# Collision risks at sea: Species composition and altitude distributions of birds in Danish offshore wind farms

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## *Abstract*

*This study investigates the collision risks of birds in operating offshore wind farms, focussing on all bird species present in the direct vicinity of the wind farms, their altitude distribution and reactions. The project was conducted jointly by BioConsult SH and the University of Hamburg in the two Danish offshore wind farms Horns Rev (North Sea) and Nysted (Baltic Sea) in the framework of a Danish-German cooperation and financed by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). Data were collected between March 2005 and November 2006, using a ship anchored at the edge of the offshore wind farms. In this way, bird species of all sizes could be considered. Daytime observations yielded data on species composition, flight routes and potential reactions of the birds. Radar observations provided altitude distributions inside and outside the wind farm area and also reactions. The results shall help to further describe and assess the collision risk of different species groups. Since data analysis is still running, exemplary results will be presented here.*

*114 species have been recorded in Nysted and 99 in Horns Rev, approximately 65% of which have been observed inside the wind farm areas. Migrating birds seem to avoid flying into the wind farms, whereas individuals present in the areas for extended time periods utilize areas within the wind farms. While a barrier effect exists for species on migration, resident species probably have a higher collision risk. Raptors migrating during daylight frequently enter the wind farm area on their flight routes, correcting their flight paths in order to avoid collisions. Radar results show that during times of intensive migration, the proportion of birds flying at high altitudes and thus above windmill height is higher than in times of low migration intensity. Consequently, there is a lower proportion of migrating birds flying within the risk area.*

*Data will be further analysed to describe altitude changes of birds approaching the wind farm.*

## Introduction

Germany intends to substantially lower its $CO_2$-emissions. One way to achieve this goal is to intensify the construction of offshore wind farms in the German waters. Consequently, plans and permissions exist for installing some 2.2 Gigawatt offshore, that is 15 offshore wind farms in the North Sea and three in the Baltic Sea (BSH 2007). These plans raise some worries, that above all migrating birds will be affected by these wind farms. Potential effects fall under three categories: 1) barrier effect – birds will avoid the wind farm areas and potentially avoid zones around these; 2) direct habitat loss caused by the wind mill structures; 3) collisions – additive mortality caused by collisions of birds with the wind mills. The Danish offshore wind farms Horns Rev, North Sea, and Nysted, Baltic Sea, have been in operation since 2002 and 2003, respectively (Fig. 1).

Finding suitable locations for the construction and operation of the wind farms has been accompanied by Danish studies following the BACI design (before-after-control-impact). With regard to bird investigations concentrated on barrier effects and habitat loss (e.g. CHRISTENSEN et al. 2004, 2005) as well as on collisions risks (KAHLERT et al. 2005, DESHOLM 2005, 2006, DONG et al. 2006), the focus was on seabirds, diving ducks and species groups which migrate and / or stage and feed at both locations in considerable numbers.

To calculate collision risks, several parameters need to be considered. Technical parameters are: height of wind mill including the rotor blades, max. chord, pitch angle, rotor diameter, rotation speed and others. Biological data include: bird length, wing span, bird speed, "flapping or gliding" and others. Given these, additional biological data are needed:

- how many birds use the considered area (wind farm and surroundings)?
- how many birds use the area impacted by the wind mills?
- how many birds fly within the collision risk area, that is:
    - within the relevant altitude class
    - within the area swept by the rotor blades?

Once these data exist, a theoretical collision risk can be calculated (BAND et al. in press, DESHOLM 2006); that is the probability with which a bird would collide with a wind mill if it does not take any avoidance action. It is known, however, that birds do recognize wind mills and react at large and small distances to avoid collision with the superstructures. Since exact data on these avoidance actions are unknown, except for some case studies, a 95% avoidance rate is assumed (BAND et al., ERICKSON et al. 2001). It has been shown for Danish offshore wind farms that by good visibility during the daytime e.g. Eiders correct their flight paths at about 3-4 km distance from the wind farms and this way take a minor detour to fly around the areas (KAHLERT et al. 2005). In bad visibility situations or at night-time, these avoidance actions take place at shorter distances. In cases where individual Eiders fly through the wind farm, they apparently chose a flight route between the wind mills keeping a maximum possible distance from them (DESHOLM & KAHLERT 2005). One must assume, that these behaviour patterns apply for most species, however, to varying degrees.

