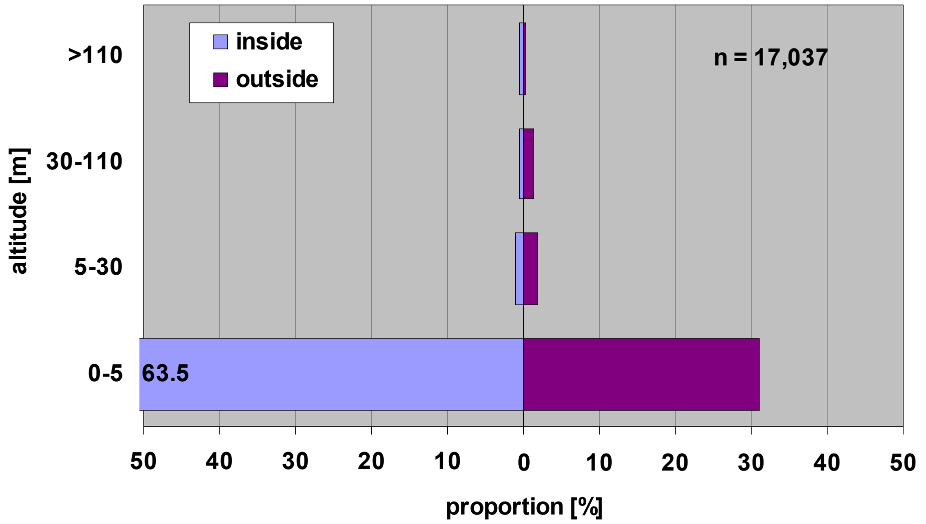


Fig. 2.77: Spatial distribution of Great Cormorants recorded during standard transect counts in Nysted wind farm area in 2005 and 2006 (n = 17,037).

The very large number of Cormorants inside the wind farm and in general originates from a few single incidents, when in autumn large actively feeding flocks (partly aggregations of up to several thousand individuals) crossed the transect line within the observation interval. More than 12,500 individuals (this is roughly three quarters of all records) were recorded in four autumn intervals only. Nine interval sums ranged from over 100 to 5000 birds. In spring, apart from one interval with 28 birds, per-interval numbers were always below 20. This uneven distribution necessarily leads to some statistical difficulties. Hence the Great Cormorant dataset had to be log-transformed.

The difference in abundance between inside and outside the wind farm is significant (GLM with log-transformed dataset: $n = 688$; $p < 0.001$). The altitude distributions of either side do not differ (ANOVA for 2 LMERs: $p = 0.601$).

It was tried to differentiate between Cormorants resident, commuting between feeding and roosting or migrating by way of grouping parameters like flight altitude, flight direction and flock size; however, this was not successful and consequently differences between migrating or staging individuals with regard to wind farm avoidance or flight altitudes cannot be calculated.

Swans and geese Cygnini and Anserini

Since in Nysted not only geese occurred but also swans these two closely related taxa of a similar migration pattern were pooled. The total number was 2197 individuals 409 of which were recorded inside and 1788 outside the wind farm. The difference is significant (GLM: $n = 2197$; $p < 0.03643$).

The altitude distribution is clearly in favour for the highest class, above turbine height (Fig. 2.78). The altitude distribution differs significantly between inside and outside (ANOVA for 2 LMERs: $p < 0.001$). Almost one third of all individuals was recorded outside the wind farm above turbine height.

Obviously swans and geese avoid both to fly through and even over the wind farm area.

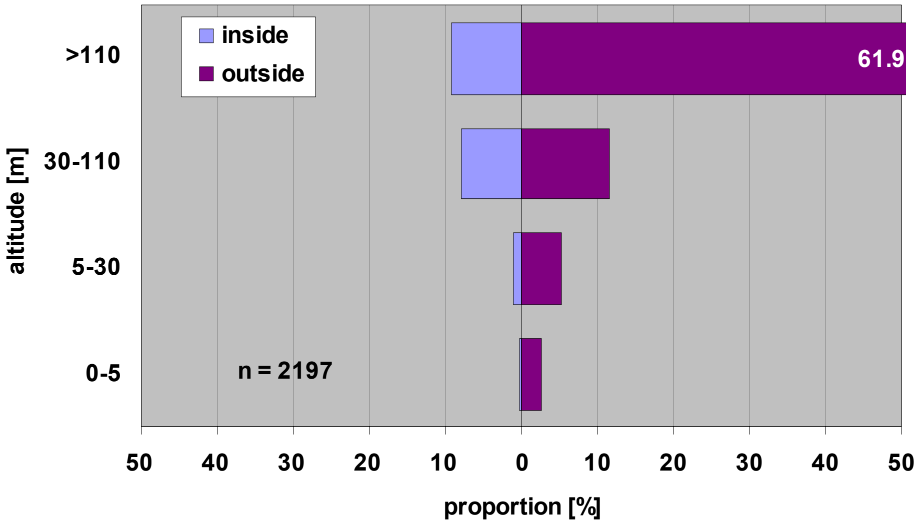


Fig. 2.78: Spatial distribution of swans and geese recorded during standard transect counts in Nysted wind farm area in 2005 and 2006 (n = 2197).

Common Eider *Somateria mollissima*

The second most abundant taxon in Nysted wind farm area was the Common Eider. A total of 13,498 birds could be counted on standard transects, divided into 1280 flying inside and 12,218 flying outside the wind farm. The avoidance of the wind farm by this large sample is undisputed (Fig. 2.79). Altitudes above turbine height and just above water level seem to be less preferred.

The difference between inside and outside counts is significant (GLM: n = 446; $p < 0.001$) .

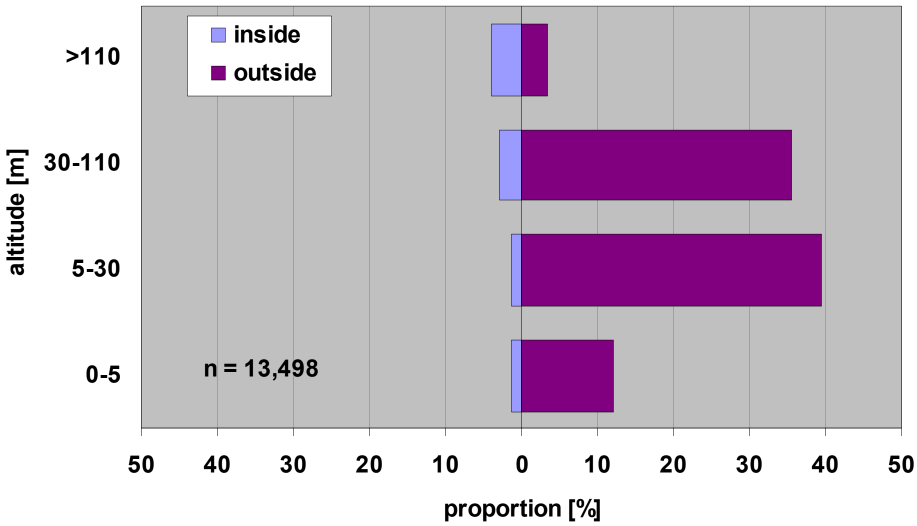


Fig. 2.79: Spatial distribution of Common Eiders recorded during standard transect counts in Nysted wind farm area in 2005 and 2006 (n = 13,498).

The altitude distribution differs significantly between both sides (ANOVA for 2 LMERs: $p < 0.001$). While outside below rotor range and rotor range are the preferred altitudes among the small fraction flying inside the preference seems to be increasingly shifted towards the higher altitudes.

Thus, Common Eiders largely avoided the wind farm, but those flying inside the wind farm area preferred higher altitudes, mainly above WTG height while the majority outside flew below and within the rotor range.

Birds of prey Falconiformes

In autumn birds of prey were recorded regularly but in comparably low numbers. Inside the number of observations was higher in the upper altitudes, including that one in rotor range, while outside the number was highest just above sea surface (Fig. 2.80). However, the raptor's dataset is too small to be treated statistically.

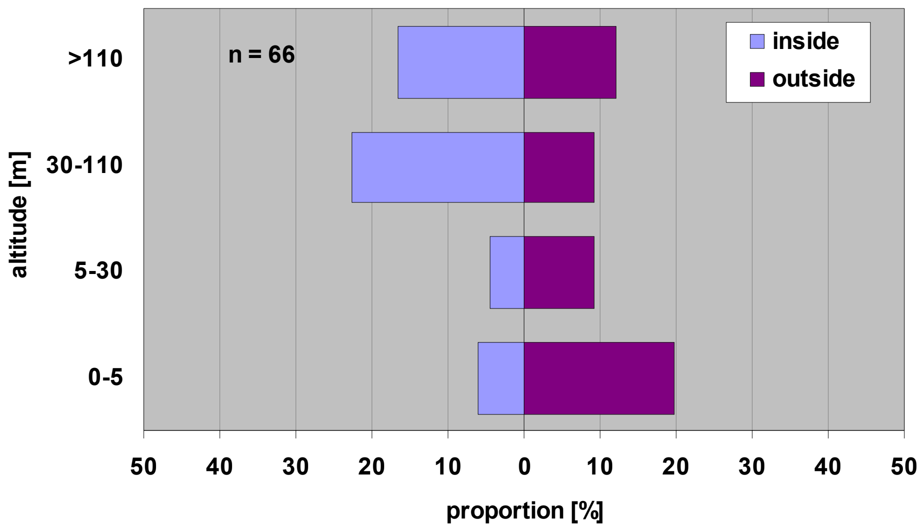


Fig. 2.80: Spatial distribution of birds of prey recorded during standard transect counts in Nysted wind farm area in 2005 and 2006 (n = 66).

Sparrowhawk *Accipiter nisus*

Since Sparrowhawk was the most abundant raptor species we will examine it more closely. When having a look at Sparrowhawk's reactions to the WTGs also those birds flying between the ship and 300 m distance at either side were included (distance class B plus the nearest 30 m); this way sample size became considerably larger.

100 Sparrowhawks were recorded during standard transect counts on both sides between the vessel and 1000 m distance 57 of which could be tracked. Seven of these are spring records while 50 records date from autumn.

Unlike in standard transect counts when the side of the transect was relevant these tracked individuals were divided in those which came out of the wind farm or entered it and those which did not touch the wind farm area at all. In Tab. 2.16 all tracked birds are listed, sorted by altitude. In brackets appears the number for each fraction showing an obvious reaction to the wind farm installations.

Tab. 2.16: Visually tracked Sparrowhawks in Nysted wind farm area and the number for each fraction showing an obvious reaction to the WTGs. See text for details.

altitude	entering/leaving wind farm area	not entering wind farm area
0 – 5 m	16 (2)	2 (1)
5 – 30 m	11 (0)	6 (1)
30 – 110 m	16 (4)	3 (1)
> 110 m	3 (0)	0
Σ	**46 (6)**	**11 (3)**

Although the dataset was not large enough for statistical testing we can say that Sparrowhawks frequently fly into the wind farm and rarely any reaction to the structures can be recognised.

Gulls Laridae

All gulls were pooled regardless of their species belonging. The most abundant gull species in Nysted wind farm area was Herring Gull. Only Common Gull occurred in considerable numbers, too. Little Gull (other than in Horns Rev in Nysted this species was included in the group of gulls as only 170 individuals were recorded), Great Black-backed Gull, Black-headed Gull, Lesser Black-backed Gull and Caspian Gull were observed only in small numbers. The fraction of unidentified species within the gulls is rather small.

2852 gulls were recorded, 1126 inside and 1726 outside the wind farm. Gulls are the taxon with the least difference between both the numbers and the altitude distributions inside and outside the wind farm (Fig. 2.81). However, outside significantly more birds were observed than inside (GLM: n = 848; p < 0.001).

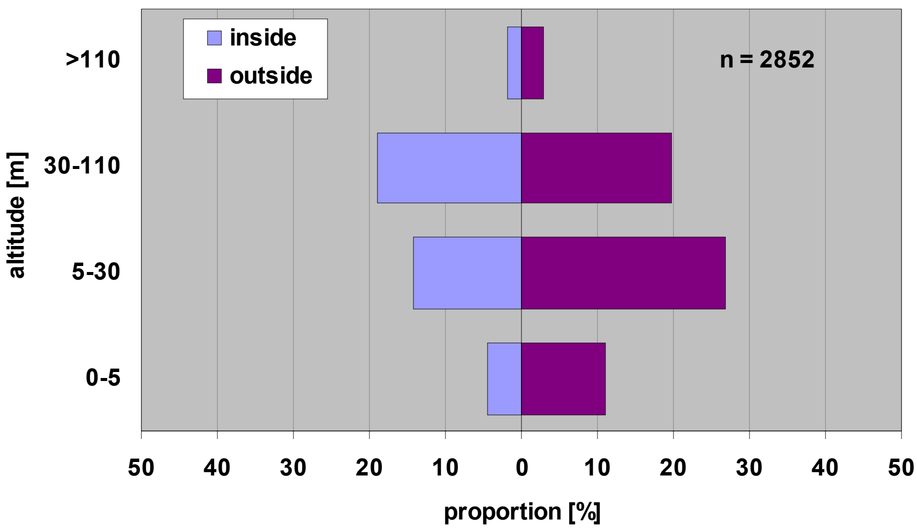


Fig. 2.81: Spatial distribution of gulls recorded during standard transect counts in Nysted wind farm area in 2005 and 2006 (n = 2852).

Both within the wind farm and outside altitudes above the turbines are least preferred and that altitude band just above the water is not much occupied either. Most birds were found within rotor range and below at both sides. Inside more birds were counted within rotor range unlike outside where it was the other way round (ANOVA for 2 LMERs: $p < 0.001$). Thus, altitude distributions of gulls are rather similar on each side both in terms of numbers and proportions; however, statistical testing reveals that more gulls fly outside than inside and the altitude distributions are different.

We can show the relation between wind and flying altitude well for gulls. Staging gulls appear flying in any direction around the observation platform. Therefore we should expect a variety of flying altitudes because the wind direction in relation to the bird is different in every case. Using the example of gulls in Nysted, Fig. 2.82 shows a clear tendency of a preference for lower flight altitudes with a decreasing TWC. This tendency proves valid independently of season and both inside and outside the wind farms, respectively.

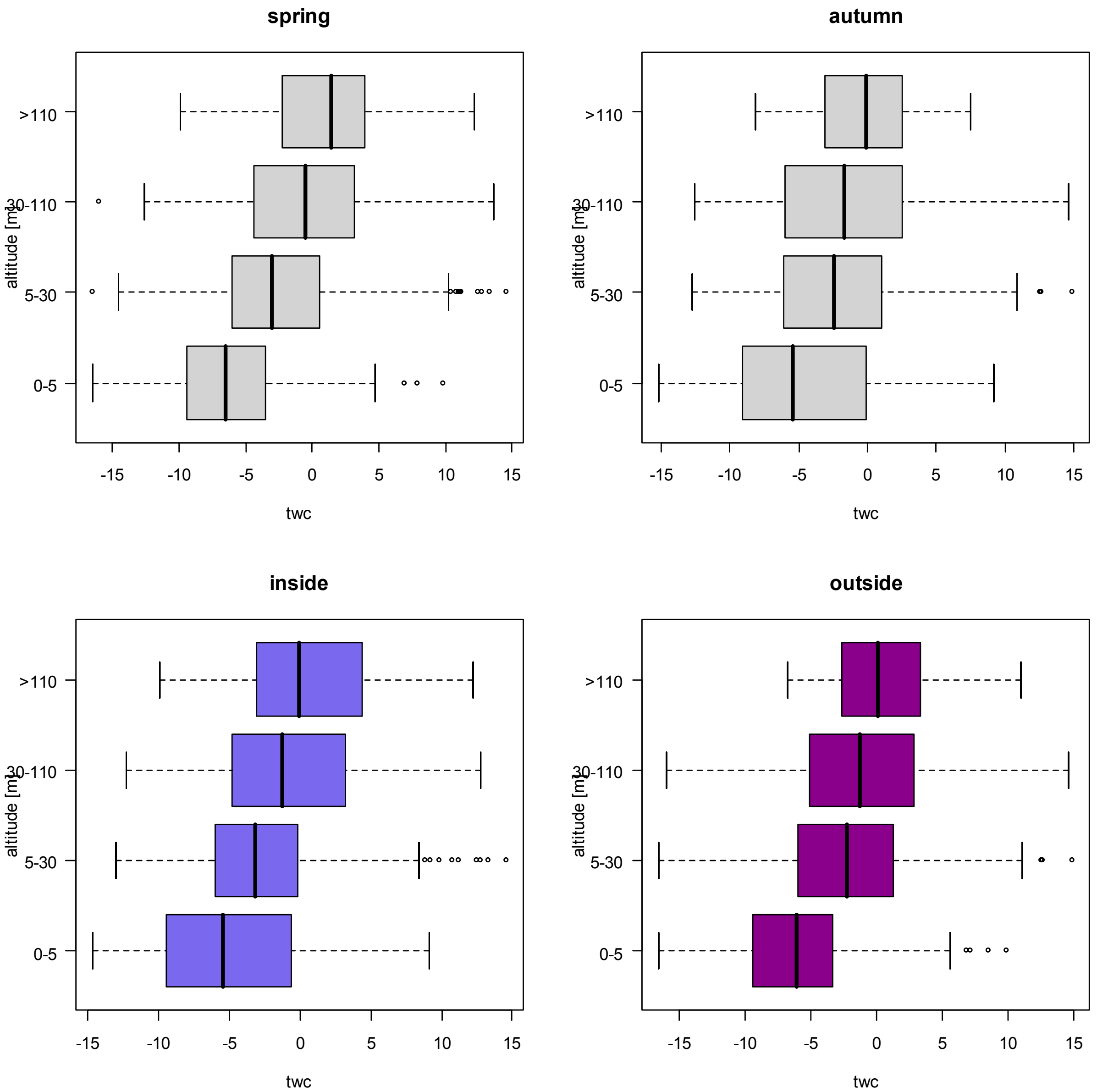


Fig. 2.82: Relation between flying altitude and tailwind component (TWC) in gulls at Nysted wind farm area. Boxes show the first and the third quartile; the bold line shows the median; whiskers show the minimum/maximum value and 1.5 times the interquartile range respectively, whichever is the smaller. In the latter case outliers are plotted individually. n = 1804.

