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

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Content

1. Foreword

Offshore wind farming is a hot topic in Germany. No serious doubts exist about the necessity to expand renewable energies in order to reduce harmful emissions and wind farming is widely recognised to be highly efficient in this respect. Still, although intended to protect the environment, the public debate about offshore wind farming is coined with concerns about environmental impacts. In the public, the sea is apparently often perceived as untouched nature which shall now be increasingly covered with obstacles for birds and noisy activities scaring off porpoises and seals. This may not always be the case, but knowledge about the possible impacts of offshore wind farms is still limited and urgently needs to be expanded. Taking this into account, the governments of Germany and Denmark have agreed to cooperate 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 cooperation and to study the responses of migrating birds and harbour porpoises in Danish offshore wind farms. The two Danish Energy companies Elsam and Energi E2 and the Environmental Group 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 real offshore wind farms.

Here we present a first status report in the midst of the project, presenting first results of the fieldwork in spring and autumn 2005. We are aware of many limitations of preliminary results and still surprised by some findings and thus are careful to draw conclusions at this stage of the project. However, we have to stress one issue: the main challenge in assessing the impacts of offshore wind farms is still the secrecy of animal life at sea. In order to predict the responses of birds and porpoises to offshore wind farms we need to understand the biology of these animals and thus need more data about their occurrence and behaviour at sea. We hope that the investigations will give a useful contribution in this respect.

The report is certainly biased towards results from Nysted wind farm. This was inevitably caused by the more benign conditions in the Baltic Sea, as compared to the harsh environment in the North Sea.

2. Summary

In 2005 we started a two-year project on the responses of harbour porpoises and migrating birds in the Danish offshore wind farms Horns Rev, North, Sea, and Nysted, Baltic Sea. In this status report, first results are presented. 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 Elsam and Energi E2.

Harbour porpoise study – logging click sequences by means of T-PODs

The study on harbour porpoises was designed as an array of short transects where five T-PODs were deployed to log harbour porpoise echolocation signals. Positions with T-PODs covered positions inside and outside the two wind farms Nysted and Horns Rev. In each wind farm area, two rows – totalling in ten instruments – were deployed simultaneously. During the campaign 2005, we changed the position of the rows one time.

We scheduled test-tank and in-situ calibrations of T-PODs. The first exercise identified individual threshold values of absolute sensitivity and estimated the detection range of approximately 300 m with almost no directionality. The latter exercise identified relative values of specific harbour porpoise echolocation parameter (e. g. porpoise positive minutes per day) to calculate the individual deviation from averages of T-POD bundles deployed together for several days . We identified a specific instrument with long deployment time and small deviation of the overall bundle average as the ideal reference instrument. Referring to this standard T-POD we were able to calculate individual correction factors for all T-PODs used in this study.

In Nysted wind farm area, hydrophones were deployed from June, 14th to December, 7th totalling in 1,563 entire days (90% of maximal achievable days) of data logging with no considerable times of ambient noise clutter. In Horns Rev wind farm area hydrophones were deployed from June, 15th to December, 5th. Omitting times with significant ambient noise clutter, the logging effort was 751 entire days (43% of maximal achievable days).

In the number of porpoise positive days (PPD), the two wind farm areas did not differ. Considering the entire investigation period, in Nysted 97% of the days showed at least one harbour porpoise encounter and in Horns Rev 98% respectively. The more detailed time basis hours and minutes (PPH and PPM) revealed differences in echolocation activity in the two wind farm areas, as the percentage of positive times was considerably higher in the Horns Rev area (factor 2.3 referring to PPH and factor 4.0 referring to PPM).

In both wind farm areas the echolocation activity decreased in late autumn, as indicated by decreasing PPM per day and increasing waiting times between two encounters of harbour porpoises.