The actual collision rate depends largely on the avoidance rates. It has been shown, that a 10% variation of the technical or biometrical parameters changes the calculated collision risk by 5-10%. However, a 10% change – in this case lowering - in avoidance rate changes raises the collision risk 20fold (CHAMBERLAIN et al. 2006). Collisions increase the mortality of a population, depending on the population ecology of each species (life span, reproductivity, fecundity and age of first reproduction etc.). This effects the population development. Population models incorporate these data and can calculate the species-specific effects of this added mortality (e. g. REBKE 2005). Finally, the results of such model calculations must be tested in real-time situations. This means, predicted collision rates should be verified by effect-monitoring. Some exemplary collision studies have already been conducted for onshore installations (e.g. GRÜNKORN et al. 2005). However, to date, almost all attempts to quantify collision rates at offshore installations have failed to do so (see DESHOLM 2005, WIGGELINKHUIZEN et al. 2006).

In the framework of a Danish-German cooperation, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) has initiated and financed a study to collect and analyze data and assess the collision risk in operating offshore wind farms.

# Sites and methods

## Sites

The investigations have been conducted at the two Danish offshore wind farms Horns Rev (North Sea) and Nysted (Baltic Sea) (Figure 1), in operation since 2002 and 2003, respectively.

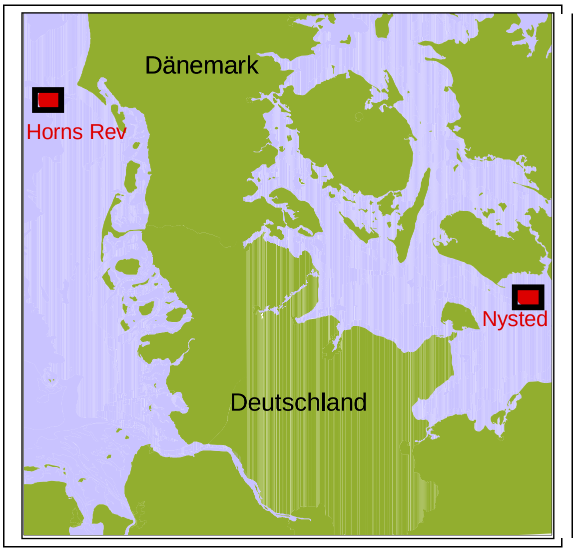


**Figure 1: The Danish-German North Sea and Baltic Sea and the position of the two wind farms Horns Rev and Nysted.**

The ship was always positioned at some 100-200 m distance from the border of the offshore wind farms, from which it was expected that the seasonally specific bird migration would come from. In this way, birds flying towards the wind farm could be observed (Fig. 2).