Terns Sternidae

Far more terns were observed outside than inside the wind farm. No birds flew higher than the turbines and only few birds flew just above the water surface. The vast majority was recorded in the altitude below rotor range. Due to small numbers overall statistical analysis was not possible.

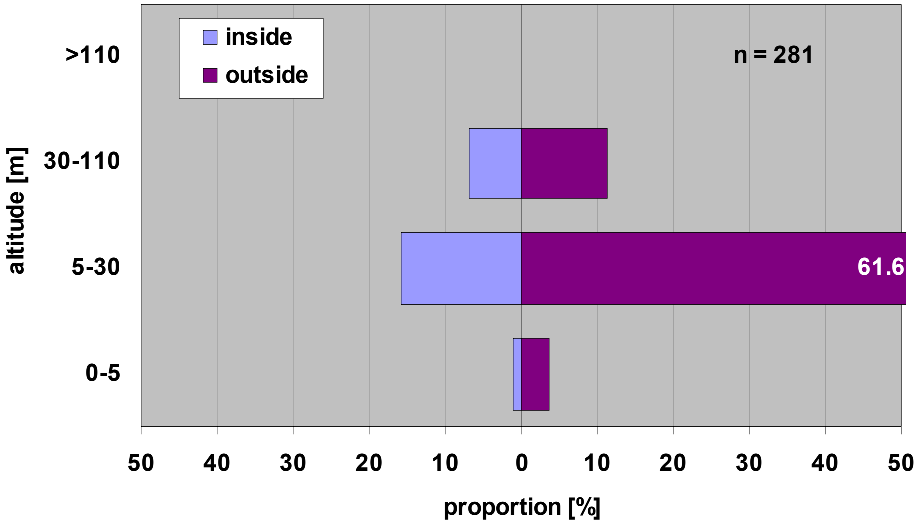


Fig. 2.83: Spatial distribution of terns recorded during standard transect counts in Nysted wind farm area in 2005 and 2006 (n = 281).

Songbirds Passeri

Songbird distribution is presented in Fig. 2.84. Remarks about validity and statistics made in the Horns Rev section apply for Nysted, too. What we can conclude is that songbirds in Nysted mostly preferred the altitude below rotor range, followed by the one just above the water surface. The puzzling fact that more songbirds are detected at the wind farm side might be an artefact; it seems likely that songbirds are easier detected by the naked eye in front of a wind turbine (transect wind farm side) than in front of a unobstructed sky (transect non wind farm side) and this way an underestimation of songbirds in that altitude band on the non wind farm side is likely.

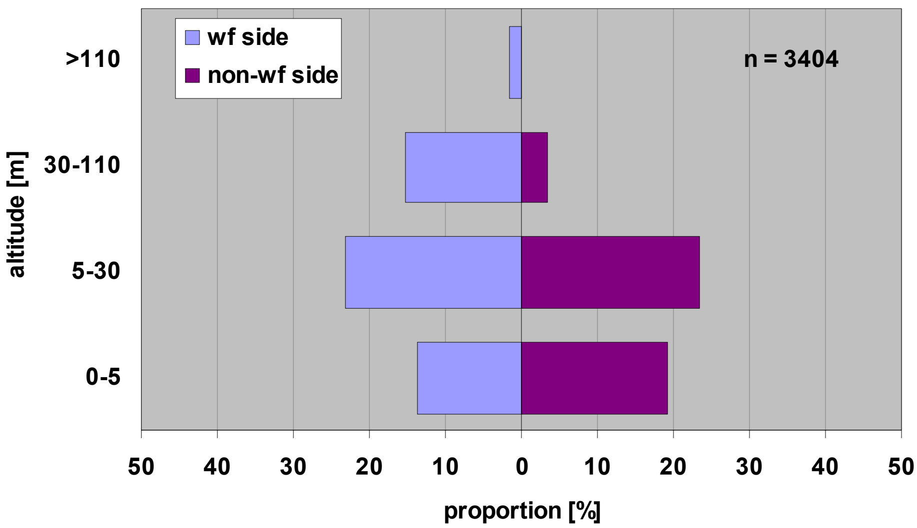


Fig. 2.84: Spatial distribution of passerines except corvids recorded during standard transect counts in Nysted wind farm area in 2005 and 2006 (n = 3404).

Meadow Pipit *Anthus pratensis*

Meadow Pipit again was the largest single species fraction among passerines (almost one third). The differences in spatial distribution of this species to all other songbirds are slight and can not be interpreted strictly (Fig. 2.85).

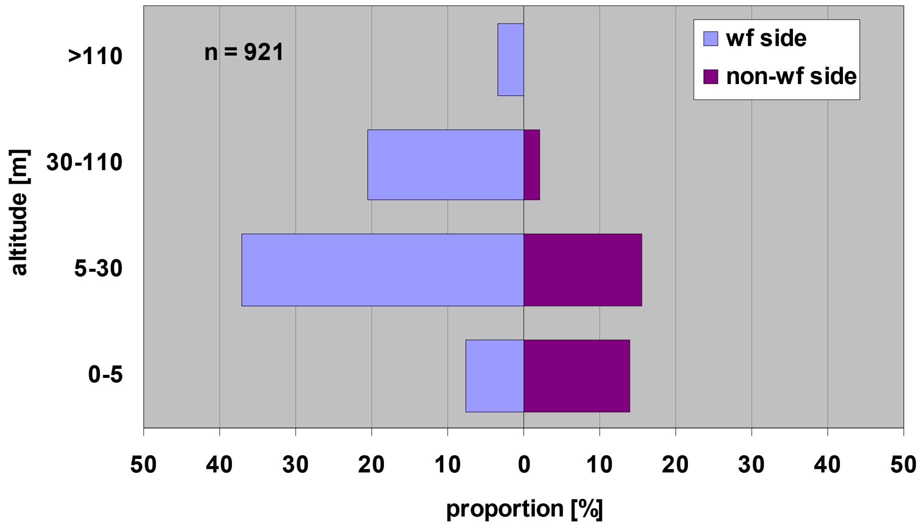


Fig. 2.85: Spatial distribution of Meadow Pipits recorded during standard transect counts in Nysted wind farm area in 2005 and 2006 (n = 921).

Finches Fringillidae

The family of finches was the second largest taxon within songbirds. Their distribution (Fig. 2.86) shows another sample differing from the total of songbirds.

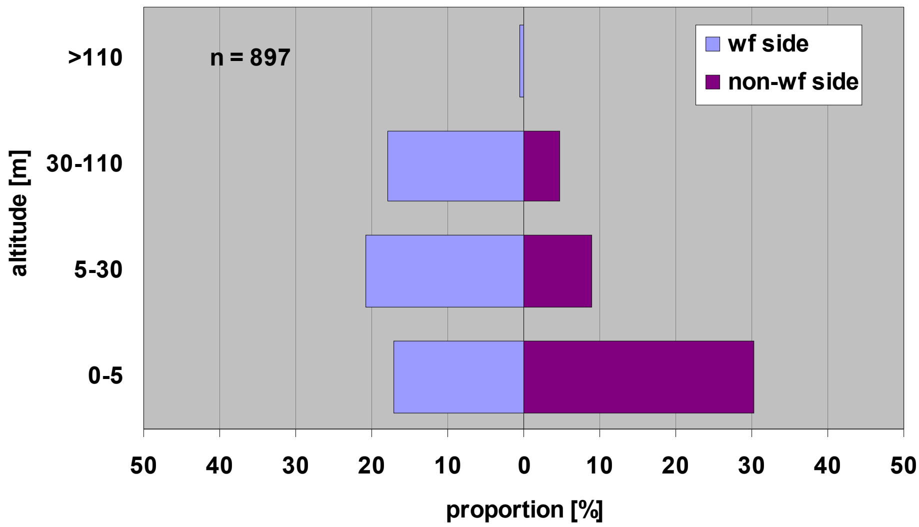


Fig. 2.86: Spatial distribution of finches recorded during standard transect counts in Nysted wind farm area in 2005 and 2006 (n = 897).

2.2.3.3. Reactions of birds towards the turbines

In **Horns Rev** 3452 birds were tracked in spring and 1167 in autumn on the wind farm side during the whole study paying special attention to their possible reactions towards the wind turbines (cf. the methods chapter); the high number in spring resulted from the large numbers of Common Scoter. The number of tracked birds in each taxon and the corresponding percentage of individuals showing a reaction in Horns Rev is charted in Fig. 2.87 (spring) and Fig. 2.88 (autumn).

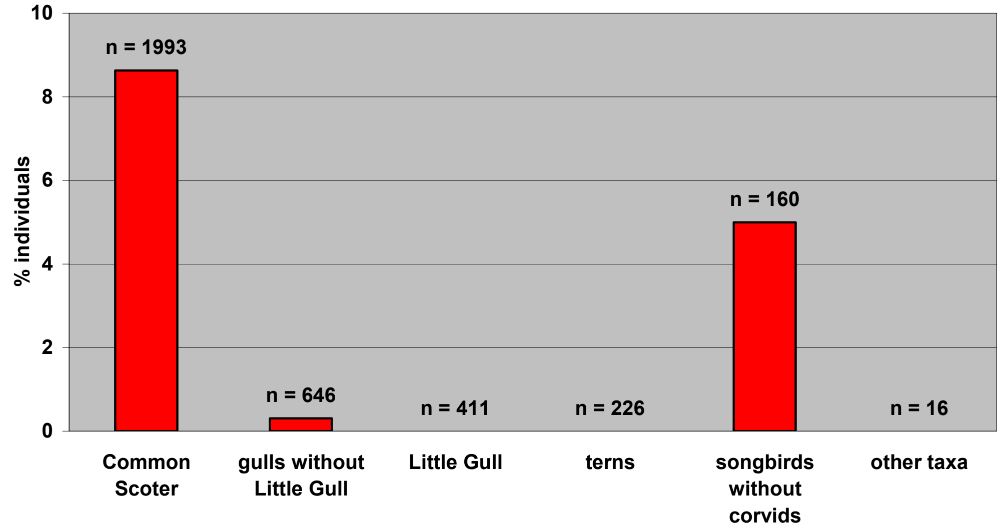


Fig. 2.87: Percentage of birds assorted by taxa showing reaction towards the wind turbines in Horns Rev wind farm in spring (n=3452).

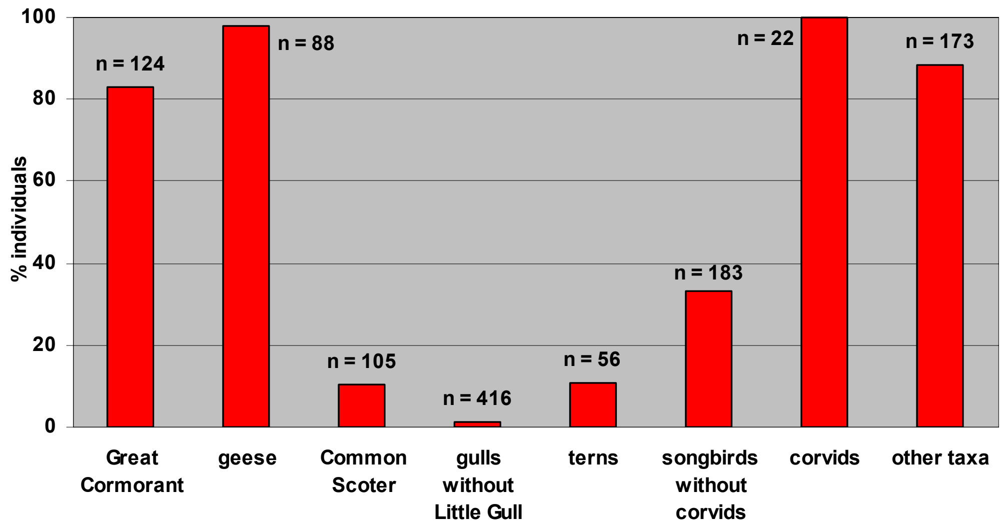


Fig. 2.88: Percentage of birds assorted by taxa showing reaction towards the wind turbines in Horns Rev wind farm in autumn (n=1167).

The largest numbers of individuals could be tracked in Common Scoter (spring), gulls without Little Gull (both seasons) and Little Gull (spring), corresponding to their general appearance in the area.

Less than ten percent of Common Scoter were disturbed by the turbines (in autumn the percentage was similar though total number was much smaller). In gulls (without Little Gull) the relevant percentage was about one percent and Little Gulls did not show any reaction at all.

Terns did not show any reaction either in spring but over ten percent responded obviously in autumn, however, total number was comparably low then.
For Great Cormorant and geese (both only autumn) in more than 80% and almost 100% respectively an obvious reaction was observed. The reaction rate of 100% in corvids is not representative as it refers to a single incident concerning a flock of 22 Jackdaws.

In **Nysted** the number of tracked birds was 1650 in spring and 8537 in autumn; the high numbers autumn is due to high numbers of Cormorants. The number of tracked birds in each taxon and the corresponding percentage of individuals showing a reaction in Nysted is charted in Fig. 2.89 (spring) and Fig. 2.90 (autumn).

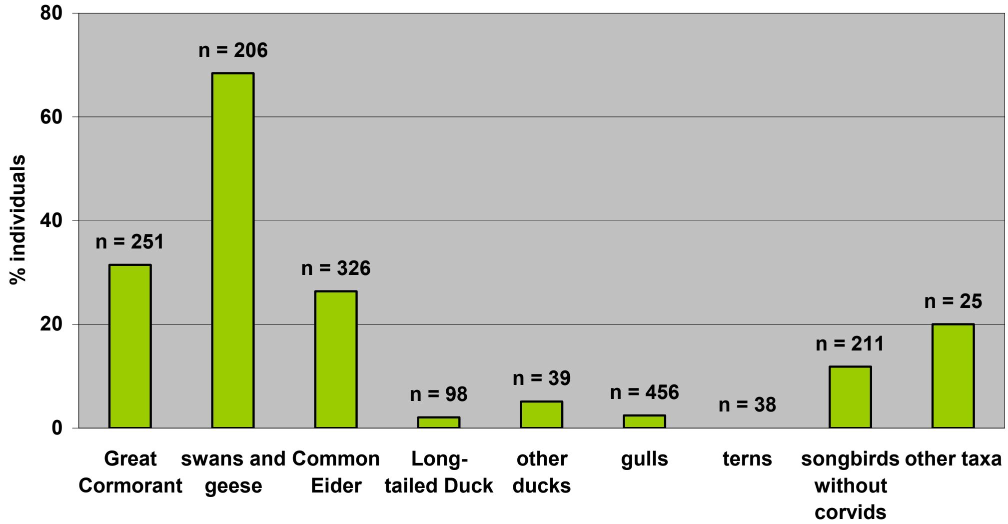


Fig. 2.89: Percentage of birds assorted by taxa showing reaction towards the wind turbines in Nysted wind farm in spring (n = 1650).