In Nysted, the diurnal rhythm of harbour porpoise click activity pattern differed considerably between single T-POD rows. Within three T-POD rows, porpoise echolocation activity was

significantly higher outside the wind farm than in the wind farm. In three of four rows the echolocation activity shifted from a maximum at night in recorded PPM to a maximum at day (or dawn) or to no distinct difference between four day light phases. The spatial distribution and the correlation with wind speed were inconsistent between single rows. In two rows, T-POD positions inside the wind farm logged higher echolocation activity under calm conditions of 0 to three m/s and the PPM per hour decreased subsequently with increasing wind speed.

In Horns Rev, especially in autumn considerable ambient noise clutter limited the logging effort. Being aware of periods with deleted logging effort, the indicators of harbour porpoise presence showed high values and no longer times without any identified click sequences. The echolocation activity (PPM per day) and the diurnal rhythm were inconsistent between rows and single T-POD positions, but we have first indications, that the presence of harbour porpoises inside the wind farm was higher than outside. If these differences were the result of different behaviour of harbour porpoises in a future step click train details will be analysed. The presented review will be the basis for this issue.

Bird study – collision risk of flying birds

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 25 trips with 83 effort days were carried out. The two study periods aimed to focus on migrating birds and thus to cover the main migration periods; hence investigations were performed out between March 30th and May 24th and between September 5th and November 19th.

During the study period several nights with a medium migration intensity could be studied which allowed to record more than five bird echoes per radar screenshot. We had the impression, that no night with very strong migration occurred. Altitude distribution of migrating birds was rather variable but on average altitude distribution was skewed towards the lower altitudes in both study areas. In both wind farms a tendency appeared that a slightly lower number of birds was recorded on the wind farm side of the ships as on the opposite side but we can't draw final conclusion yet, whether this results from avoidance of the birds.

Acoustic observations indicated that species composition at night was dominated by songbirds, mainly thrushes.

Visual observations identified the species composition during daylight period. In both areas important percentages were formed by typical water bird taxa like ducks and gulls as well as passerines which pass the areas during migration. In Nysted additionally a major fraction was formed by cormorants.

For the birds covered by visual observation both an altitude distribution pattern and a spatial distribution pattern with respect to the wind farm position could be shown.
The altitude distribution was rather variable between seasons and areas even within taxa. Most species/groups apparently avoided the wind farm when on migration. However, resting and foraging cormorants and gulls were frequently registered inside the wind farm.
The data indicate a marked avoidance response of migrating birds during daylight, which was however much less clear from the radar and only slightly indicated especially at night. The contrasting results of visual observations during the day and radar observation during night may indicate a reduced ability of migrating birds to avoid the wind farms at night but further investigations are required before conclusions can be drawn.

An outlook is given dealing with possible changes and enhancements and final results to be expected.

3. Harbour porpoise study – logging click sequences by means of T-PODs

3.1. 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 mills 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 Engineering at Horns Rev and Energi E2 in Nysted) are accompanied by a variety of research projects carried. Baseline studies, technical and progress reports are available (www.hornsrev.dk, www.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) 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 the marine facilitation ordinance (Seeanlagenverordnung) 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 mainly by the noise emissions of operating wind mills.
The responses of harbour porpoises to offshore wind farms are monitored by continuous registration 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 porpoises to the operation of the turbines. Unlike visual observation, a deployment of PODs at the wind farms allows to relate 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 a 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), 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.

3.2. 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 Engineering 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 investigations focus on larger birds (ducks, geese, gulls), since many of the observations and measurements (visual, radar) are made 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 NERI 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.

3.3. Description of the offshore wind farms

3.3.1. Horns Rev

The offshore wind farm “Horns Rev” is situated approximately 35 km west of Esbjerg/DK (Fig. 3-1). The wind farm area is located in the south-eastern part of the Horns Rev, approximately 14 km west-south-west of Blåvandshuk in the Danish part of the North Sea. 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 reef is a permanently submerged sandbank. It is built 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 sand bank. The water body is typically estuarine, with mixing freshwater from the east and North Sea water from other directions.