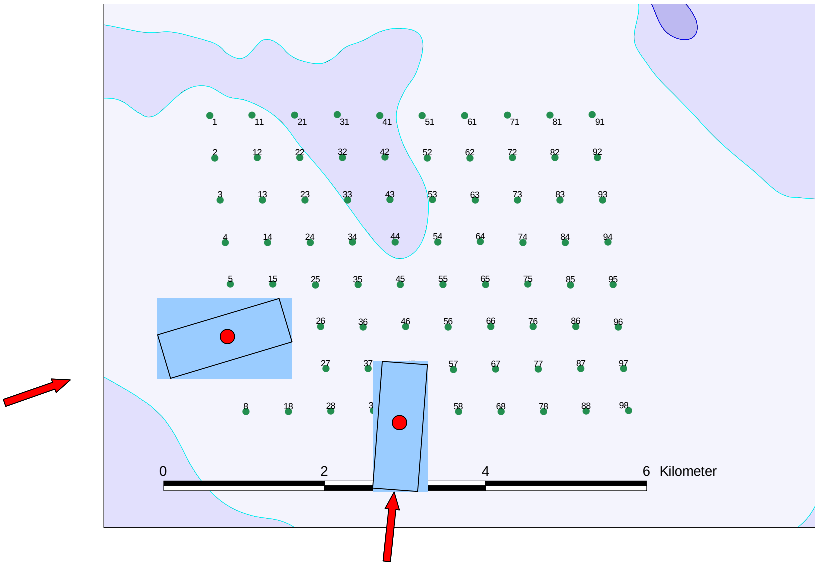


**Figure 2: Two exemplary ship positions, also showing the observation range, here at Horns Rev during spring; migrating birds were expected to arrive from southerly or south-westerly directions. Red dots = ships; red arrows = expected migration directions; grey rectangles = observation range for visual observations and radar observations with the radar rotating vertically.**

## Radar observations

Two radars were used on each ship. A Decca BridgeMaster E was turned into a vertical direction (vertical radar), to measure numbers and altitudes of birds inside and outside the wind farms. A Raytheon Pathfinder was used in its normal horizontal position (horizontal radar), to register flight paths and potential bird reactions. Technical specifications can be found in Table 1.

**Table 1: Technical specifications of the radars used**

| | Decca BridgeMaster E | Raytheon Pathfinder |
|---|---|---|
| **power output [kW]** | 25 | 10 |
| **frequency [MHz]/ wavelength [mm]** | 9410±30 / ~31,86 | 9410±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]** | 2440 | 1830 |

The horizontal radar was used in a range of 2780 m (1,5 nautical miles). The vertical radar was switched every 30 minutes between the ranges of 500 m and 1500 m. Both radars ran continuously during the observation periods. We adjusted the vertical radar in such a way that it turned more or less parallel to the expected migration direction of the birds. At the same time, the radar had to be adjusted to turn more or less perpendicular to the wind farms side in order to be able to separately register signals inside and outside the wind farm.

We took pictures of the radar screen with a digital camera (screenshots) every 150 s. Parallel to these, we recorded digital images via a frame grabber onto a PC in two ways – first as a screenshot taken simultaneously with the digital camera screenshots, and secondly an integrated picture was taken every 150 s, overlaying 15 digital images taken every 10 seconds to document all signals and signal tracks of that 150 s period. In addition, signals and their tracks were copied manually onto transparencies fixed to the radar screen.

Data of these recordings – as there are signal altitude and distance - are transferred to databanks. Data correction was applied using the „distance-sampling“ method (BUCKLAND et al. 2001, BSH 2003, 2007).

### Visual observations

Visual observations were conducted from sunrise to sunset, 15 min in each 30 min period. Two transects parallel to the vertical radars were observed. One person observed the transect leading into the wind farm, a second person leading away from the wind farm. Visual observations yielded data on numbers and species composition, flight paths and altitudes as well as potential reactions of the birds.

### Nocturnal observations

Acoustic surveys were conducted from sunset to sunrise, 10 minutes for each 30 minute period. Recording the birds flight calls yielded again a species composition and an impression of migration intensity. However, since not all birds call during migration and calls can only be heard up to species-specific distances, data gathered from these surveys is biased and limited.

### Observation efforts

Observations were conducted during a total of 179 ship days, not accounting for transportation to and from the wind farms (Tab. 2).

**Table 2: Effective ship days in the years 2005 and 2006**

| | Horns Rev, North Sea | Nysted, Baltic Sea |
|---|---|---|
| **spring 2005** | 9,5 | 20 |
| **autumn2005** | 26 | 27,5 |
| **spring 2006** | 21,5 | 28 |
| **autumn2006** | 18,5 | 28 |
| **totals** | **75,5** | **103,5** |

## Results

At the time of this paper, we are reporting exemplary results, as data analyses and assessments have not yet been finalized.

### Diurnal observations – species, altitude distribution, avoidance

A total of 114 bird species were recorded at Nysted in the Baltic Sea. Of these, 73 species (64%) were also observed inside the wind farm. At Horns Rev in the North Sea, a total of 99 species were recorded, with 64 (65%) also observed inside the wind farm.