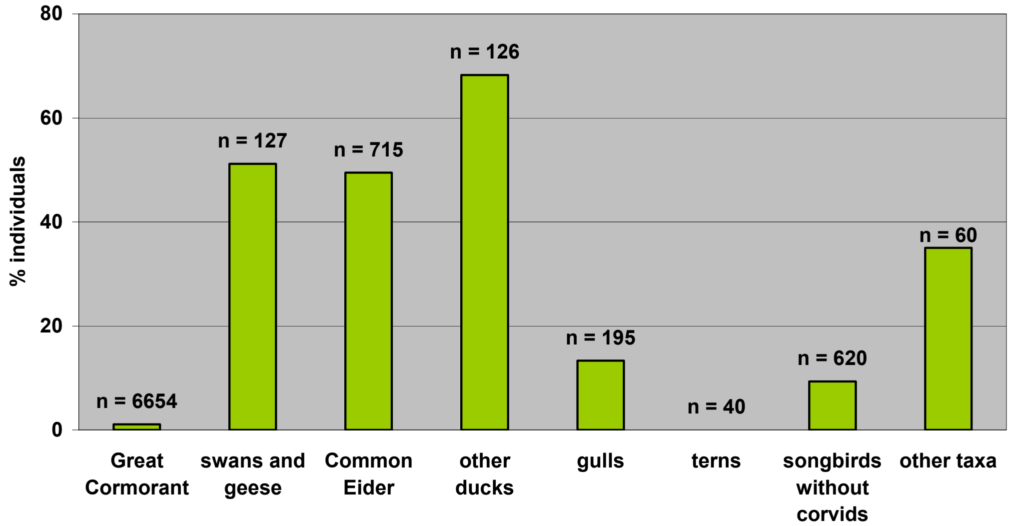


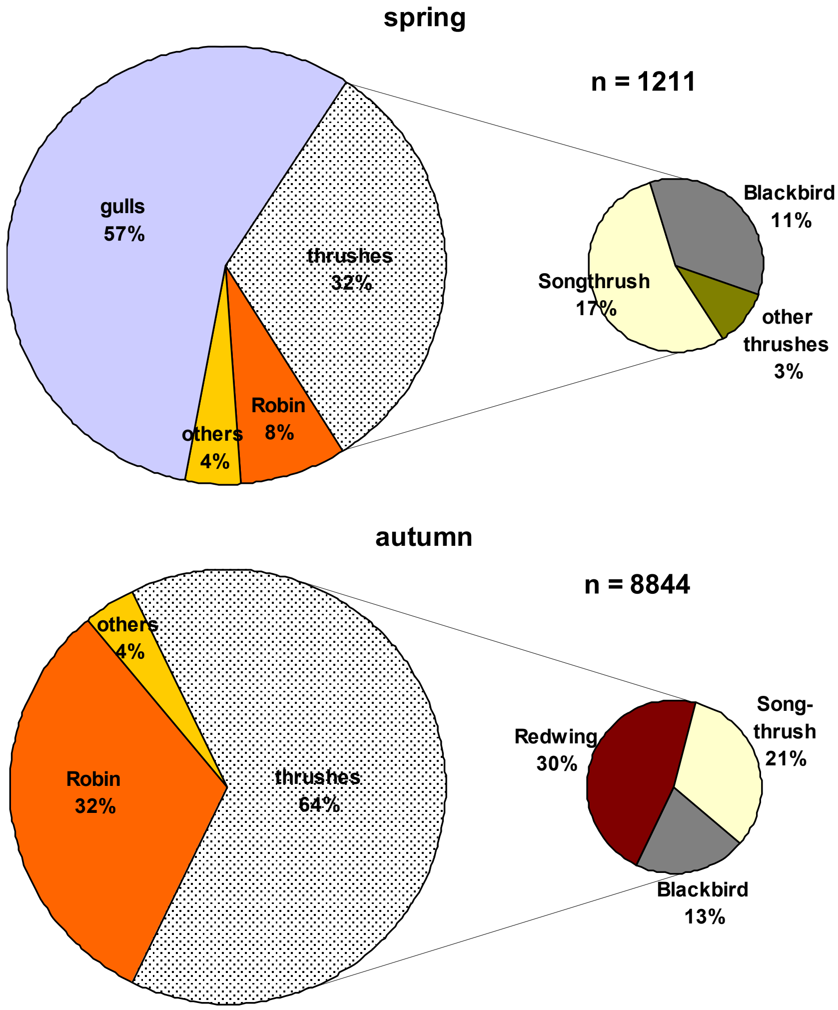
Fig. 2.90: Percentage of birds assorted by taxa showing reaction towards the wind turbines in Nysted wind farm in autumn (n = 8537).

The largest number of tracked individuals was yielded for Great Cormorant in autumn. This is due to the huge feeding associations which occurred in Nysted wind farm area in autumn. Only slightly more than one percent of all Cormorants tracked in autumn showed a reaction

while in spring almost in one third a reaction was recorded. In contrast, Cormorants in spring, while being less abundant, had considerable proportions of reacting individuals.
Swans and geese responded notably in about 70% and 50% of cases respectively in spring and autumn, Common Eiders in roughly one quarter and one half of the cases.
Similar like in Horns Rev, in spring gulls do hardly respond at all and terns do not respond at all. In autumn, unlike in Horns Rev gulls show reaction in almost 15% of cases while terns do not respond at all. However, the number of observation for terns is low both in spring and in autumn. Songbirds responded in about ten percent of cases both in spring and in autumn.

2.2.4. Acoustic observations

The species composition was similar in both areas and was dominated by typical nighttime migrating songbirds. If the calls of gulls are disregarded – gull calls do clearly not reflect migration activity but indicate the presence of staging individuals and were recorded in considerable numbers only in spring in both areas – thrushes (namely Redwing, Songthrush and Blackbird) and Robin made up the largest proportions in spring and autumn both in Horns Rev and in Nysted (g1Fig. 2.91 and Fig. 2.92).
Only in Nysted further taxa were recorded in fractions exceeding five percent. These were ducks and waders in spring (Fig. 2.92 top). However, as ducks are no nocturnal migrants their calling activity only indicates the presence of resting individuals like in the case of gulls. The majority of duck calls originates from the substantial wintering populations of Common Eider and Long-tailed Duck in Nysted wind farm area.
Considerable numbers of songbird taxa besides the two mentioned ones were only recorded in Nysted in autumn: Dunnock, a typical nocturnal migrant, made up 3% and interestingly finches, a typical diurnally migrating taxon, formed 2% of nighttime records (Fig. 2.92 bottom).



g1Fig. 2.91: Species composition in percent from call counts during night time in Horns Rev wind farm area in spring (top) and autumn (bottom), 2005 and 2006 (n_{spring} = 1211; 24 observation nights. n_{autumn} = 8844; 42 observation nights).

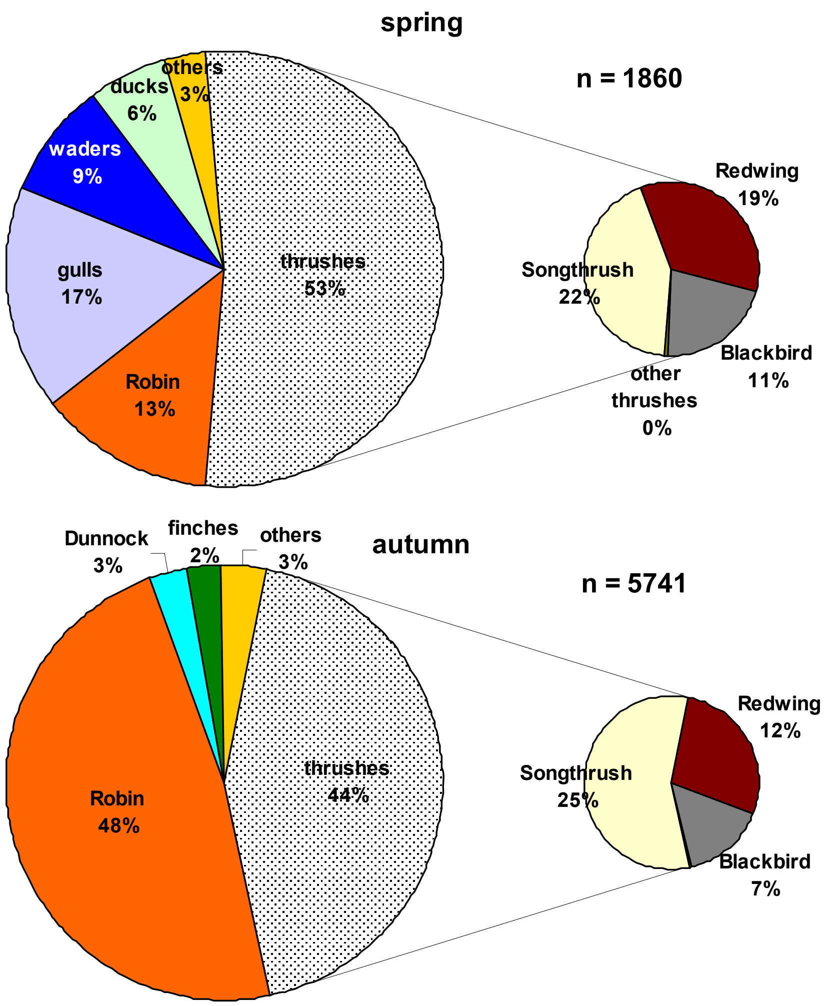


Fig. 2.92: Species composition in percent from call counts during night time in Nysted wind farm area in spring (top) and autumn (bottom), 2005 and 2006 (n_{spring} = 1860; 45 observation nights. n_{autumn} = 5741; 52 observation nights).

The numbers of counted bird calls per observation night are shown in Fig. 2.93 to Fig. 2.96 for both years. In spring 2005 the dataset for Horns Rev was too small to demonstrate the temporal situation. Hence, spring numbers from Horns Rev are only illustrated for 2006.
Bird call counts are several times higher in autumn than in spring (both areas; cf. g1Fig. 2.91and Fig. 2.92). Count numbers for both seasons are much higher in Horns Rev than in Nysted, both in maximum values (cf. Fig. 2.93 to Fig. 2.96) and in numbers averaged per observation night (50/211 for spring/autumn in Horns Rev and 41/110 for spring/autumn in Nysted).

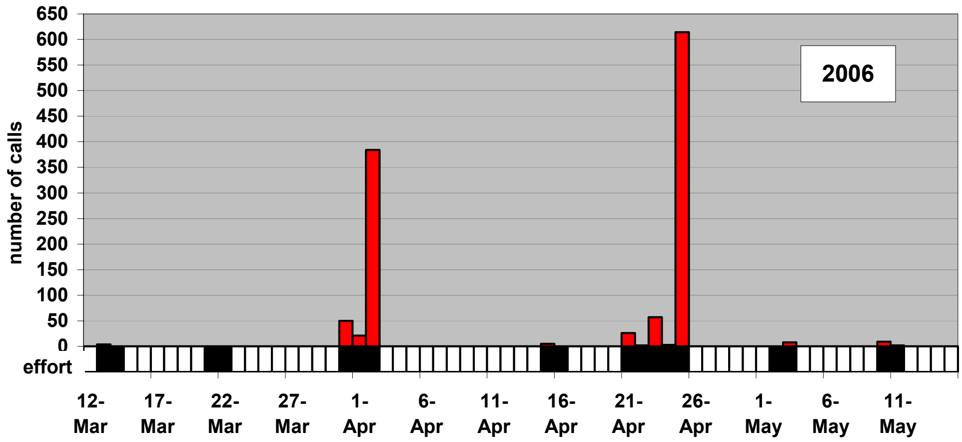


Fig. 2.93: Number of birds calls recorded per night (all species) in spring in Horns Rev wind farm area in 2006. Note that calls are shown and not single individuals. Observation nights are indicated black at the bottom bar.

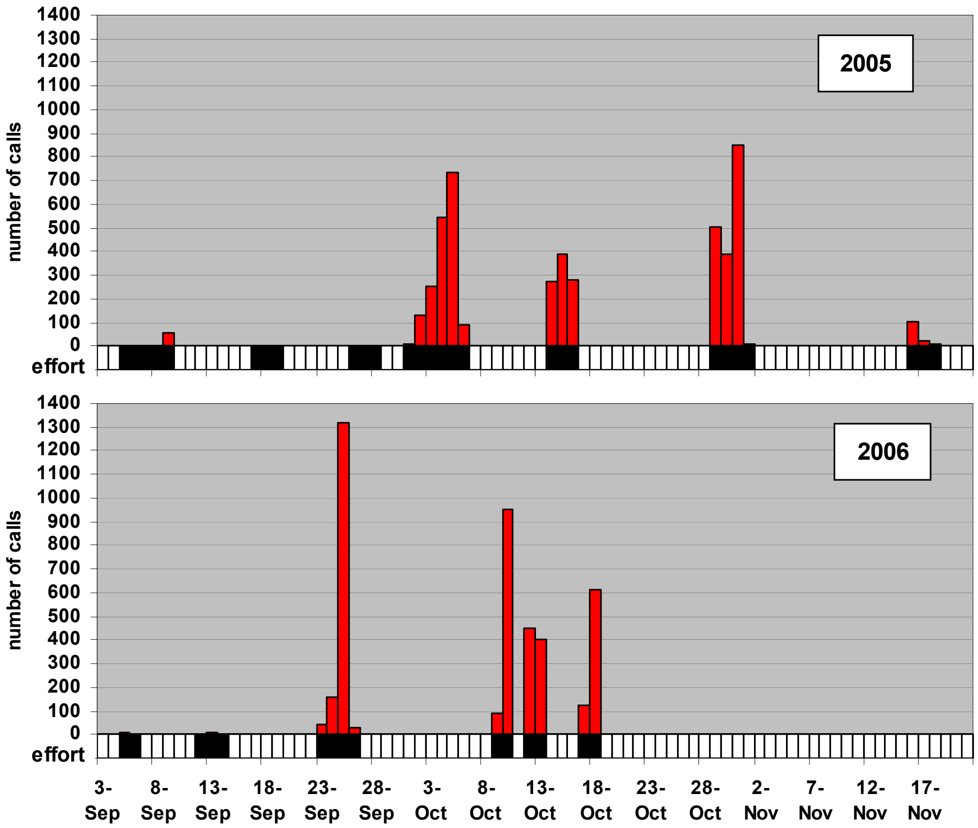


Fig. 2.94: Number of birds calls recorded per night (all species) in autumn in Horns Rev wind farm area in 2005 and 2006. Note that calls are shown and not single individuals. Observation nights are indicated black at the bottom bar.

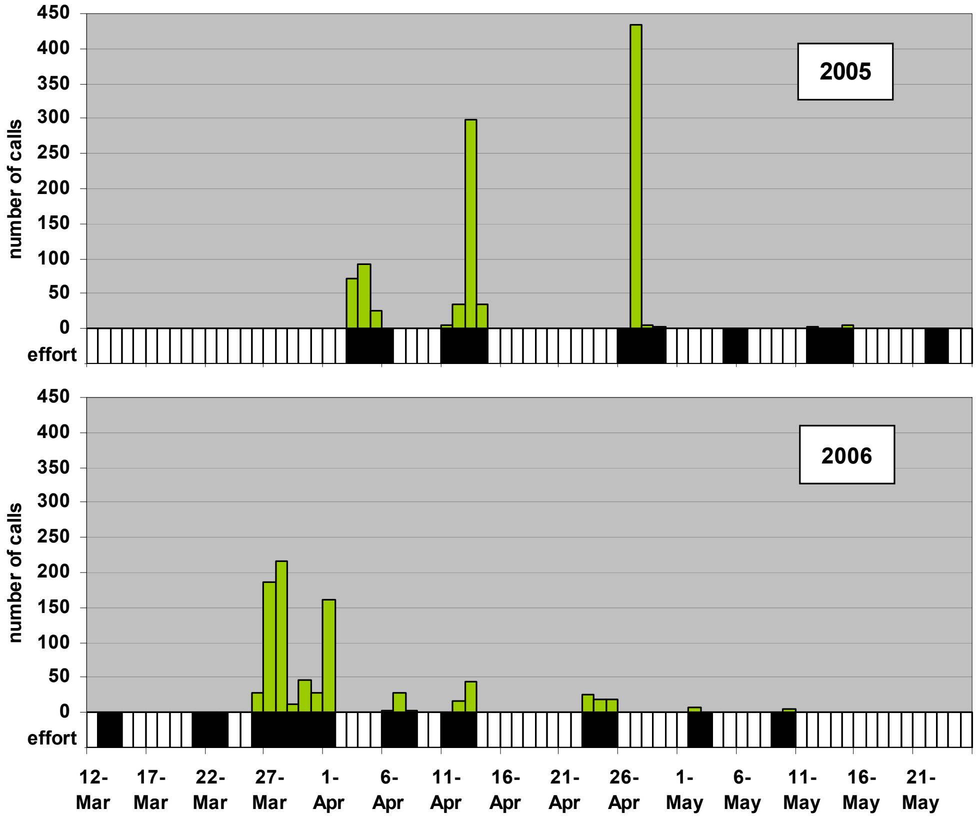


Fig. 2.95: Number of birds calls recorded per night (all species) in spring in Nysted wind farm area in 2005 and 2006. Note that calls are shown and not single individuals. Observation nights are indicated black at the bottom bar.