In 2002, the Danish Power company Elsam Engineering erected 80 turbines with an output of two MW each (Fig. 3-2). As such the total installed capacity is 160 MW. The height of the turbine tower is 70 m and the rotor diameter reaches 80 m resulting in a maximum height to the upper wing tip of 110 m. The minimum free height from sea level to lower wing tip is 30 m. The distance between adjacent turbines and the turbine rows is 560 m giving an open space of nearly 500 m between the turbines. The turbines are equipped with white strobe light installed in a height of about ten m above sea level to ensure visibility for ship traffic and with red strobe light at the top of the turbines as a marking for air traffic. The wind farm covers an area of approximately 20 km² (CHRISTENSEN et al. 2004). A buried sea cable leads from a transformer platform to the shore. The wind farms operational phase started in autumn 2002.

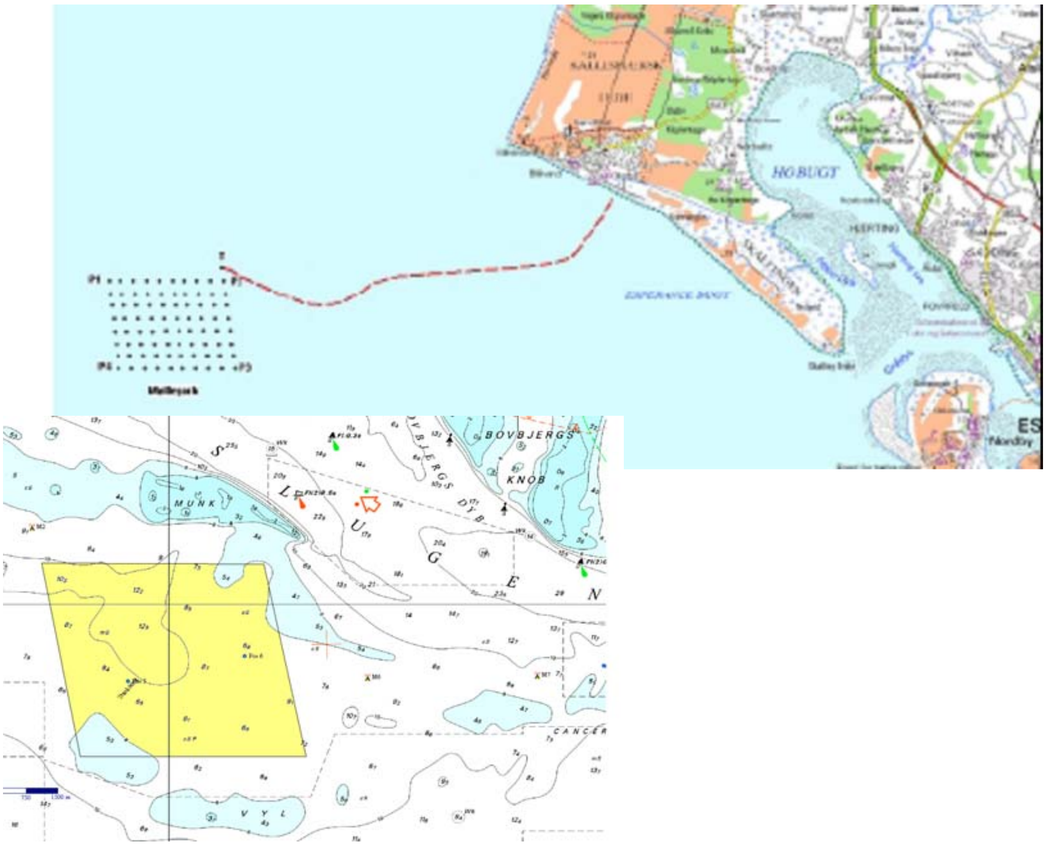


Fig. 3-1: Location of the Horns Reef wind farm.