Some species show an apparently marked avoidance of the wind farms. Both the Common Scoter (*Melanitta nigra*) and several goose species (*Anser spec., Branta spec.*) were observed only outside or exclusively above the wind farms for most of the time (Fig. 3).

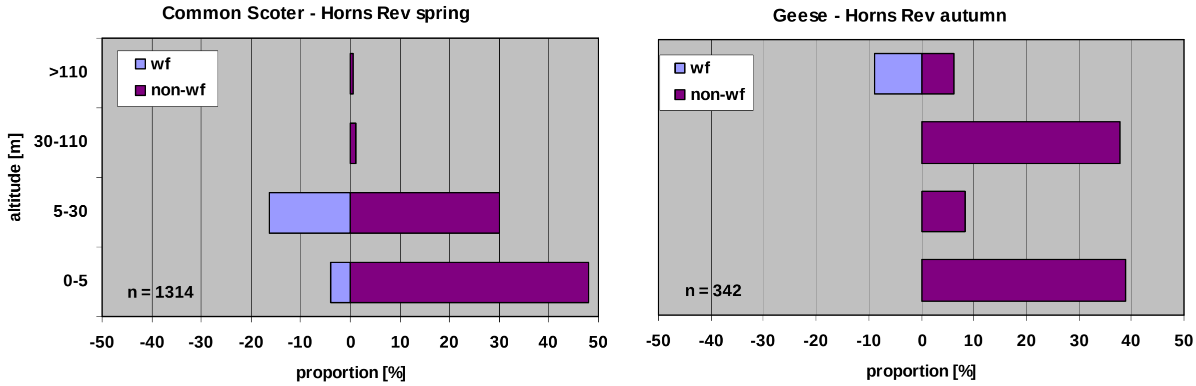


**Figure 3: An example of altitude distributions (visual observations) at Horns Rev, North Sea. Altitude classes are: 0-5 m – very low over the water; 5-30 m – below rotor blades; 30-110 m – within the rotor area; > 110 m – above the rotor area.**

Other species, however, showed less avoidance of the wind farm areas. These include most of the gull species, such as the herring gull (*Larus argentatus*) and the common gull (*Larus canus*), which have been present over longer time periods at the sites. There seems to be no avoidance of the wind farm at all, and also the altitude class of the "within the rotor areas" has been frequently used. On the other hand, the little gull (Larus minutus), a non-resident migrating species which has been observed at Horns Rev, showed a distinct but not complete avoidance of the wind farms in both migrating and feeding patterns (Fig. 4).