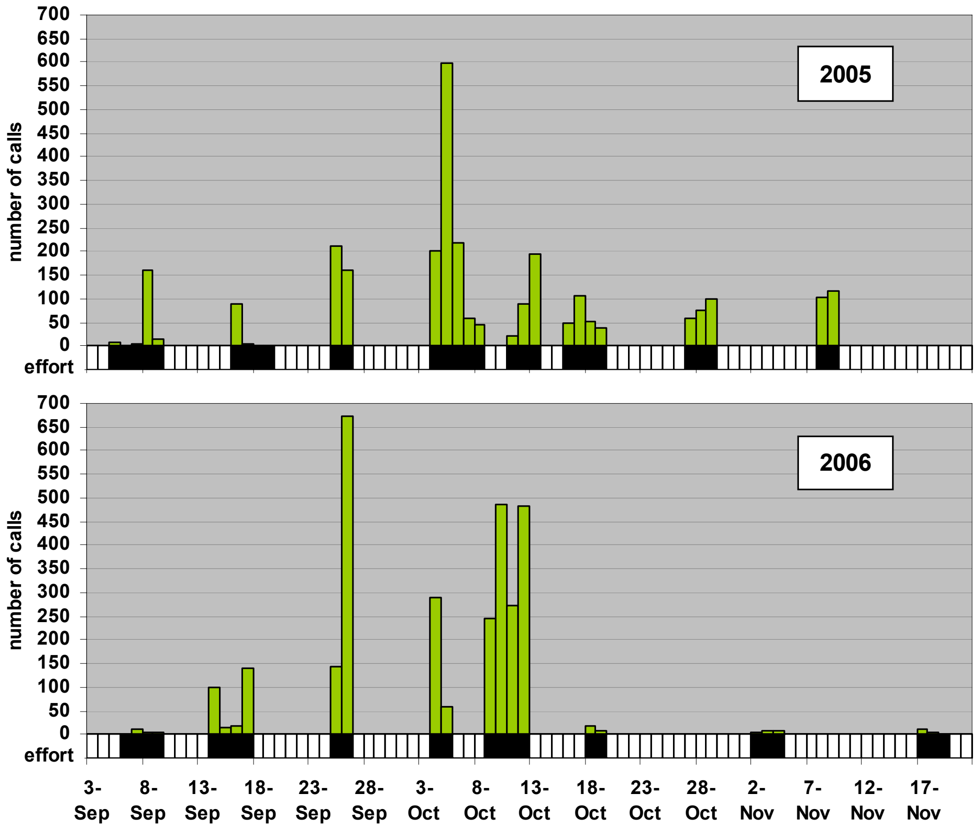


Fig. 2.96: Number of birds calls recorded per night (all species) in autumn in Nysted wind farm area in 2005 and 2006. Note that calls are shown and not single individuals. Observation nights are indicated black at the bottom bar.

2.3. Discussion

This is the first extensive study (in European waters) to conduct ship-based work at existing large offshore wind farms and to collect data to investigate into the associated collision risk of migrating birds. New ground has been entered and new methods had to be applied which were recommended and known prior to the beginning of this study (BSH 2003, BSH 2005, Desholm et al. 2004). The approach of this study took into account the focus, results and methods used of the Danish long-term EIA studies including baseline data and monitoring data after construction at both locations (summarized in Petersen et al. 2006).

At first, the methods applied during this study will be discussed. Secondly, some results of the radar and visual observations will be discussed, representing species numbers, species composition, migrations intensities and distributions inside and outside the wind. The complex avoidance and potential collision risk is discussed in a separate chapter, where the results of the relevant radar or visual observations are assessed.

2.3.1. Methods applied

2.3.1.1. Ship-based investigations

A vessel offers the only possibility to make observations in the close vicinity of the wind farm when no other platforms are available or accessible. Observing near the wind farm again is necessary to assess collision risk especially when it is vital to record behaviour, identify birds to species level, to observe birds close to the wind turbines and to allocate bird observations to inside or outside the wind farm. Earlier investigations in offshore wind farms have exclusively been conducted from land (e.g. Nysted) or from fixed platforms (Horns Rev); both options have to cope with strong limitations. Using a vessel as operation platform, however, is also a compromise. There are some limitations with regard to methods (e.g. one cannot use a scope) and to weather conditions (sea state). However, these are compensated by the benefit to deploy a platform in dependence of season and weather conditions at the desirable locations, in this case preferable at those sides of the wind farm where migrating birds encounter the structure.

Unfavourable weather conditions restrict the methods of visual and radar observations regardless of the platform type – ship or solid platform. Regarding visual observations mainly poor visibility or inclement weather (strong winds, rain) restrict observation time and data quality. During poor visibility visual observations cannot be carried out properly although these weather situations are assumed to be most relevant in terms of collision risk. During darkness and fog, radar can compensate for visual observation lacks, but radar up to date yields no data during rain.

The vessel itself might influence count numbers. On one hand birds might approach the vessel, e.g. gulls or exhausted songbirds during migration or birds avoid ships like e. g. divers and ducks, leading both to over- or underestimation, respectively. Gulls never gathered around the anchoring vessel like they do behind other ship types, especially fish trawlers. In Horns Rev sometimes flocks of almost 100 individuals were resting on the water near the vessel. Some of them will have been counted when they crossed the transect on flight while leaving or arriving. However, their number is marginal compared to the total gull count.

Songbirds circling the vessel or landing on it were excluded from the transect count dataset. Divers and ducks are known to have high flush distances when approached by an object on the water like e.g. an observation vessel during bird count transects. We cannot rule out that flying divers and ducks avoid the vessel. In terms of overall numbers of these species, we consider an underestimate to be irrelevant; in terms of flight paths of approaching individuals it is possible, that e.g. Common Eider in Nysted might show evasive reactions some 2-3 km from the ship, which would not be noticeable from the vantage point.

2.3.1.2. Timing of counts / observation periods / weather

Since birds prefer specific conditions to migrate, periods with low or high migration intensity alternate in dependence of short- and long-term weather conditions. The influence of weather on bird migration is highly complex and confounded by a number of factors and cannot to be considered in detail during this study (e.g. Richardson 2000, Hüppop et al. 2004, Liechti 2006, Thorup et al. 2006, Liechti & Schmaljohann 2007, Hill & Hüppop 2008). Birds, in particular passerines, accumulate on land or at certain landscape features, waiting for favourable weather conditions to cross larger water bodies. They then take off during dusk. Characteristics of periods with high migration intensity are in general: tail winds (TWC > 0), good visibility, and temperature induced migration (falling temperature and rising pressure (= cold fronts) in autumn, rising temperature and falling pressure in spring), no heavy rain or snow (Åkesson et al. 2002). Characteristics of periods with low migration intensity are: head winds (TWC < 0), bad visibility, inclement weather (e.g. Richardson 1990). While there are no clear-cut parameter separation between periods of high and low migration intensity due to the number of potentially influencing parameters, some patterns and peaks of migration become more intense in situations when birds “wait” for good conditions. Thus, when at the location of migration initiation, after a longer period of bad conditions the situation changes into good conditions, pronounced migration peaks can occur (e.g. Åkesson & Hedenström 2000, Erni et al. 2002). However, after such a peak, migration intensity may decrease, even though good conditions stay. Consequently, during a migration period of approximately 90-100 days a large proportion of this migration happens during a few nights (e.g. Richardson 1990, Alerstam 1992, Berthold 2000, Gatter 2000, Zehnder et al. 2001).
We deliberately tried to conduct our observations during periods of good migration, particularly during tailwind situations. Also, boat trips were generally conducted during at least decent weather conditions (low sea state, low chance of rain). Thus, our results are likely to be biased towards high migration intensity. Consequently, a true “migration phenology” cannot be given and comparisons with other continuously running studies are difficult.

2.3.1.3. Radar devices

Radar serves as an indispensable tool, to gather data a) 24 hours a day also at nighttime, b) at ranges larger than can be observed with visual observations, c) on altitude distributions. It is recommended as one of several remote techniques for offshore investigations (Desholm et al. 2004); in Germany it has become mandatory for offshore EIAs (BSH 2007) and has been applied in numerous offshore and onshore studies. Applications are known from other European countries like the UK (e.g. AMEC Wind Ltd. 2000, Metoc 2001, Drewitt & Langston 2006) and from the USA (e.g. Anderson et al. 1999, AWEA 2004, NWCC 2008). Several types of radar devices exist and have been used in bird studies (Eastwood 1967, Bruderer 1997 a/b, 2003, www radarconference.de). For ship-based investigations the marine surveillance radar type (turning t-bar) had been recommended (Dirksen et al. 2004, BSH 2007) and is up to date the only radar device which has been used on vessels offshore for bird studies. Radar configurations used in this study can cover ranges from 250 m to more than 12 km, and can be used in horizontal and vertical mode. Recording radar data by taking screenshots using a "frame grabber" or a digital camera is also a standard procedure. The use of a more sophisticated system of processing the raw radar signal data (Krijgsveld et al. 2005, Kelly et al. 2007, Merritt et al. 2008) was still under technical scrutiny at the begin of our investigations. Within the scope of other investigations, other radar types have been used, e.g. weather surveillance radar (Gauthreaux & Belser 2003, Ruth et al. 2005, Larkin & Kamen 2007), military tracking radar (e.g. Bruderer et al. 1995); lately, pencil beam radar types are applied to measure altitude and potentially wingbeat frequency of birds or insects (Kelly et al. 2007, Ruth 2007).

2.3.1.4. Radar: signal / bird identification

Using marine surveillance radar, it is not possible to distinguish between bird sizes or species (Eastwood 1967, Bruderer 1997 a/b, Schmaljohann et al. 2008). To infer about species composition during day- and nighttime migration, additional aspects have to be considered to characterize migration patterns as well as to correctly assess results.

Species composition can be inferred from the two methods applied:

- Daytime observations adequately cover 1000 m distance and the lower 200 m altitudes for larger birds, while practical no observations are made above 200 m; for smaller birds the observation range is considerably lower;
- Nighttime acoustic observations will cover even less altitude, since – depending on weather conditions, especially wind – passerine calls can only be heard up to 50-100 m; species composition is biased since not all birds emit calls during nocturnal migration (chapter 2.2.4 and discussion in chapter 2.3.4).

In addition we follow the assumption, that passerine migration occurs only during a few days during one season (see discussion in chapter 2.3.1.2); this allows to conclude, that during those mass migration days the majority of individuals registered by the radar particularly during nighttime will be passerines. During the other "low-migration" periods, the species composition of the radar signals is to a high degree unknown.

2.3.1.5. Radar: detection probabilities as relevant for altitude distributions inside and outside the wind farms

A main prerequisite of our investigations is to be able to compare signal distribution between inside and outside the wind farm areas at different altitudes.

Comparisons of overall pooled data inside with those outside the wind farm show, that altitude distributions above 100 m at the 500 m range and above 200 m at the 1500 m range are overall fairly similar in "shape" at both wind farms, but that differences in the number of signals between inside and outside the wind farm exist (Fig. 2.97, Fig. 2.98, Tab. 2.17). We registered between 8% and 28% more signals outside the wind farms. For the 500 m range, large proportions of those differences (73,5% and 64,7%) occur in the lowest altitude categories, hinting at a potential avoidance of the wind farm areas in these altitudes (but see below). At the 1500 m range, differences occur more or less for all altitude classes, with a slight preference of the lower altitudes in Nysted.

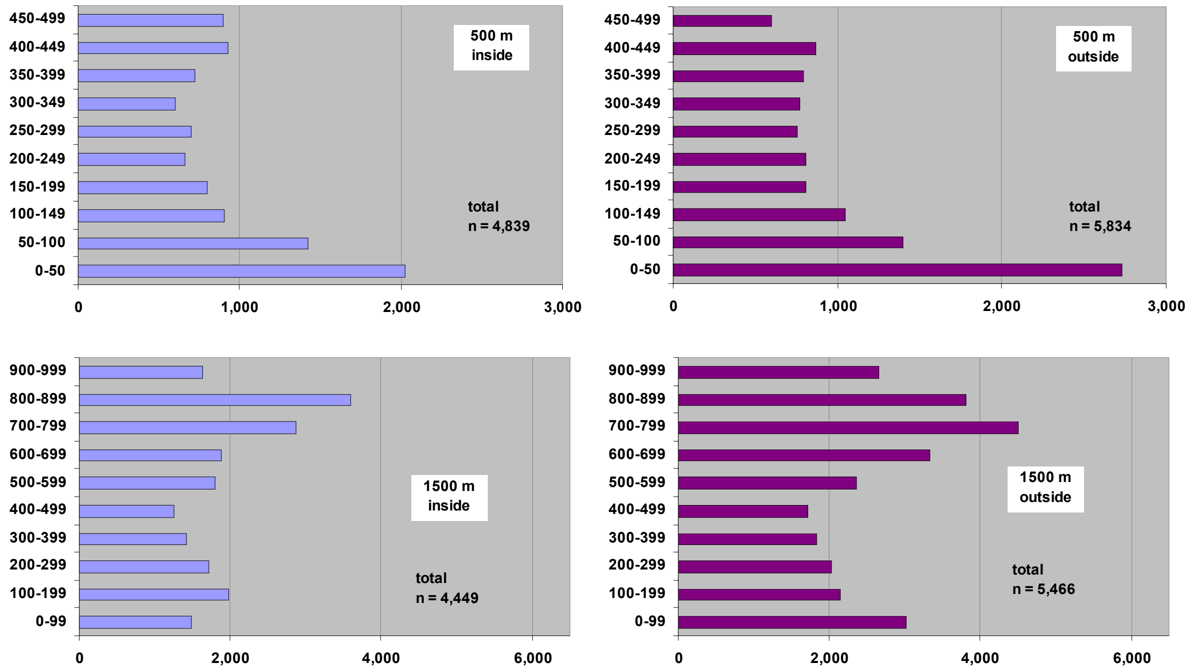


Fig. 2.97: Horns Rev – inside/outside wind farms: summaries of altitude distributions (number of distance corrected signals per altitude band, n for uncorrected signals). Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

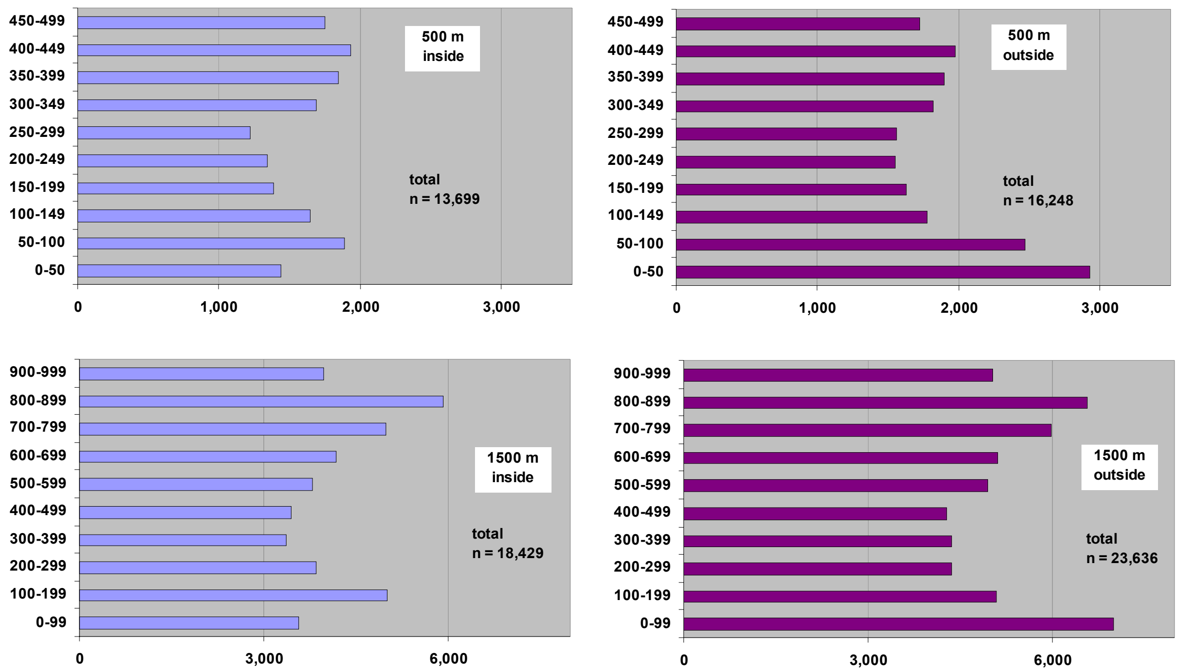


Fig. 2.98: Nysted – in- or outside wind farms: summaries of altitude distributions (number of distance corrected signals per altitude band, n for uncorrected signals). Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

Tab. 2.17: Signals in- or outside wind farms: number of distance corrected signals inside and outside wind farms for ranges 500 m and 1500 m. Differences between selected lower and upper altitude groups.