Fig. 3-2: Horns Rev wind farm (Photo BioConsult SH).

The coordinates (Gauss-Krüger) of the square are*:*

P1: 423,974/ 6.151.447,

P2: 429.014/ 6.151.447,

P3: 429.492/ 6.147.556,

P4: 424.452/ 6.147.556.

3.3.1. Nysted

The offshore wind farm “Nysted” is situated approximately 10 km south-west of Gedser/DK and 10 km south of Nysted/DK on Lolland/DK. The wind farm area is placed about four km south of the partly exposed sandbank Rødsand, which extends over 25 km from Hyllekrog/DK to Gedser/DK. This formation separates a shallow lagoon area with water depths of 0.5 to four 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 1-2 m.

In this area, a consortium of the enterprises Energi E2, DONG and EON constructed in 2003 72 wind mill plants with an output of 2.2 MW each (Fig. 3-1). As such the total installed capacity is 158 MW. The turbines have a hub height of 68.6 m or 77.2 m and a rotor diameter of 82.4 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 buried sea cable leads from a transformer platform to the shore near Nysted. The wind turbines are equipped with red warning lights for the sake of sea and air traffic. The turbine foundations are gravity foundations in concrete 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. The foundations cause an increase of the overall surface area of up to 56.000 m² (Energi E2 2002). The wind farm officially started in normal operation December 1st 2003.

Fig. 3-1: Nysted offshore wind farm (Photo: Energi E2).

The co-ordinates (LAT/LONG) of the wind farm square are:
54°34.20´/ 11°40.02´,
54°33.60´/ 11°45.54´,
54°31.56´/ 11°45.54´,
54°32.14´/ 11°40.08´.

The sea floor at the wind farm consists of glacial sediments and the area is mainly covered of 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 from the inner Baltic origin.

3.4. Design of the Harbour porpoise study

An offshore wind farm may affect harbour porpoises in at least three different ways: physical habitat loss, disturbance from operating turbines and disturbance from service operations. On the other hand, a wind farm may attract porpoises due to higher density of prey because fishing will be prohibited inside the wind farm area and the foundations may attract fish as they function as artificial reefs.

Detecting and quantifying numerical and spatial changes in the distribution of a species roaming widely in offshore waters as the harbour porpoise remains a difficult task. Given a density of one or two animals per km^2 (BIOCONSULT SH & GfN 2002, SCHEIDAT et al. 2003, HAMMOND et al. 1995) the sighting rates from ship or aerial surveys are highly variable and very dependent on counting conditions, especially weather conditions and sea state (TEILMANN 2003). Due to the low densities of porpoises and the patchy distribution, the number of animals seen within a planning area of an offshore wind farm is probably too low to detect moderate differences in numbers before and after the wind farms are installed. Unless there is a very marked avoidance or attraction of the wind farm area, visual surveys are not sufficient to control for changes in numbers or distribution within an area of wind farm size, although they give very valuable information about larger scale distribution patterns and seasonal variations in numbers as well as about distribution patterns during single days. The results of visual surveys are therefore still essential for impact studies.
In consequence we applied a passive approach, using timing hydrophones with data logger (T-PODs). Harbour porpoises use high frequency echolocation clicks of narrow bandwidth and short duration for orientation and prey capture (e. g. AMUNDIN 1991b, VERBOOM & KASTELEIN 1995, 1997, VERFUß et al. 2005, Teilmann 2003). These sound characteristics make the echolocation signals of harbour porpoises unique and well suited for remote acoustical monitoring. Hydrophones receive the specific echolocation signals and log the click sequences. T-PODs continuously record the acoustic signals produced by porpoises within a small area. The devices used in this study were deployed in a transect array of five hydrophones in a row.
The main objectives of this study are to analyse the effects of an operating off-shore wind farm on the temporal and spatial pattern of harbour porpoise acoustic activity at a much smaller spatial and temporal scale than other studies. MADSEN et al. (2005) reviewed hearing thresholds of Odontocetes and noise emission of wind turbines and concluded that it is unlikely that harbour porpoises can hear operating wind turbines at distances beyond several hundred meters. We thus chose a small scaled approach.
The number of signals is assumed to reflect the local harbour porpoise abundance, but data obtained by acoustic surveys cannot yet be transferred into densities. On a scale of about two kilometres we assume that the distribution of harbour porpoises will be more homogeneous and not strongly influenced by water depth or hydrographical features such as fronts in salinity or water temperature.