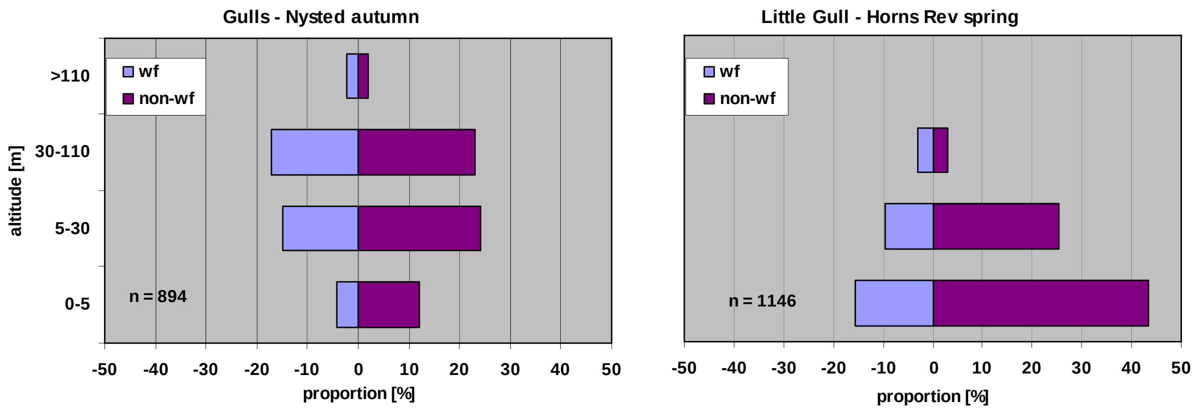


**Figure 4: Examples of altitude distributions of gulls in both wind farms. Legend see Fig. 4.**

Another example are raptors, which also migrate across the sea within the wind farm areas. A total of 185 individuals of 14 raptor species has been observed at both wind farms. Of those, at least 88 individuals have been recorded flying within or above the wind farms. For the sparrowhawk (*Accipiter nisus*), we have enough observations to analyze both the altitude distribution and the reactions. The latter can only be listed for a selection of individuals which have been observed more intensively. Reactions are most frequently avoidance reactions in short to medium distances, leading to the conclusion that the bird either does not enter the wind farm areas or that the bird adjusts its flight path such that it keeps a certain distance to the individual wind mills (Fig. 5).

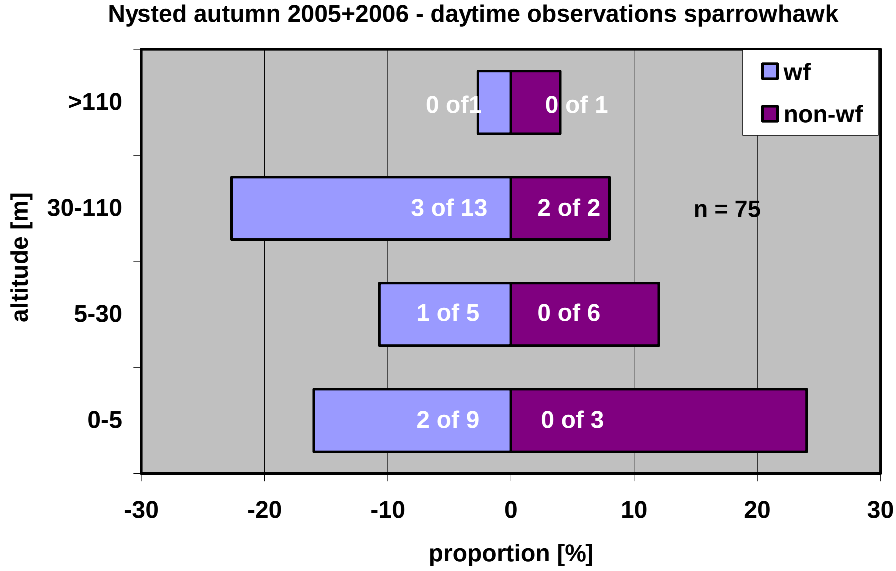


**Figure 5: Altitude distributions and reactions for the sparrowhawk at Nysted, Baltic Sea. Legend s. Fig. 4. White letters denote the number of reacting birds (see text for details).**

## Radar observations – diurnal and nocturnal altitude distribution

Radar data of the ranges 500 m and 1500 m will be analysed and presented separately. In order to take into account that fact that bird migration concentrates during certain time periods dependent on long and short-term weather situations, we present data from the 5 days/nights with the most intense migration as well as data for the rest of the observation period. In the example of data collected for autumn at Nysted in the Baltic Sea, it becomes evident that during nights of intense migration the altitude distribution is clearly pushed towards the higher altitudes. This means that less birds are recorded in the lower altitude classes. During times of high migration intensity, only 25% of the signals were recorded within the risk area of altitudes below 200 m (wind mills have an altitude of 110 m including rotor blades), and only 13-14% below 100 m. During the other time periods, 46% of the signals are below 200 m during the daytime, and 41% during the night. Likewise, 34% are below 100 m during the daytime and 23% during the night (Fig. 6 and 7).