	HORNS REV					
	range = 500 m			range = 1500 m		
	fractions		total	fractions		total
altitude categories	**0-100**	**100-500**	**0-500**	**0-200**	**200-1000**	**0-1000**
signals inside	3,454	6,206	9,660	3,456	16,173	19,629
signals outside	4,128	6,449	10,577	5,173	22,240	27,413
difference absolute	674	243	917	1,717	6,067	7,784
difference [%]	**16.3**	**3.8**	**8.7**	**33.2**	**27.3**	**28.4**
difference "explained" [%]	**73.5**	**26.5**		**22.1**	**77.9**	
	NYSTED					
	range = 500 m			**range = 1500 m**		
	fractions		**total**	**fractions**		**total**
altitude categories	**0-100**	**100-500**	**0-500**	**0-200**	**200-1000**	**0-1000**
signals inside	3,326	12,809	16,135	8,591	33,570	42,161
signals outside	5,396	13,938	19,334	12,107	40,702	52,809
difference absolute	2,070	1,129	3,199	3,516	7,132	10,648
difference [%]	**38.4**	**8.1**	**16.5**	**29.0**	**17.5**	**20.2**
difference "explained" [%]	**64.7**	**35.3**		**33.0**	**67.0**	

To illustrate these effects, all radar signals are pooled per wind farm and year and are displayed with the signals on the wind farm side on the left and those outside the wind farm on the right half of each figure (Fig. 2.99 and Fig. 2.100).

For Horns Rev, the example of the pooled data for 2005 (Fig. 2.99) show that of the 500 m range the overall signal distribution is regular, however, concentrations can be seen at altitudes < 100 m with signals lacking at that altitude inside the wind farm at distances 250 to 500 m from the ship. The data of the 1500 m range clearly demonstrate decreasing detectability beyond 400-600 m. Also, there seem to be fewer signals inside the wind farm within the area below 400 m and closer than 700 m to the ship compared to outside the wind farm.

For Nysted, the example of the 2006 data (Fig. 2.100) includes considerably more signals than shown for Horns Rev 2005. For the 500 m range results are comparable to those of Horns Rev, also with apparently less signals in the low altitudes inside the wind farm. The figure of the 1500 m range also shows the drop in sensitivity, however, it seems that sensitivity is less reduced for birds flying above than for those flying towards or away from the radar. In addition, a lack of signal density is obvious in the area of altitudes below 300 and distances beyond 600 m from the ship inside the wind farm.

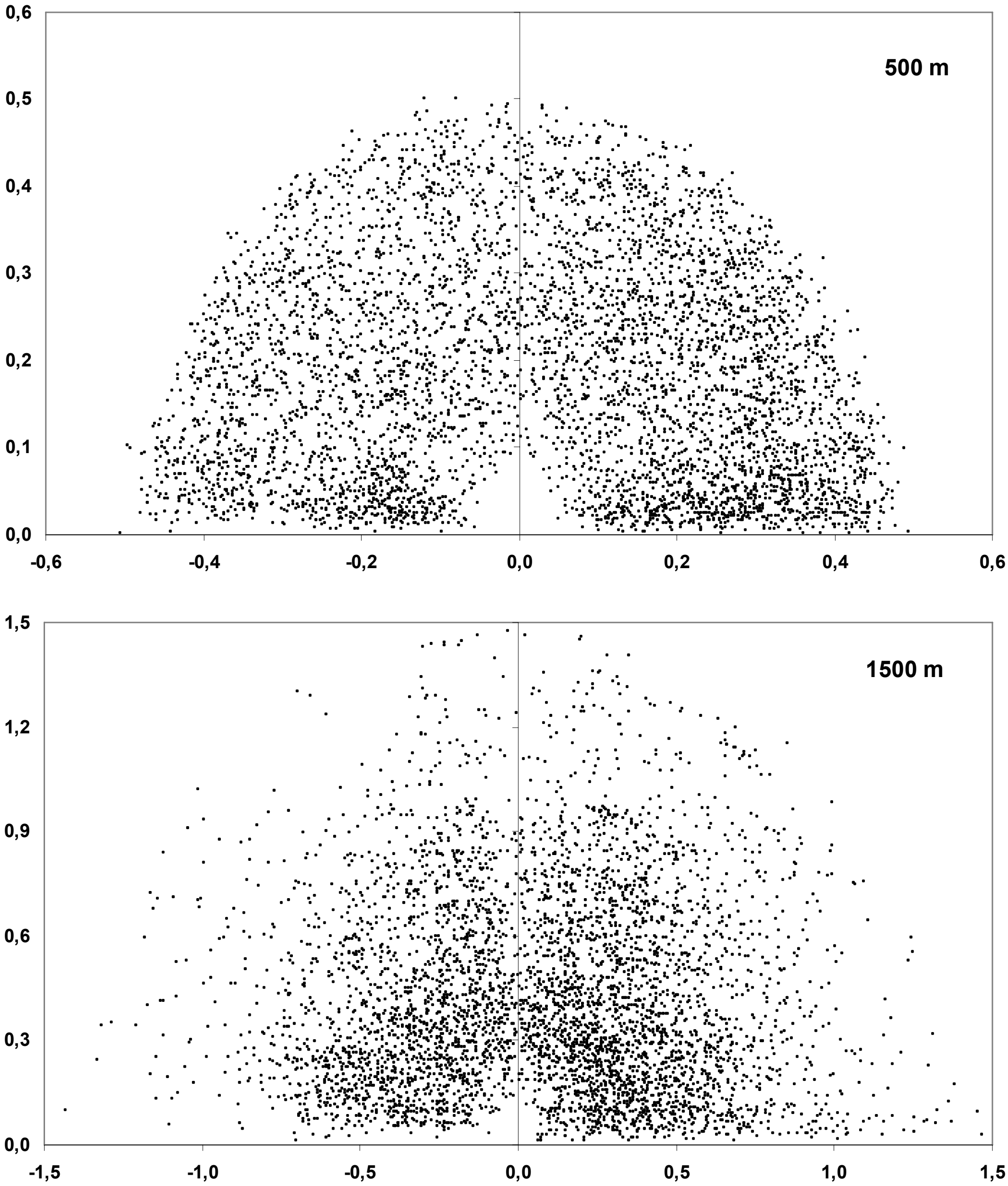


Fig. 2.99: Horns Rev – raw uncorrected radar signals pooled for the year 2005; signals inside the wind farm on the left, outside the wind farm on the right (500 m: n = 5,175; 1500 m: n = 4,892).

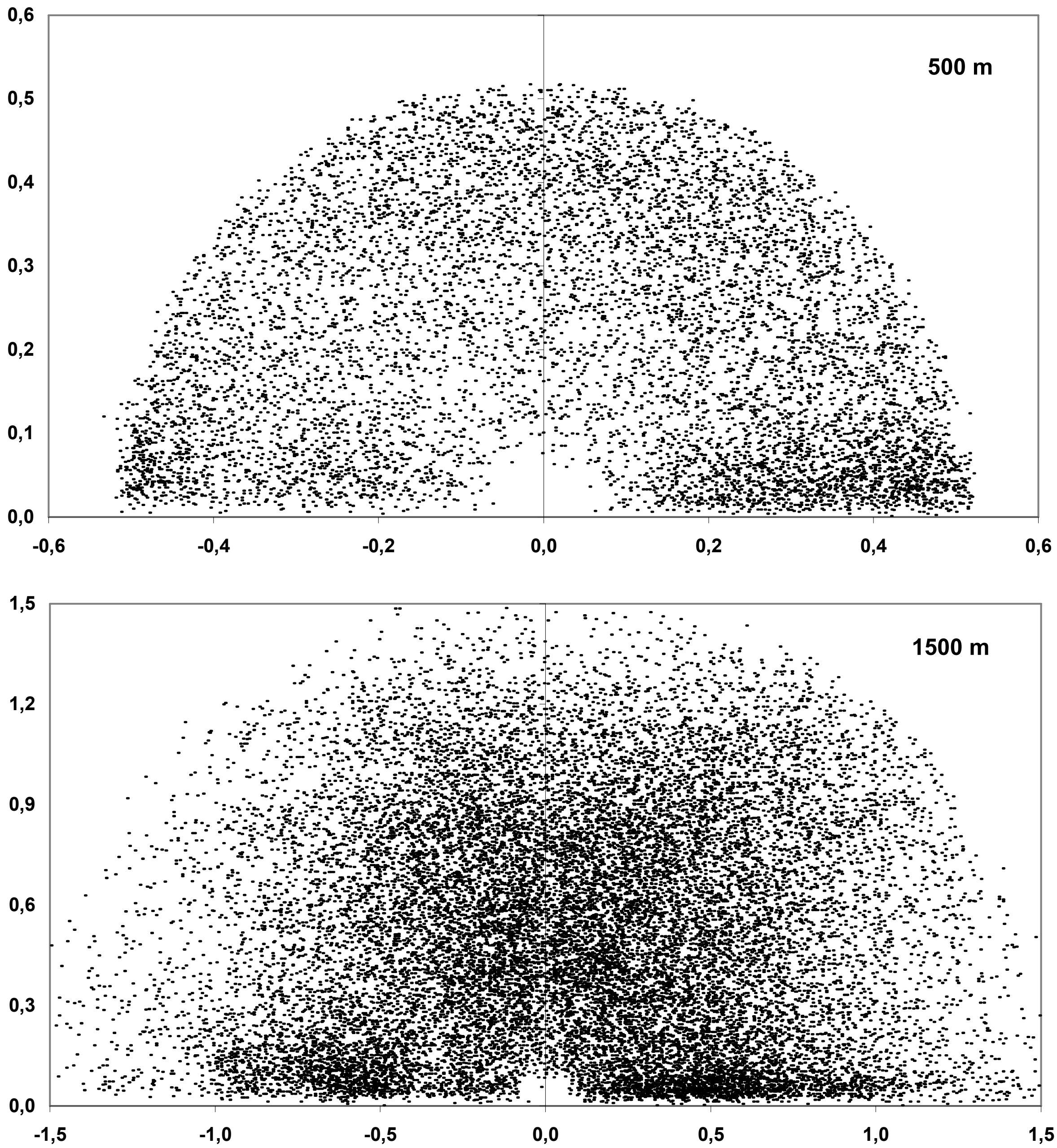


Fig. 2.100: Nysted – raw uncorrected radar signals pooled for the year 2006; signals inside the wind farm on the left, outside the wind farm on the right (500 m: n = 8,621; 1500 m: n = 21,793).

Differences in signal detection as shown and compiled above can have several reasons:

1) Signals are “hidden” by the turbine structures and associated disturbances;
2) Detection varies with the “bird aspect”, i.e. the flight direction of the bird in relation to the radar;
3) There are true differences in bird densities inside and outside the wind farm.

Ad 1) Signals / birds are most likely hidden by the turbine structure and their associated disturbances, covering varying proportions of the radar screen (Fig. 2.9, Fig. 2.10). “Hidden areas” regard in the majority of cases the wind farm side, however, rather frequently mirrored disturbances also appear on the other side of the radar screen.

To account for those would entail to a) measure the extent of the “hidden area” per screenshot; b) to correct for this “hidden area”.

Firstly, manually determining the individual size of the “hidden areas” per screenshot is not possible considering a total number of 73,575 screenshots (Tab. 2.7). However, this is not trivial, since the areas covered by noise are highly variably regarding extent and position on each screenshot, and it would require a time-intensive measuring of the “disturbed” area per screenshot, which has not been applied during this study. Neither was it possible to categorize the “hidden areas” depending on e. g. weather conditions, heeling ship or rain. Many situations, above all during weather conditions with wind speeds above 2 m/s and sea state of more than 1, additional disturbances even appear on the screen as well as the disturbances by the turbines are aggravated.

Secondly, since the distribution of signals on the radar screen is subject of these investigations and is assumed to be influenced at least by altitude and its position with regard to wind farm – and thus irregular - correction is not possible.

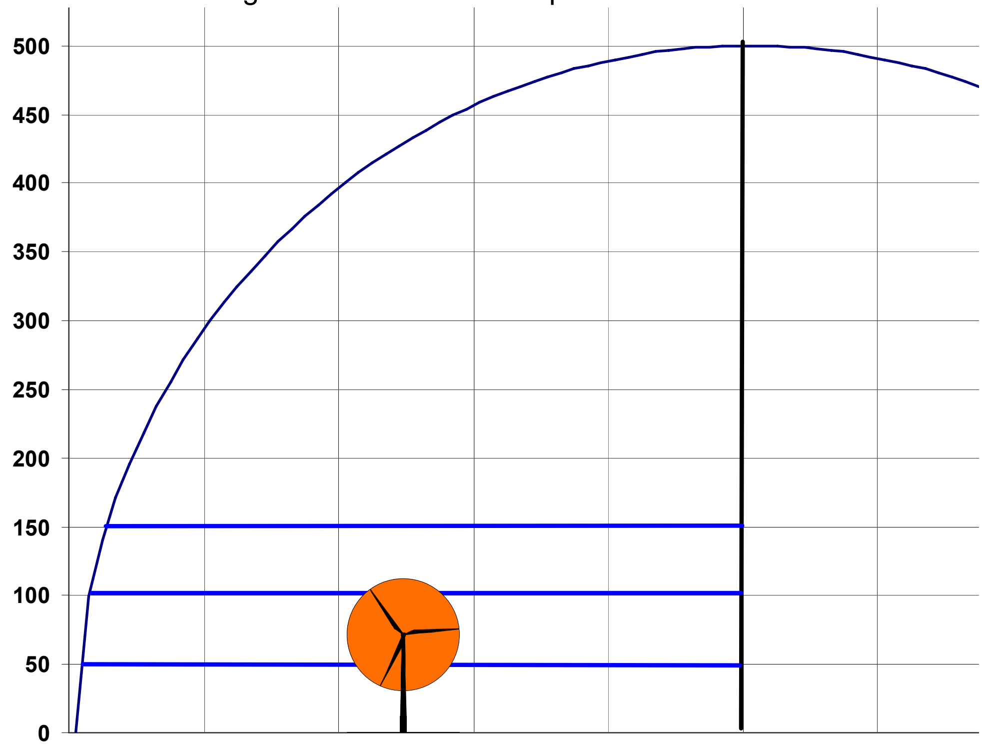


Fig. 2.101: Graphical visualization of areas directly covered by wind turbine structures per altitude band.

Tab. 2.18: Areas covered by wind turbine structures per altitude band.

500 m range	area of altitude band [m²]	area covered by <u>one</u> turbine per altitude band [m²]	area covered by <u>one</u> turbine per altitude band [%]
altitude 0-50	24,987	1,280	5.1
altitude 50-100	24,812	3,749	15.1
altitude 100-150	24,262	392	1.6
altitude 0-200	100.658	5.421	5,4
entire quarter circle	196,349	5,421	2.8
1500 m range	**area of altitude band [m²]**	**area covered by <u>two</u> turbines [m²]**	**area covered by <u>two</u> turbines [%]**
altitude 0-100	149,950	10,842	7.2
altitude 0-200	298,600	10,842	3,6
entire quarter circle	1,767,145	10,842	0.6

A conservative approach to estimating potential losses of radar signals is to calculate the areas “directly hidden” only by the turbine structures per altitude band, that is the area covered by the rotor and the mast. To simplify, the wind turbine is represented in “front view” (Fig. 2.101); this leads to an overestimate, because the three dimensional wind turbine can appear on the two-dimensional radar screen in smaller aspects. However, since the turbine disturbance also contains “hidden areas / blurs” around the turbine structure, an underestimation of the overall “hidden areas” is much more likely. On the 500 m range, where in general one turbine is within radar range, the calculatory area “hidden” by a turbine accounts for different area proportions in the three lowest altitude bands, e.g. for 15.1% in the category 50-100 m (Tab. 2.18). For the 1500 m range, where in general two and more wind turbines are reproduced on the radar screen (Fig. 2.10), only the lowest altitude band 0-100 m is affected, since the proportion of the turbines reaching into the 100-200 m band is negligible and thus not calculated.

By choosing one and two turbines in the two different radar ranges, respectively, the minimum of “hidden area” is represented. The proportions of “directly hidden area” given in Tab. 2.18 correspond well with the registered differences of inside and outside migration intensity for the 500 m range (Tab. 2.17); for the 1500 m range, registered differences are larger and cannot be accounted for solely by “directly hidden areas”.

Ad 2) Birds of different sizes have different detection probabilities (Eastwood 1967). In addition, the so-called radar cross-section *“…a measure of the size of a target as seen by the radar…”* (Bruderer 1997a) of a bird changes dependent on the position of the bird with regard to the radar device. Thus detection probability decreases: birds beamed on the side = birds beamed from below > birds beamed on the head > birds beamed on the rear (see also Poot et al. 2006). During our investigations the vertical radar antenna rotates parallel to bird migration in order to a) detect potential vertical avoidance reactions of birds, b) attribute signals to inside or outside the wind farm. Under the assumption that in most situations bird migration direction was such that birds approached the radar from outside the wind farm and flew away from the radar towards and inside the wind farm, we must take into account that approaching birds will have a higher detection probability than birds flying away from the radar. Poot et al. (2006), using a comparable radar setup (marine surveillance radar 25kw) including an automated radar registration system, report that detection probability for birds flying away from the radar represents only 60-99% of the birds approaching the radar. These proportions are dependent on migration intensity and altitude: During intensive migration higher numbers of smaller sized birds are aloft and detection differences become larger. Detection differences are smaller in the lower altitudes, since low flying birds represent in general the resident large species like gulls and other waterbirds.