The idea of working with T-PODs along transects is simple: if harbour porpoises avoid wind turbines, the instruments in the vicinity of a turbine will log continually less porpoise clicks than those further away. As the detection range of single T-PODs is less than approx. 350 m, a high spatial resolution of the data is assured. Due to the real-time detection of porpoise clicks by the T-PODs it is possible to correlate the presence of harbour porpoises in the vicinity of the wind turbines with their noise emission, which is primarily correlated with wind speed. In this context the high spatial and temporal resolution of the study will be very useful. It will be possible to analyse effects of wind turbine operating characteristics on harbour porpoise click activity, whereas no visual observations are possible at higher wind speeds, when the turbines are working at full capacity.

Baseline observations showed that harbour porpoises are abundant in both wind farm areas (TEILMANN et al. 2001, TOUGAARD et al. 2003, 2004, 2005a and b). To reveal potential changes in echolocation signals of harbour porpoises depending on the distance to the wind farm or single wind turbines, it is proposed to use T-PODs which are placed in transects starting inside the wind farm area and reaching outside. With this design, we can address the main questions:
Are there differences in echolocation activity of harbour porpoises inside (close to a single turbine) and outside the wind farm area (up to 1.5 km away) and are they related to wind speed and therefore to the performance and noise emission of the turbines?

3.5. Biology of harbour porpoise:

Sonic information is believed to be the major channel for orientation and communication of marine mammals (see 3.4). As a consequence, they can be sensitive to additional artificial noise sources (RICHARDSON et al. 1995). In the last decades the marine environment has been exposed to an increasing noise emission of human activities. Shipping traffic is in particular contributing to the emission of low frequency noise (below one kHz). Under water, low frequency sounds with high source levels propagate very far (URICK 1967).

3.5.1. Characteristics of harbour porpoise echolocation clicks

In contrast to other odontocetes, harbour porpoises do not whistle. Compared with dolphin clicks, porpoise clicks are relatively long and highly tonal. The figure 4 shows the waveform (red) and spectrum (black) with the scale units being kHz. The click beam has a three dB width of 16 degrees (AU et al. 1999). The click spectrum does not change much at increasing angles from the centre of the beam (AU ET AL. 1999).

Harbour porpoises produce short high frequency echolocation clicks of a narrow bandwidth centred near 130 kHz, with little energy below 100 kHz (VERBOOM & KASTELEIN 1997). These characteristics make the signals suitable for automatic remote detection. Echolocation clicks are used for orientation (VERFUß et al. 2005) and prey capture (BUSNEL & DZIEDZIC 1967, SCHEVILL et al. 1969, VERFUß & SCHNITZLER 2002) and possibly also to some extent for communication (VERBOOM & KASTELEIN 1997).