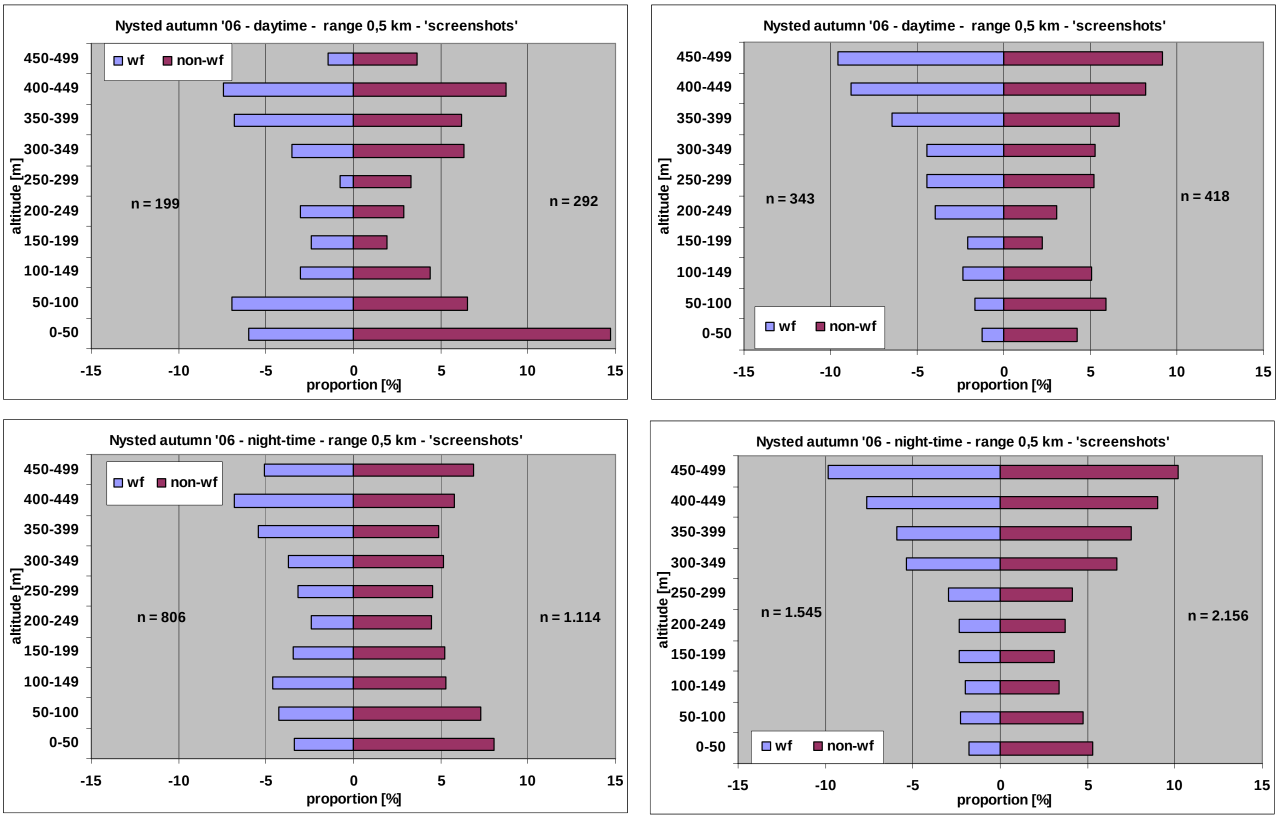


**Figure 6: Altitude distributions for Nysted, Baltic Sea; range 500 m. Left: low migration intensity; Right: high migration intensity; Top: daytime; Bottom: night-time.**