Regarding the results of our own investigation, no corrections are made with respect to differing detection probabilities, since tests with the radar devices used are not undertaken, results from Poot et al. (2006) cannot be generalized and other studies for this type and configuration of radar are not available to date. However, potential differences between in- and outside the wind farms must be discussed in light of these findings.

Ad 3) To detect true differences in signal densities inside and outside the wind farm with the current hard- and software techniques, topics under 1) and 2) need to be considered. With only the own data available and in the absence of true calibration possibilities (Schmaljohann et al. 2008), a systematic correction with regard to the above mentioned topics is not possible.

We conclude that:

- Altitude distributions in general are valid; the exclusions of screenshots with rain, large disturbances and presumably large proportions of unknown objects are a minimum requirement.
- Differences between inside and outside the wind farm must be considered with caution. The overall small differences between inside and outside the wind farms might not be conclusive, while strong differences do not exist in the pooled data.

2.3.1.6. Visual observations: Altitude distributions

So far no systematic ship-based visual observation study was conducted in large offshore wind farms putting the main focus on flight altitude. Christensen et al. (2004) carried out trials to calculate flight altitudes from measurements with a declinometer at Horns Rev wind farm in 2003. 61 birds and flocks respectively were included and 77 measurements were taken. During our study we recorded flight altitude classes of altogether over 7,500 events (single birds and flocks respectively) from four migration periods (two years) in both wind farm areas. This can be seen as a substantial step towards a better knowledge of altitude distributions offshore with a focus of altitude distributions inside and outside the wind farms; furthermore it is one of the first attempts to analyse the impacts of offshore wind farms on flying birds.

Obviously one of the biggest problems when dealing with flight altitudes is the accuracy of the measurement and estimation respectively (Dierschke 2003, Hüppop et al. 2004). While Christensen et al. (2004) used a declinometer to obtain measurements as exact as possible, the use of such a device is hardly feasible on a moving platform like a boat. We estimated altitudes in categories leading to ranked rather than to continuous data; Hüppop et al. (2004) also applied visual estimation, however from land based vantage points and with different altitude categories.

Our altitude classes were chosen following the wind turbine measurements, with the categories “below”, “within” and “above” rotor range plus “flying very close to the water surface “. These categories are in the scope of our investigations and thus suffice in terms of assessing the collision risk and it was not deemed necessary to use a finer scale of altitude.

For the wind farm side the error in estimation should be marginal as the turbines formed a useful guidance for altitude classification; however, on the site opposite to the wind farm, this estimation is subject to considerable subjective error.

Intercalibration between the observers was done regularly and intercalibration with the radar was done as often as possible.

2.3.1.7. Visual observations: Double counts

An error source of the transect method can be potential double counts. It was not feasible to track every single bird and for local birds with a large activity range such as gulls this was also impossible. For birds which were counted in very low numbers and which are typical migrants double counts are not likely at all. These are cranes, waders, skuas, pigeons, Short-eared Owl *Asio flammeus* and swifts. Also, typical landbirds which pass the sea only during migration such as birds of prey and songbirds are not a matter of possible double counts. A potential exception are Sparrowhawks which sometimes flew non-directional and

appeared flying in any direction, even opposite to the migration direction. They frequently approached the vessel and circled around it, yet double counts of this species are still not likely.
Taxa most likely to be double counted are the more resident bird groups like Great Cormorant in Nysted, gulls (incl. Little Gull) and Common Scoter and Common Eider in Horns Rev and Nysted respectively. All are present in the area in large numbers. Cormorants in Nysted commute between roosts and foraging sites and hence will have crossed the transect line twice or more in different directions during one day. Common Scoters and Common Eiders shift between different spots and gulls often fly opportunistically in any direction within a certain range and therefore might have passed the transect more than once.
As we have no idea about the amount of double counts we do not correct for it but we do not consider them to be of concern either.

2.3.2. Radar observations: Migration intensities and altitude distributions inside and outside the wind farms

Migration intensity (or bird density) as measured during radar studies is generally given as the so-called “mean traffic rate” (MTR; echoes * hour^{-1} * km^{-1}) (e.g. Hüppop et al. 2002, Wendeln et al. in prep.) or “flux” (Krijgsveld et al. 2003); in other cases it is given as signals per radarscreen (Hüppop et al. 2005). Precondition for the calculation of the MTR is, that the vertically turned radar rotates perpendicular to the expected bird migration direction. Vertical radar cuts a slice through the air space (Fig. 2.5) and in those cases birds crossing this slice have a short distance of detection and appear on the radar screen as single dots (without a track).
During our studies, the vertical radar has been rotating parallel to the expected migration (Fig. 2.1, Fig. 2.2) and birds flying along the radar beam are registered as yellow dots with a blue track (Fig. 2.7, Hüppop et al. 2005). With the ship close enough to the offshore wind farm, altitude distributions can be described separately for inside and outside the wind farms; also, tracks can be analysed with regard to vertical avoidance reactions. Consequently, migration intensity sampled by this method is not comparable to other studies. Thus, the parameter “signals per screenshot” suffices and no effort has been made to calculate an MTR or signal densities for a given air volume.
Those migration intensities vary with time of day, year and season as described in chapter 2.2.1.1. Massive migration with high bird numbers - generally songbirds - occurs during nighttime. Depending on the migration speed of the individual species and the distance to the location of migration initiation on land, birds can be observed after a time-lag at the offshore locations covered by radar (e.g. Åkesson et al. 2002). Consequently, migration intensity increases some time after sunset / civil twilight, peaks after a while and generally ceases with the morning dawn. This has also been found in related offshore studies (e.g. Zehnder et al. 2001, Hüppop et al. 2005).
For the migration intensity data pooled over all, for seasons and for years, some general patterns emerge. There are more signals in autumn than in spring and more signals during night than during day. These results are in line with many other studies (Hüppop et al. 2005, 2006a); they might be even more pronounced during our investigations, since our effort concentrated on the migration seasons and within those on days with favourable migration

conditions (chapter 2.3.1.2). For Horns Rev applies, that the high autumn migration intensities are due to birds taking off close to Blåvandshuk, whereas during spring migration birds approach more broad-front from the Southwest and are less likely to pass the wind farm location; consequently, spring migration intensity was considerably lower.
For most seasons, higher migration intensities are registered at Nysted both day and night (Fig. 2.18, Fig. 2.19); results of daytime observations support that in Nysted more birds have been counted than in Horns Rev, even when subtracting the incidents of high Cormorant counts (Fig. 2.64, Fig. 2.65). Methodological reasons may account for this such that timing of observation has been different in both wind farms; ship trips to Horns Rev have been more weather dependent than to Nysted, potentially giving a bias to the results. Also, different species are represented in the results. Nysted is located close to land, clearly within a migration route of sea ducks (Petersen et al. 2006); songbirds and raptors cross the Baltic at this location more easily. In contrast, Horns Rev is more of a true offshore location, lacking the massive seaduck migration; only those songbirds and raptors appear at this location which are destined to start a considerable offshore distance. No references can be made to other studies at the Baltic and North Sea to further discuss these differences, since recorded bird numbers have not been related to observation effort and are thus not comparable to our study. Also, up to date no gradient of migrating bird density depending on distance to shore has been detected (e. g. Hüppop et al. 2004).

Altitude distributions for the 500 m range show, that at Horns Rev a relative dominance of the lower altitude band exists for day- and nighttime data, whereas at Nysted no clear preference of lower altitudes is registered (chapter 2.2.1.3). This might suggest for Horns Rev, that at this resolution resident birds dominate the overall lower migration intensity. At Nysted, this dominance cannot be registered within a generally higher migration intensity.
At the 1500 m range, more relevant for the discrimination of intensive and low migration, at Horns Rev, peak migration events in autumn 2005 override the effects of the other three seasons with generally low migration intensity. Thus, a relative dominance of the higher altitudes above 700m, as registered during autumn 2005 might conceal potentially less typical altitude distribution during the other seasons. At Horns Rev, nighttime distribution clearly shows migration at high altitudes. At Nysted, most altitude distributions of the pooled data show no obvious patterns; only the separation into day and night reveals a higher migration intensity above 500 m during nighttime in contrast to a regular altitude distribution during day. We conclude, that for Nysted – in contrast to Horns Rev - an overall medium to high migration intensity exists, either characteristic for the location or biased by different investigation effort.

2.3.3. Visual observations: Species composition, numbers, spatial distribution inside and outside the wind farms

The two wind farm sites and investigation areas are situated in important spots for migrating and staging birds. **Horns Rev** wind farm is situated ca. 14 km westsouthwest of Blåvandshuk, a spit representing the nearest shore and the westernmost point of Denmark. Naturally a concentration of migrating landbirds can be observed at this prominent geographical structure, especially in autumn. The neighbouring open North Sea and the edge of the Wadden

Sea with its tidal characteristics create a specific environment which yields large numbers of migrating and staging waterbirds like divers, seaducks, waders and others (Jakobsen 2008, Blew et al. 2007). Finally the shallow submerged sandbank of Horns Rev itself forms an important habitat, namely for Common Scoter (Petersen et al. 2006, Peterson & Fox 2007).

Nysted wind farm is situated south of a row of sandbars forming the incomplete edge between a broad sound and the Baltic Sea. The present mixture of several different habitat types leads to large numbers of different staging bird taxa like Great Cormorant, seaducks (most numerous Common Eider), gulls and others (Kahlert et al. 2002).

The headland Gedser Odde some 12 km east of Nysted wind farm is a concentration spot for bird migration. It forms a prominent protrusion in the coastline where in autumn migrants following the coastline meet the open sea and cross it southwestbound (Kahlert et al. 2000, 2001, Desholm et al. 2003). In spring, diurnal migrants concentrate at the German island of Fehmarn to cross the Fehmarn Straits and then follow the coastline in eastern direction leading them into the investigation area. Migration of geese and birds of prey is very conspicuous there. Songbirds are not that noticeable but even more numerous (e.g. Koop 2002, Koop 2004).

In both areas, Horns Rev wind farm and Nysted wind farm, ornithological investigations were carried out in the course of the EIAs by the Danish National Environmental Research Institute (NERI; Department of Wildlife Ecology and Biodiversity), covering the late 1990s and thus the situation before construction of each wind farm. A comprehensive summary of the regarding monitoring work is given in Petersen et al. (2006).

At Blåvand Bird Station, a bird observatory at Blåvandshuk, regular bird counts are carried out since 1963. Recently, count data from 1993 – 1999 were published (Jakobsen 2008).

Number of **divers** recorded during our investigations in Horns Rev is remarkably low. Horns Rev area is known to be an important place for migrating and wintering divers. Petersen et al. (2006) documented seasonal high densities throughout their study period of seven years. Highest numbers are encountered from February to April (Petersen et al. 2006) and in March/April plus September/October (Blåvandshuk, Jakobsen 2008) respectively.

The fact that we had only two spring records at all might be partly because we missed the migration peak in spring 2005 due to the delayed onset of the field survey that year. During spring 2006 the observation program was fulfilled, but also started late due to a very cold early March. Certainly our low counts of divers owe to the fact that they avoid the wind farm area in a large scale in terms of general distribution (Petersen et al. 2006); also, divers exhibit large flight distances (e.g. Bellebaum & Diederichs 2006) and boat traffic might be an additional disturbing factor. In Nysted divers do not play an important role. Counts were higher in spring there.

The **Gannet** does not occur in the Nysted area but is a typical species in Horns Rev. Although highly pelagic Gannets are known to appear close to the coast line after the breeding season (e.g. Jakobsen 2008). Their general distribution is highly variable and depends largely on the mobile food resources (Petersen et al. 2006). Due to low counts of this species during our visits could we cannot draw conclusions regarding wind farm avoidance.

For **Cormorants** the situation is different in the two investigation areas. In Nysted both staging and migrating birds are present in the area. There is no systematic / objective way to distinguish between those two groups, even though we have clues from our observations to allocate birds/flocks to either category: Single individuals or small groups flying in low altitudes (up to ca. 30 m) in any direction (including migration direction) are most likely local birds as well as the huge social feeding association of up to several thousand individuals. Medium sized flocks in higher altitudes (rotor range and above) flew mostly in migration direction and showed - in opposite to the former group - frequently reactions towards the turbines. These birds will be passing migrants not familiar with the local situation.

In Horns Rev the number of resident Cormorants is small in comparison. Flock size, flight directions and altitudes indicate a very high proportion of migrants. At Blåvandshuk Cormorants were counted in considerable numbers only in late summer and in autumn (Jakobsen 2008). Both in Horns Rev and Nysted Cormorants habituated to the wind farm and used the foundations and in Nysted the meteorological measuring masts around the wind farm as perches. While these birds use the structures, they approach the risk zone more often. Very conspicuous in Nysted were huge social feeding associations of up to several thousand individuals (cf. Desholm et al. 2001, Desholm et al. 2003, Petersen et al. 2006). They occurred in the immediate vicinity as well as inside the wind farm but were always restricted to the lowest altitude of just above the water surface as birds flew only from the end to the head of the diving and swimming flock.

Geese occurred in both areas migrating, however in low numbers. Geese are more likely to follow the coast line during migration. Thus, only few observations exist close to the offshore wind farms, of which anecdotal observations exist. At Blåvandshuk geese were recorded regularly in considerable numbers especially in autumn (Jakobsen 2008). In Nysted wind farm area several thousand geese (probably Barnacle Geese) were observed in the morning of May 7th 2005 migrating along the coast line in easterly and northeasterly directions far north of the wind farm.

Common Scoters occurred in both areas but were not present in considerable numbers at Nysted. The coast line along Blåvandshuk, Skallingen and Fanø and the eastern Horns Rev have always been an important site for Common Scoters (Jakobsen 2008, Petersen et al. 2006). Densities even increased and distribution partly shifted in recent years. However, the present distribution offshore is patchy and along the Horns Rev structure densities are lowest at the wind farm site (Petersen & Fox 2007). Hence our count numbers are far below the ones of Blåvandshuk (Jakobsen 2008).

Proportions of birds entering the wind farm correspond in our and the Danish investigations (Petersen et al. 2006). Although the majority flies outside the wind farm we must assume that considerable numbers of Common Scoters pass through it and also linger inside. Anecdotal observations on passage to/from the anchoring sites and during POD deployment revealed that in spring 2006 large numbers swam inside the north-western part of the wind farm. Thus, Common Scoters do avoid the wind farm to some extent, but not in a large scale. Common Scoters do use the wind farm area both passing in flight and staging on the water and it can be expected that a habituation exists (Petersen & Fox 2007).

Common Eiders occurred in both areas. In Horns Rev distribution is mainly restricted to the coast line where they occur in higher densities (Petersen et al. 2006); numbers are too low to be analysed for the wind farm area. The area south of Nysted around the wind farm is an important spot for Common Eider with substantial numbers present throughout the year between the headland Hyllekrog and Gedser Odde, the cape structure southeast of Gedser (cf. Fig. 1.3). Highest abundances are encountered in March/April and October/November (Petersen et al. 2006). Inside-outside distribution recorded during this study shows a strong avoidance of the wind farm. However, Eiders passed by the wind farms in frequently close distance, sometimes taking “shortcuts” by passing through the wind farm at its corner, and consequently high numbers were recorded at the study site. Accordingly Petersen et al. (2006) found high densities around the wind farm and medium densities even partly inside.

Birds of prey do occur offshore on migration. In Horns Rev birds of prey did not play an important role as numbers were very low. However, four Red Kites *Milvus milvus*, a species of conservation concern, were observed October 5th 2005 during anecdotal observations circling above the wind farm. The Nysted area, in contrast, represents an important raptor migration route between Gedser Odde and the Fehmarn Strait (Kjellén 1992 – some 4700 Honey Buzzards per autumn, Koop 2004). Hence a considerable number of species and individuals was recorded. In general most birds of prey (except falcons) are considered to migrate mainly at higher altitudes and under good weather conditions as they take advantage of cost-saving thermals. In Nysted area migrating raptors could be observed in altitudes of up to 500 m. However, narrow straits are often passed in active flight, especially in a geographic environment which does not provide good thermal soaring possibilities. In our study most species or groups used the entire altitude range observed. Osprey, Honey Buzzard, Red Kite and Rough-legged Buzzard were registered only in the higher two altitude bands. One Sparrowhawk was observed perching on a turbine foundation, but this can be seen as an exception.

Little Gulls occurred only in Horns Rev in substantial numbers. They pass the area during migration and are often feeding at the water surface the same time. Obviously Little Gulls did not avoid the wind farm surroundings as they occurred numerously. These findings do not coincide with Petersen et al. (2006) who found a significant preference for the wind farm area regarding Little Gull distributions (aerial counts). But they clearly avoided entering the structure and they strongly prefer flying at altitudes below rotor range. Hence collision is only likely with foundations and the lower part of the tower at poor visibility.