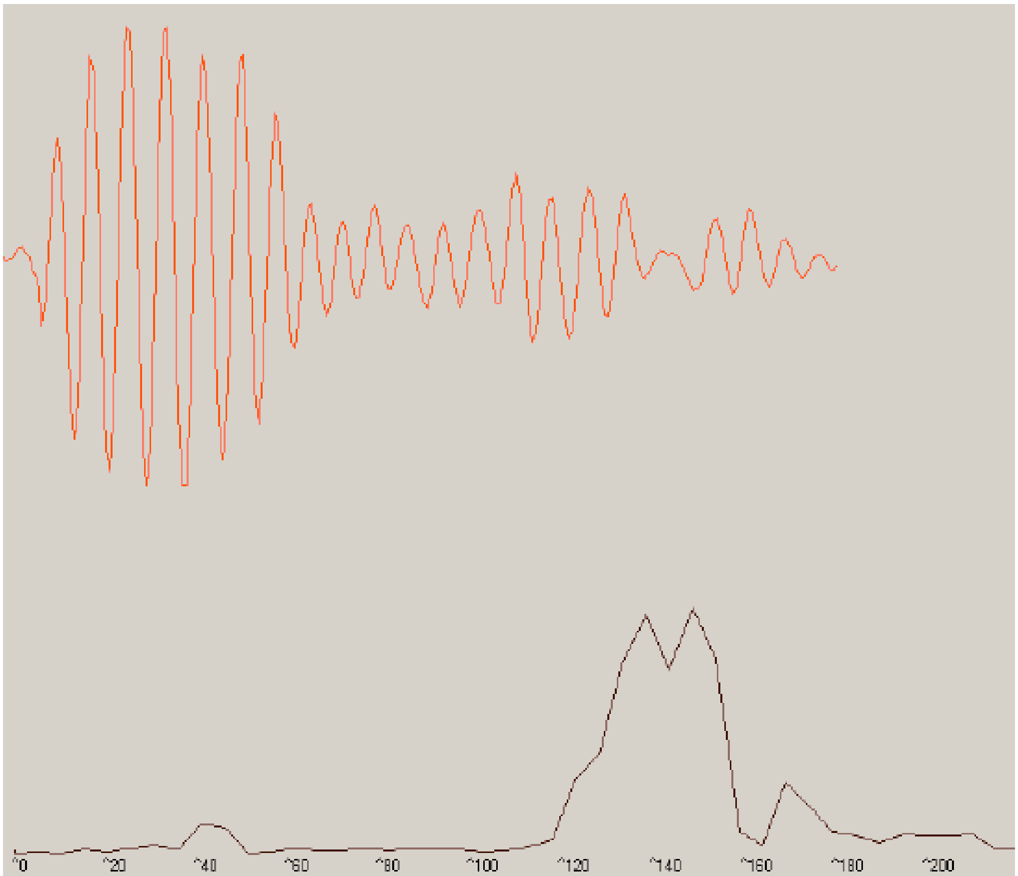


Fig. 3-1: Waveform and frequency spectrum of a porpoise echo-location click. The waveform is 200 µs long, the unit of the X-axis of the spectrum is kHz. (out of FISHER &TREGENZA 2003, www.chelonia.demon.co.uk).

Subsequently produced clicks form specific click trains and show pulse (click) repetition frequencies or interclick-intervals between ten and 100 clicks per second. It is believed that lower click frequencies indicate echolocation that is used for navigation whereas trains with higher and accelerating values ("fast trains") are known to be used in the process of prey capture (KASTELEIN et al 1997, AMUNDIN 1991b, VERFUß et al. 2005, this study). These click trains show rapid rises in the interclick-interval (Fig. 3-2) commonly resulting in up to 600 – 800 clicks logged per second. High frequency click trains - buzzes - are known to be used in the final stages of attempts to capture prey. The highest frequences recorded are around 1,200 clicks per second produced from harbour porpoises during feeding bouts in T-POD trials in Yell Sound/GB in 2002 (FISHER & TREGENZA 2003).