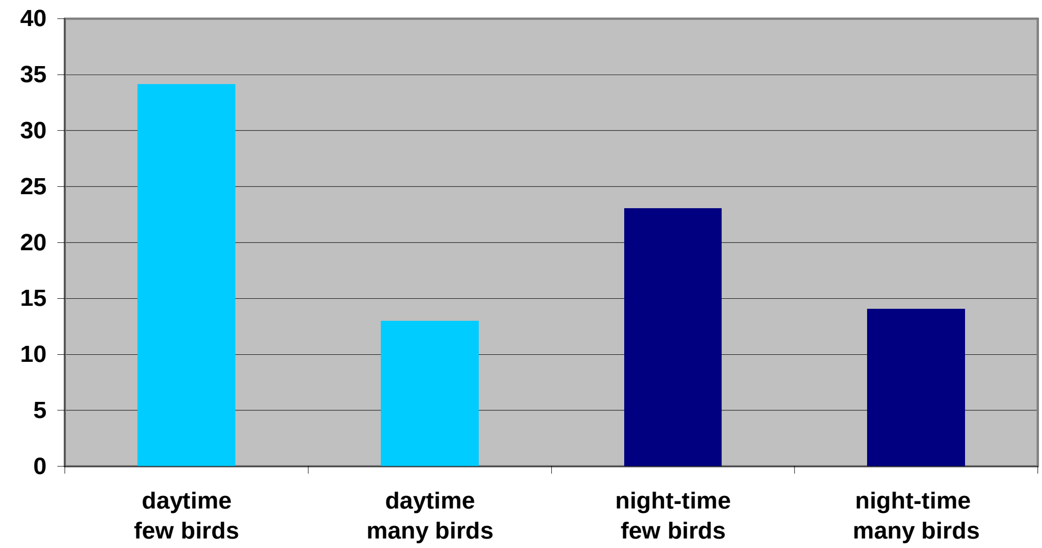


**Figure 7: Signals below 100 m in days and nights with different migration intensities (Nysted, Baltic Sea, autumn).**

Analyzing the range of 1500 m, one can see that generally during all time periods, but especially during times of intensive migration, a large percentage of birds is recorded far above 500 m. During low migration intensity, only 50% of the signals are above 500 m, during high migration intensity this value is 85-90% (Fig. 8).