For **gulls** other than Little Gull the situation is rather similar in both areas. Most species regularly occur. The only species not present year round is Lesser Black-backed Gull (plus a few rare vagrant species). In Nysted it was recorded only in small numbers while in Horns Rev it was abundant. During their presence from April till September Lesser Black-backed Gulls show a movement pattern comparable to that of other gull species in both wind farms.

Gulls do show avoidance, however, they are the species showing least differences between inside and outside, thus they seem to be well habituated to it. They gather on the water within the wind farm and do often fly within rotor range.

Only 39 individuals of **auks** (Guillemots and Razorbills) were observed on standard transect counts in Horns Rev. This number is far below what is to be expected considering other studies in that area. Auks are regularly counted in considerable numbers at Blåvandshuk in October (Jakobsen 2008) and Petersen et al. (2006) found an abundant distribution offshore during autumn and winter with highest numbers in October and November. They could not prove large scale wind farm avoidance. With regard to vessels, auks escape only late in front of moving ships and regularly approach and anchoring vessels (own observations). Regarding auk's behaviour towards vessels it would not seem likely that they keep far off the structure. The data of Jakobsen (2008) show that there is a large variability in the occurrence of auks between years which might explain our count number. However, Petersen et al. (2006) recorded their second largest number during an aerial count in November 2005 and thus within our study period. All but one of the recorded auks flew within the 5 m above water surface.

Due to their body size **songbirds** (apart from corvids) are the group most difficult to record during visual observations, since they are hard to spot in a marine environment. Often flight calls are the first hint. Even when tracked with binoculars a finch-sized bird is hardly visible or even pursuable at a distance of 300 m and for a thrush that distance is not much further. In consequence songbirds just could be seen entering the wind farm from the anchoring site but could not be tracked inside the wind farm or even spotted within that distance. As songbirds were recorded in the distance zone B no direct statement is possible about inside-outside proportions and thus about direct avoidance. Registration of songbirds was limited to the lower three altitude bands and records from above turbine height were only made accidentally. Results of Hüppop et al. (2004) also confirm our findings that passerines rarely use the lowest altitude band just above the water level. Thus records predominantly regard rotor range and the altitude band below it. It is known that passerines lower the migration altitudes under low pressure conditions which often coincides with rain and snow fall (Åkesson et al. 2002). Then birds will fly under poor visibility well between the turbines.

In dense fog flocks might seek any solid structures and approach them. E.g. in the morning of April 1st, 2006 a flock of 350 Chaffinches and 35 Bramblings circled the vessel under such conditions with a sight range of less than 200 m and eventually headed into the wind farm. That particular morning was characterised by intense songbird migration and sight ranges always below 500 m due to fog, drizzle and rain showers.

2.3.4. Acoustic observations

The audibility of bird calls offshore depends both on the presence of noise clutter such as wind and waves which could drown the calls and on the flying altitude of the birds. Thus, the weather has an important influence on the detectability and thus the number of recorded calls. Besides the large proportion of gulls and their vocalisations especially in Horns Rev may conceal bird calls of other species and thus migration events in spring. Last but not least, some bird species do not emit flight calls at all, and those that do might not call continuously (see also Kunz et al. 2007).

While we can not derive a proper migration phenology from these numbers, we get hints in which periods flight activity is strongest. In spring this is from end of March until end of April (Fig. 2.93 and Fig. 2.95) and in autumn this is from the last decade in September until the end of October (Fig. 2.94 and Fig. 2.96). Within these periods numbers vary strongly. In some nights no calls were recorded at all.

Acoustic observations help to support radar observations with call phenologies and - more important - with some species identification. This way, the well known mass migrations of the three thrush species and Robin as well as additional species are documented. However, neither quantitative results nor additional information with regard to numbers aloft or their position with regard to wind farms are yielded by this method. While it is known, that birds emit flight calls more frequently in inclement weather or when circling tall structures (Kunz et al. 2007, Hill & Hüppop 2008), recordings may eventually help to identify those situations during operation of a wind farm and could potentially deliver additional data to initiate mitigating actions like turning off individual turbines or an entire wind farm.

2.3.5. Avoidance and assessing the collision risk

2.3.5.1. Introduction

Since men made structures exist, there have been collisions of birds with them. The topic is well known and the problem has been described for any tall structures like buildings, towers, masts, light-houses, power lines and others long before modern wind turbines existed (see e.g. Erickson et al. 2001, Wiese et al. 2001, Woodlot Alternatives 2003, Podolsky 2004, Ballasus 2006). With the development and large scale use of wind turbines the basic problem remains but is supplemented by a crucial component: a moving element of the structure producing extra risk. Thus the bird can not only fly against a static obstacle alone but it can also be hit by the revolving rotor when flying on a course seemingly free from obstacles. Thus, the impact of both the non-moving part and the moving parts of the turbines have to be considered.

Ever since wind turbines have been erected onshore and more recently offshore, it has been tried to assess their impacts on birds, and a growing number of investigations has been published to address the issue, both from the scientific institutions and nature conservation bodies as well as from the wind industry itself, respectively (e.g. AWEA 2004, Desholm et al. 2004, Grünkorn et al. 2005, Hüppop et al. 2005, SNH 2005, Band et al. 2006, Dierschke & Garthe 2006, Zucco et al. 2006, Gehring & Kerlinger 2007, Kunz et al. 2007, NWCC 2008).

In recent years several attempts were made to address that problem. Approaches focussed on identifying the factors influencing the likelihood of collision and assessing the number of collision incidents (Hötker et al. 2004, Grünkorn et al. 2005, Petterson 2005, Desholm et al. 2006, Drewitt & Langston 2006, Band et al. 2007, Everaert & Stienen 2007).

From behavioural science – but also applying common sense – it is a good assumption, that birds will avoid flying very close to vertical structures, in our case into the wind farm or into the rotor swept area (Winkelmann 1989, 1992a-d, Fernley et al. 2006, Everaert & Stienen 2007). For reasons of simplicity, the first collision models with regard to wind farms have only described the probability of a bird colliding with a turbine structure as if it would "not see it" (Band et al. 2007). This has been criticized ever since (Chamberlain et al. 2005), and some attempts have been made to include avoidance reactions into the model calculations (Desholm et al. 2006, Chamberlain et al. 2006, Desholm & Kahlert, in prep.).

Clearly, the avoidance of birds flying towards a turbine structure or towards an onshore or offshore wind farm is of fundamental interest. However, we know little about the birds abilities to assess the speed of the rotor while crossing the rotor plane. Case studies and reviews show that gliding and soaring birds (using wind currents rather in addition to active flight) are more at risk (BirdLife 1995, Hunt et al. 2002, Thelander et al. 2003, Whitfield & Madders 2005, Madders & Whitfield 2006, Follestad et al. 2007, Hötker et al. in prep). The poorer the visibility the less the bird is able to react at very short sight ranges (e.g. fog, night); in these cases the question whether a bird is hit might indeed depend largely on stochastic rules as assumed in the corresponding models. However, at all other weather and visibility conditions, birds will show an avoidance reaction.

Avoidance may occur on different levels:

a) large-scale avoidance: birds see the wind farm at large distance and take an avoidance action at distances of > 2000 m. This has been shown in Danish studies mainly for seaduck species like the Common Eider (Petersen et al. 2006); it is assumed that these ducks – during good migration conditions and good visibility - become aware of a “large structure / many objects” in a landscape naturally without obstacles and chose a flight route around this structure / these objects.

b) medium- to small-scale avoidance: birds become aware of the wind farm or individual turbines at medium to small distances 1000 to 150 m – given good to medium visibility - and show an avoidance reaction; this reaction maybe a lateral or a vertical avoidance. Those avoidances can be measured directly (reactions recorded) or indirectly (numbers and altitude distributions inside and outside the wind farms).

c) “last second avoidance”: Birds either do not see a turbine (low visibility, or birds in flight formations do not look for obstacles – see case description in Petterson 2005, Fernly et al. 2006) or birds cannot see or assess the moving turbine blade. Those last second avoidances are very difficult or even impossible to register, because they are – most likely – rare, thus one must observe very small air volumes for very long times and they might occur most frequently during inclement weather and bad visibility when observations are additionally hampered (see Desholm et al. 2005).

While the latter – “last second avoidance” – is not in the scope of our study, a brief chapter will describe large scale avoidances while a more extensive chapter will discuss the medium- and small scale avoidances.

2.3.5.2. Large scale avoidance

Large scale avoidance as described under a) has not been directly measured during our investigations, since methods and observation ranges are too small; daytime observations have only included distances up to 1000 m, radar range was up to 1500 m for vertical and 2800 m for horizontal observations. Two options exist to address large scale avoidance:

1) a comparison with existing data of reference sites or data gained before the wind farms had been erected;
2) investigations carried out synchronously with exactly the same methods inside the wind farm area and at a reference area outside the wind farm some 3 to 5 km away.

As for 1), some comparisons for species numbers and distributions are discussed in chapter 2.3.3. However, different methods, different observation periods and different habitats preclude true comparisons; the high year-to-year variability of bird numbers and distribution overrides potential results even when studies are carried out at the same place (Petersen et al. 2006), and it poses problems to allocate changes in numbers to the presence of wind farms or e.g. a changing distribution of food sources (Common Scoter: Petersen & Fox 2007). Other studies include observations at Blåvandshuk from 1963 to 1992 (Jakobsen 2008) or data from Germany (Hüppop et al. 2005, Garthe et al. 2007). Clearly, observation either land based or close to the shore will record considerable more geese and ducks, birds of prey and songbirds. Thus, qualitative conclusions are possible only for a selection of species, but quantitative comparisons are difficult to achieve.

Most avoidant are certainly **divers** – medium sized waterbirds, both migrating through the area and resident in the winter half year. As they obviously tend to keep off the whole area around the wind farm they are less vulnerable to collisions but more affected by habitat loss.

As divers in both areas frequently fly within rotor range those individuals are still exposed to risk of collision to some extend. The low observation rate of **auks** (Guillemot and Razorbill) at Horns Rev might hint at a large scale avoidance looking at their numbers and distributions in other studies (Blåvandshuk 1963-1992 Jakobsen 2008, aerial counts: Petersen et al. 2006,

Dierschke & Garthe 2006). **Common Eider** in Nysted show a large scale avoidance well documented in the Danish studies (e.g. Kahlert et al. 2005, 2006). Clearly, Eider numbers documented in our study are low compared to the potential migrating population at that site; however, while many Common Eider show large scale avoidance and hence are not registered during our studies, still rather high numbers are recorded, showing a medium-scale avoidance or fly through the wind farm.
As for 2), such an investigation design has not been carried out but is recommended for future studies (chapter 2.3.6).

2.3.5.3. Medium to small scale avoidance

Medium to small-scale avoidance is clearly the topic which has been addressed during our studies.

Avoidance measured indirectly

An **indirect** approach to investigate medium to small-scale avoidance is to analyse the different distributions of birds or signals inside and outside the wind farms.
Four approaches have been tried to look at those differences:
Radar observations
1) Differences in altitude distributions with vertical radar
2) Differences in density and altitude distributions inside and outside the wind farms with vertical radar
3) Differences in density inside and outside the wind farms with horizontal radar
Visual observations
4) Differences in density and altitude distributions inside and outside the wind farms

Radar observations:
1) The differences in altitude distributions at different time periods with regard to migration intensity, day- and nighttime, season show, that generally at periods of intensive migration (mass migration, nighttime etc.), higher proportions of birds fly at higher altitudes (chapter 2.2.1.4 and discussion in chapter 2.3.2). This is not an active avoidance of the wind farm or individual wind turbines. Most birds utilize good to optimal migration conditions with regard to weather (Alerstam 1990, Alerstam & Lindström 1990, Richardson 1990, Berthold 2000, Gatter 2000, Åkesson & Hedenström 2000, Zehnder et al. 2001, Åkesson et al. 2002 and other). During those periods, the majority of birds flies at high altitudes and relatively lower numbers of birds occur at the risk area of wind farms. It must be noted, that the numbers of birds in the risk zone during those mass migration evens are by no means small, since high numbers of birds are aloft during those periods.
2) Another way to indirectly measure avoidance is to detect different bird densities between inside and outside the wind farm (results in chapter 2.2.1.4, discussion of methods in 2.3.1.5 and of results in 2.3.2). Taking into account the presence of “hidden areas” on the radar screen and the differences in detectability of birds approaching or flying away from the radar, vertical radar results in the range of 500 m cannot successfully detect avoidance within 500 m of the wind farms for any signal category. While the variability of the results is very high, the differences between inside and outside the wind farm below 200 m are small. In addition,

the potential artefacts presented in chapter 2.3.1.5 make an assessment of the small differences impossible.

3) Horizontal radar results suggest, that for most tracks, densities inside the wind farm are lower than outside the wind farm. However, interpretation of these results is difficult. Firstly, horizontal radar data could only be analysed for selected periods characterized by very calm weather conditions; it turns out that this selection yields more daytime than night-time data (Tab. 2.11) and it could be likely, that signals of day active birds dominate the results. Secondly and more importantly, additional data on vertical or horizontal reactions (Tab. 2.9 and Tab. 2.13 and explanation of results) cannot at all support those different densities. In detail, this means that a) signals moving towards the wind farm do not show vertical or horizontal deflections, thus they must enter the wind farm and that b) signals moving out or away from the wind farm “increase” on the horizontal radar outside the wind farm, which cannot be explained. Thus, it must be concluded, that radar signals are entirely concealed, or they are so strongly disturbed by the wind turbine signals, that they cannot be discerned from clutter, i. e. cannot be identified as birds by the person analysing the radar screenshots. Consequently, detection of signals inside the wind farm is considerably lower than outside the wind farm and true differences cannot be detected.

In comparison, Danish studies have also used horizontal radar to track birds outside and inside the wind farm. However, most of their analyses used flight directions or changes of flight directions in order to document an avoidance of the wind farm. While those data show on one hand large evasive reactions of birds around the wind farms, which can partly explain lower densities within the wind farms, direct comparisons of densities inside and outside the wind farms have not been conducted and pictures of track density published in these reports also suggest, that less signals can be detected inside the wind farm (Kahlert et al. 2005). In addition, with a considerable larger radar range and a focus on larger birds the Danish results would be hardly comparable to ours (Petersen et al. 2006).

4) Visual observations offer a far greater chance to assess those differences inside and outside the wind farms, in addition considered at different altitudes.

Common Scoter and **Common Eider**, two seaducks of comparable body size and occurrence pattern comparable to divers, also avoid to enter the wind farm but do not avoid as much the surrounding area. Hüppop et al. (2004) found 54% of all seaducks in their study (three different areas with no turbines present) flying just above water surface (0 – 5 m) and another 30% between 5 and 10 m. Our results show, that differences between the two numerous species exist; Common Scoter almost exclusively fly below rotor range (0 - 5 m and 5 - 30 m) and show during our study period a strong avoidance of the wind farms; hence, the individuals inside wind farms are only vulnerable to collisions with the vertical structure of the lower tower under poor visibility. Common Eider show an even stronger avoidance of the wind farm, but a different altitude distribution than Common Scoter. For Common Eiders in the wind farm we must assume a likelihood for collision when visibility is poor because 38% of all observations were made within rotor range. This number is almost identical with the results of Petersen et al. (2006), who estimated flying altitudes of waterbirds - presumably Common Eiders - by means of TADS (Thermal Animal Detection System). 37% of their TADS records of Eiders were within rotor range, while the remaining proportions were recorded below rotor range, comprising our lowest two altitude bands; we recorded 48% in that range. In contrast, studies at Tunø Knob, Denmark, found 91% of the Eider flocks in altitudes < 10 m, and only 2% at heights at heights > 20 m (Larsen & Guillemette 2007).

Great Cormorant (in Nysted wind farm) and **gulls** are the two taxa which seem to have well habituated to the wind farms. Both are resident year round, yet in variable numbers (Petersen et al. 2006). Nevertheless Cormorants and gulls are well distinguished with regard to their collision risk.

It seems to be a valid assumption that migrating Cormorants pass the area in higher altitudes than resident and staging individuals. In Horns Rev, almost all Cormorants are migrating. In Nysted, a high proportion of Cormorants in spring also belong to the migrating group, however, in autumn high numbers of resident and staging birds are present. Migrating individuals frequently show behaviour of disturbance but still pass the wind farm frequently within the rotor range; these must be considered being at higher collision risk. Especially in Nysted large numbers of local individuals are habituated to the wind farm; large feeding flocks of diving birds and birds just flying above the water regularly enter the wind farm and hence are hardly exposed to any collision risk.

As gulls inside the wind farm are almost as abundant as outside and as they frequently use all altitudes within the height of a turbine they are exposed to risk of collision to a certain degree even at good visibility as demonstrated e.g. in onshore wind farms (Grünkorn et al. 2005).