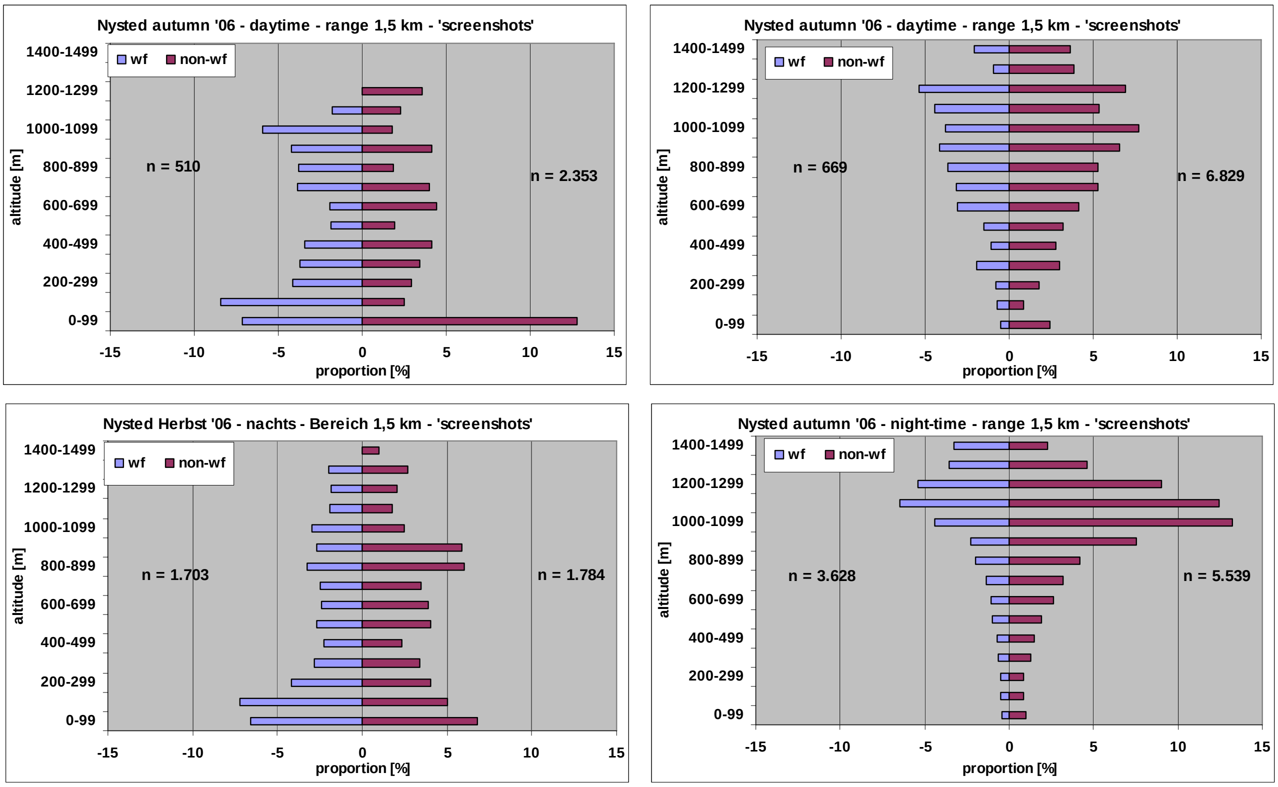


**Figure 8: Altitude distributions for Nysted, Baltic Sea; range 1500 m. Left: low migration intensity; Right: high migration intensity; Top: daytime; Bottom: night-time.**

# Discussion

The goal of these investigations is to collect and analyze data in order to further assess the collision risk of birds in offshore wind farms. These studies complement Danish studies based on platforms or on land at some distance from offshore wind farms, concentrating on seabirds and duck species (for an overview see PETERSEN et al. 2006). A further goal is to collect data on smaller birds as well as to differentiate altitude distributions inside and outside the wind farms. The only possibility is to do ship-based observations. In this way, one can be in the direct vicinity of the wind farms and be flexible with regard to the positions in relation to bird migration directions. Presented here are the results of visual and radar observations. Results allow conclusions on species composition, altitude distributions inside and outside the wind farms and potential reactions of birds to the wind farms. Further analyses will yield altitude changes of birds approaching the wind farm during the day and night.

Species seem to avoid the wind farm areas during migration, whereas resident, non-migrating species or species spending extended time periods in the area (non-breeding, staging and overwintering) use areas inside the wind farms. This is a phenomenon also known from other studies (e.g. KRIJGSVELD et al. 2005). Especially at Nysted in the Baltic Sea, large groups of great cormorant (*Phalocrocorax carbo sinensis*) have been observed performing collective hunts inside the wind farms. In addition, cormorants have been observed resting on the meteorological masts or the wind mill structures during their hunts or flights to and from their roosts. Several gull species have been recorded during daytime in and around the wind farms. Consequently, a barrier effect exists for species that avoid wind farms on a large scale, while the collision risk is increased for species using the wind farm area (GARTHE & HÜPPOP 2004, GRÜNKORN et al. 2005).

Migrating raptors that are flying towards the wind farm generally fly through the wind farms. However, in many cases they adapt their flight paths in order to avoid collision with or even come too close to the wind mills. For smaller birds, namely passerines, it is difficult to quantify flight paths, altitudes or reactions with daytime observations, as those species may be sighted only in close proximity to the observation ships, and rarely can be followed beyond the border of the wind farm.

Bird migration, and above all songbird migration, is concentrated during a few time periods which depend on short and long-term weather situations. Bird species cannot be identified by the surveillance radar used. Consequently, an analysis of the most intensive migration period assures that songbird migration dominates, and that potential collision is more likely to occur at these times than during times of low migration intensity. It turns out that during high migration intensity less birds migrate within the risk areas (altitude category below 100 m).

Analyses will be continued and will finally describe altitude distributions inside and outside the wind farms at both locations during times of different migration intensities and weather situations. Analysis of flight paths recorded with the vertical radar will yield potential altitude changes of birds flying towards the wind farms. Together with the results of the daytime observations, more data will be available to further investigate and describe collision risk models for different bird taxa. However, only a successful cooperation between the research groups working on these issues will help to better integrate and understand the issue of the birds collision risks at sea.

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