Birds of prey and **songbirds** were the only two typical landbird taxa crossing the wind farms in considerable numbers. Although different under many aspects – body size, flight behaviour, raptors being only diurnal while songbirds migrate both day and night – these two groups show small scale avoidance and could be expected to be the ones most affected by collision risk.

Birds of prey, especially Osprey, Red Kite, Marsh Harrier and Common Buzzard and others, among those several Red List species, most of them strictly protected, do migrate through the wind farm area within rotor range (results from Nysted). While numbers and flight paths of raptors have registered during our investigations, a large scale avoidance pattern cannot be stated. Raptors are well known to be among the most numerous collision victims found at onshore wind turbines (Hunt et al. 2002, Thelander et al. 2003, Whitfield & Madders 2005, Madders & Whitfield 2006, Follestad et al. 2007). In Germany a central register exists for wind turbine collision victims in birds (T. Dürr, written communication, Hötker et al. 2004). Here, Red Kite and Common Buzzard form by far the largest fractions with 91 cases each out of 646 reports of 95 species in total (as of February 2008). This data base relates almost entirely to onshore wind turbines; especially Red Kites do hunt along wind turbines, thus resident individuals seem to be much more exposed to risk than migrating ones. Raptors are generally exposed to collision risk due to their flight patterns (soaring, circling in thermals) and flying altitudes and must be regarded as potential victims; however, migrating in offshore environments raptors more frequently show active flight and are this way well able to manoeuvre and react to obstacles. Also, unlike in onshore wind farms, birds of prey are not hunting in the offshore environment and incidental collisions are presumed to be less likely.

Although songbirds did not yield the highest count results in our visual observations we must assume that songbirds are the taxon migrating through the areas in highest individual numbers. Radar observations and combined searches for collision victims in coastal wind farms revealed that even massive migration in rotor height does not lead to collisions in songbirds indicating effective small-scale avoidance (Grünkorn et al. 2005). The number of songbirds in transect counts will be underestimated for the reasons described in the methodical discussion, yet the vast majority of bird signals recorded by radar during night will be songbirds. During inclement weather situations songbirds will lower their flying altitudes both during day and night; they might become disoriented and then fly between the turbines including rotor range under poor visibility; the observations of April 1st, 2006 in Nysted provide a good example (see chapter 2.2.3.2, Nysted, songbirds). During those occasions the likelihood of collisions will increase. On the other hand those situations might be rare; thus, systematic investigations are almost impossible due to potentially extreme long observation periods and only few results, if at all; in addition, inclement weather might prevent observations and their documentation altogether.

In conclusion, indirect evidence of medium to small-scale wind farm avoidance cannot be inferred from the radar results. Visual observations show, that seaducks (Common Eider, Common Scoter) show a strong to medium avoidance, but do occur and fly within the wind farms also at turbine height; of Cormorants, migrating individuals fly at higher altitudes but show only weak avoidances while resident Cormorants do utilize the wind farm area, yet the majority uses only the lowest altitude band. Birds of prey occur in low numbers but fly through the wind farms. Visual observation data for songbirds do not show regular avoidance of the wind farms.

Avoidance measured directly

A **direct** approach to investigate medium to small-scale avoidance is to analyse the reactions of birds towards the wind farm or wind turbines.

Three approaches have been tried to look at reactions:

Radar observations:

1) Vertical deflections of flight directions, recorded by manually tracking signals with the vertical radar;

2) Lateral deflections of flight directions, recorded by measuring changes in flight directions of approaching birds with the horizontal radar.

Visual observations:

3) Reactions of birds approaching the wind farm

Radar observations

1) Manually following and thus tracking of individual signals on-screen (vertical radar) is a method to record "altitude changes" for a range up to 500 m (see chapter 2.1.3); at the 1500 m scale, signals and turbines are so small, that no altitude changes would be registered.

Manually tracking signals is considered to be the most sensitive method to identify radar detected bird signals, because moving signals were much easier and securely to be identified as birds than signals on a screenshot which sometimes may be hard to distinguish from disturbances and artefacts. Also, signals sometimes disappear and reappear on the screen; a person is able to allocate those different signals to one bird or bird flock, which would not be possible viewing a digital screenshot or using automatic recording devices (Desholm et al. 2004).

Results of these observations are inconclusive. Firstly, only small proportions of the manually tracked paths "flying towards" show vertical avoidance reactions. Secondly, the proportions of vertical reactions of the altitude bands < 200 m (risk area) are not different from those at

200-500 m (non-risk area). Thirdly, no differences in vertical avoidance reactions can be detected for signals moving towards compared to signals moving away from the wind farm.
A closer look at the data available may elucidate this situation: For signals visible on the vertical radar, it is unknown where in the horizontal plane those signals are located. With regard to a vertical avoidance it must be noted, that birds which head directly for a turbine, should take avoidance action, while birds which "see" a large gap or an alley between turbine rows (e.g. for Eiders see Desholm & Kahlert 2005) have no reason to show a vertical avoidance reaction (Fig. 2.102). In a simplified approach, meant to describe the situation of a bird approaching the outer row a an offshore wind farm, the "wind farm affected area" can be described by the 2-dimensional area of wind farm length multiplied with an altitude of 200 m. Number and dimensions of rotors and shafts of the wind turbines and the row width reveal, that the "actual risk area" represents only 4.4% to 8.3% of the "wind farm affected area" (Tab. 2.19). This calculation only describes the case, when rotors are turned that way that they maximally reach into the alleys between rows and that birds approach the wind farm directly at an angle of 90°. Additional visual features shall not be neglected: a bird flying towards a wind farm somewhere below 100 m above sea level, will – from a distance - "see" a "wall of obstacles" for most of the area, but also some obvious broad "alleys" at varying angles (Fig. 2.102). Thus, a bird might be facing a changing picture while approaching a wind farm; it may decide to take an avoidance reaction in the far distance; if it does not react, an "alley" might become visible or not while it comes closer.
These considerations suggest, that only a fraction of approaching birds might take an avoidance reaction, and it seems less likely that this fraction is measurable.

Tab. 2.19: Calculation of risk area – of the first turbine row - under the assumptions that a) a bird approaches a wind farm at a degree of 90°, b) and rotor turning plane is also perpendicular to birds path

wind farm side	rotor diameter [m]	turbine shaft width [m]	no of rows	distance between rows [m]	wind farm affected area < 200 m [m²]	rotor swept area [m²]	turbine shaft area [m²]	risk area [m²]	risk area [%]
Nysted East / West	82	5	9	480	637.538	47.529	5.310	**52.839**	**8,3**
Nysted South	82	5	8	850	1.075.856	42.248	4.720	**46.968**	**4,4**
Horns Rev East / West	80	5	8	560	672.640	40.212	4.800	**45.012**	**6,7**
Horns Rev South	80	5	10	560	864.800	50.265	6.000	**56.265**	**6,5**

Fig. 2.102: Visualisation of "obvious alleys" (green arrows) and "cluttered obstacles" (red lines) for a bird approaching a wind farm.

2) Horizontal radar was used to measure flight track angles in four different distance bands (500 m wide) of approaching signals. Results show, that angles do neither differ nor increase with decreasing distance to the wind farm. Variability of these results is too high (e.g. see standard deviations in Tab. 2.13) to yield any significance, and contra-intuitive examples exist, where the deviation decreases with decreasing distance to the wind farm, e.g. at Nysted East during nighttime.
As with the vertical deflection analyses, a closer look at the data may help to explain those failures to yield clear results. On the horizontal radar the altitude of a signal is not known; thus no information exists whether the signals and tracks recorded are within wind farm height (with a potential to react) or way above (with no reason to react). Also, approaching birds may show different reactions while approaching the wind farm, deflecting at first and potentially turning into an "alley" when it recognizes it (Fig. 2.102); a mixture of both effects potentially overrides true differences. To further analyse these effects, the fate of each track should be registered to separate those tracks eventually entering the wind farm from the others. But manually followed tracks are not available for the horizontal radar data, thus a "reaction" expressed for each individual flight trajectories cannot be analysed.

Visual observations
3) Reactions of selected birds or bird groups have been recorded during the visual observations; the nature of the reactions has not been recorded. At Horns Rev, during spring generally only low proportions of the observed birds reacted; for Common Scoter with a high number of registrations this is about 8%. During autumn, Great Cormorant and geese on migration show high proportion of more than 80%. At Nysted, an interesting result is that of Cormorants during spring – assumed to be migrating individuals – some 30% show reactions while during autumn, when large flocks of resident birds are present, this applies to only 1%. While the few occasions of swans and geese showed 70% to 50% respectively, most notably the Common Eiders showed some 25% reactions in spring and some 50% in autumn. At both wind farms, gulls, including Little Gull, had very low proportions reacting. For songbirds, varying percentages between 5% and > 30% reacted.

2.3.6. Conclusions and outlook

Summarizing the results of this study, we know, that of the vast numbers of migrating birds crossing open waters where offshore wind farms exist or will be constructed, only a fraction comes close to these obstacles. High proportions of waterbirds (pelagic species, seaducks, swans, geese and other) apparently avoid the wind farms at a large scale, thus they do not come even close. Those birds which migrate closer to the wind farms during daytime, such as large numbers of Common Scoter, Common Eider, Great Cormorants, terns and others show a clear, yet not complete avoidance of the offshore wind farms. In conclusion, the above mentioned species groups are effectively avoiding offshore wind farms and not a risk from collisions, at the same time being affected by a habitat loss and barrier effects. In contrast, resident species like gulls and non-migrating Cormorants regularly enter the wind farms; thus, they potentially take advantage of the wind farm area as a new food source but are exposed to a certain collision risk. This is also true for the small numbers of raptors actively flying through the wind farms. Very large numbers of songbirds cross the Baltic and the North Sea. Most of them migrate during favourable weather conditions; then large proportions are flying at altitude bands > 300 m. Nonetheless, a still considerable proportion migrates within the risk area of wind turbine height; our study has shown a daytime avoidance of the offshore wind farms, but at nighttime results were not clear and it must be assumed, that these species pass through the wind farms in considerable numbers. Also, our results have not been able to show significant active avoidance reactions, indicating that a response will occur at very short distance. Thus we assume that those birds do enter the wind farms as they also do on land. In the absence of collision data offshore, onshore studies show that those migrating songbirds apparently cross wind farm areas without colliding. While we conclude, that large proportions of potentially affected birds are not exposed to a collision risk, situations of – unforeseen – inclement weather have the potential to leading to considerable collision numbers, as has been documented for all kinds of structures off- and onshore.

The investigations carried out during this study yielded valuable results with regard to bird numbers, species distribution and migration intensities in the direct vicinity of offshore wind farms. In addition, results on avoidance and reactions towards the wind farm or individual wind mills have been recorded. While a large body of new results and conclusions can be drawn from these studies, some results do not live up to the aspirations during the start of the project. The presence of wind turbines has considerably hampered analyses of radar results in the absence of a sound knowledge about radar sensitivity and areas potentially concealed by disturbances (wind turbines) on the radar screen. Thus, differences of bird densities or distributions in the areas outside or within the wind farm area cannot be analysed. While valuable results on the bird reactions towards the wind mills have been gained from the visual observations, radar results are again inconclusive. In consequence, no quantitative data have been collected to be entered into collision risk models or to be directly compared to other studies, either during baseline or during operational phases in these offshore wind farms.

Some related research projects have started since 2005. However, they have encountered comparable difficulties. While onshore studies offer a number of advantages (no clutter by sea surface, solid platforms, collision victims can be searched etc.), radar studies in an offshore environment using marine surveillance radar either from land or from a ship pose considerable problems with regard to clutter, signal identification and sensitivity problems (e.g. Krijgsveld et al. 2003, 2005, Poot et al. 2006, Schmaljohann et al. 2008). The British initiative "Collaborative offshore wind energy research into the environment (COWRIE), contractor of the latest best practice guidance (Desholm et al. 2004), has most recently asked for assistance in offshore bird studies with regard to a number of potential remote sensing techniques, including assessment and monitoring of bird movements, collision risk, collisions and avoidance rates at proposed and constructed offshore wind farms with particular reference to identified key bird species, limitations and practicalities of methods, addressing turbine shadow, wave clutter, ground-truthing, inclement weather and bird densities as well as further detection probabilities. This request clearly demonstrates a general need for more efficient methods for these projects, however, it seems that easy and fast solutions are not in sight. New radar techniques within reasonable price ranges have not been invented; a pencil beam radar for measuring distances and offering some bird species identification via wingbeat frequencies has yet to be tested at the offshore environment (Schmaljohann et al. 2008). Thermal Animal Detection Systems (TADS) have been tested during the Danish studies; they may be able to cover a range very close to the wind turbines in order to detect "last second avoidances" or collision, but since those locations are rare and the area covered is small, a very high and expensive effort has to be invested with potentially very few results. As of now, camera systems have not been installed or tested offshore. An indirect method for registration of bird collisions has been developed using video cameras and microphones combined with event triggering by acoustic vibration measurement, potentially able to count the number of collisions as well as to identify the species (Wiggelinkhuizen et al. 2006a) After prototype testing with a tennis ball, the system detected during a monitoring period of about one year two bird collisions (Wiggelinkhuizen et al. 2006b).

In addition to the problems addressed above, following research needs are suggested:

1) species specific avoidance / attraction pattern – the wind farm sensitivity index (WSI) for seabirds, developed by Garthe & Hüppop (2004) should be further developed to include the latest behavioural observation results and further non-seabird species.

2) the effects of illumination of the wind farms should be addressed with potential suggestions for mitigating measures. Light has been an issue of some recent projects with regard to bird collision at man-made structures (Longcore & Rich 2004, Evans et al. 2007, Gehring & Kerlinger 2007, van de Laar 2007, Longcore et al. 2008).
In Germany, a study about this topic has just been presented (*HiWUS-Studie 'Entwicklung eines Hindernisbefeuerungskonzeptes zur Minimierung der Lichtemissionen an On- und Offshore-Windenergieparks und -anlagen' im Auftrag des Bundesverbandes Windenergie (BWE)*; here the focus is on minimizing the light emissions of wind farms and turbines while still complying with the safety requirements of the air traffic.

3) There is a need for a study design including an offshore wind farm site at a reference site some 5 to 10 km away, using the same methods, in order to assess different species numbers and composition, altitude distributions, migration intensities etc.. One of the most critical points would be to gain data both from inside the wind farm and from outside on the same platform. In an optimum design two separate vessels would be deployed simultaneously, one right in the centre of the wind farm and the other one well outside in that direction where migrating birds approach from. Counts and radar observations from these two platforms at the same time could doubtlessly be allocated to either fraction and properly compared with each other. This is necessary for a proper treatment of songbirds and most preferable for all other taxa, too.

4) For monitoring issues and long term studies, remote sensing devices should be developed and installed on turbine foundations or solid platforms to be run automatically. That would increase observation time and eliminate impairment by the ship movement like the shifting horizon in the vertical radar.

Little advice can be given to address the situations of bad visibility like night time, rain and strong winds, as those are crucial situations in terms of collision risk.

3. Acknowledgements

The governments of Germany and Denmark have agreed to co-operate in environmental research on offshore wind farming. We are very grateful that the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety has enabled us to conduct the first research project based on this co-operation and to study the responses of migrating birds and harbour porpoises in Danish offshore wind farms. The project was skilfully managed by Projektträger Jülich (PTJ). The former Environmental Group, consisting of Elsam Engineering, Energi E2, The Danish Energi Authority and the Danish Forest and Nature Agency, which coordinates the various Danish research projects on offshore wind farming, kindly gave us the opportunity to conduct the study in the two offshore wind farms Horns Rev, North Sea, and Nysted, Baltic Sea. So, for the first time we were able to do research in offshore wind farms.

Following persons have been attending the boat trips and participated in the investigations (in alphabetical order):
Heike Büttger, Lorna Deppe, Ansgar Diederichs, Tobias Dittmann, Dietrich Frank, Martin Gottschling, Bodo Grajetzky, Steffen Gruber, Thomas Grünkorn, Christiane Ketzenberg, Karsten Kohls, Henning Kunze, Jan Meißner, Nadine Oberdiek, Stefan Pfützke, Lisa Schüler, Esther Verjans, Ingo Weiß, Markward Wittmann, Stefan Wolff.

We have quite enjoyed the management, care and support in all situations of the captains and their crew of the MS Christoffer and MS Søløven, namely Jørgen Roed, Lissi Roed, Thomas Roed, Svend Erik Dam and additional crew members.

Jochen Bellebaum helped during the first boat trip on the Baltic Sea with regard to using the radar and the associated hard- and software. Helmut Wendeln and Jan Kube helped in discussing several aspects of data analyses.

Rafael Villegas-Patraca from Veracruz, Mexico, participated during a boat trip in October 2005 and in turn invited Jan Blew to a the North American Ornithological Congress 2006 in Veracruz, Mexico, organizing a workshop and an giving an oral presentation.

Thanks to Sven Adler for statistical support.

Useful and constructive comments on this report were provided by Miriam Brandt and Ansgar Diederichs.

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