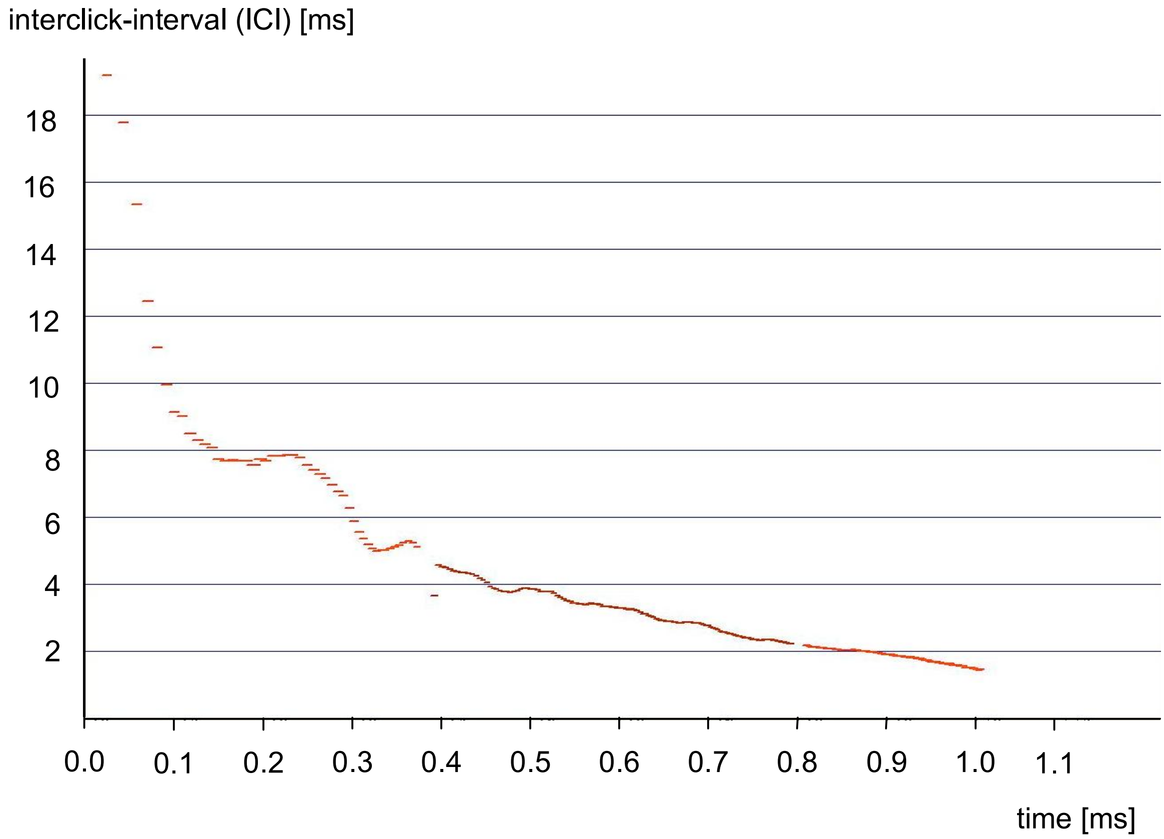


Fig. 3-2: Typical accelerating click train pattern, which is characteristic for prey capture (own data).

3.5.2. Population status

Harbour porpoises are coastal animals and although capable of diving to depths of more than 100 m (TEILMANN 2000), they are regularly found in shallow waters and are often seen foraging very close to shore, even in the surf zone.
Harbour porpoises are generally known to be generalists and as opportunistic in their feeding behaviour (KOSCHINSKI 2002). Adults primarily feed on fatty fish species such as herring, mackerel, eelpouts but also on small cods with maximum lengths of 20-25 cm (BACH et al. 2000). Porpoises are often seen alone, but may aggregate in small groups when fish schools are present.

In European waters, the harbour porpoise is an endangered indigenous marine mammal (annex 2 and 4 of EU habitat directive).

3.5.2.1. Harbour porpoise occurrence at Horns Rev

Harbour porpoises are distributed throughout the entire North Sea and high densities are found in the German Bight. The SCANS survey of 1994 estimated 260,000 porpoises in the North Sea (HAMMOND et al. 1995, HAMMOND et al. 2002). Results of the latest SCANS survey of 2005 have not been published yet. A large neighbouring area west of Sylt/D has been identified as a high density area (BIOCONSULT SH & GfN 2002, SCHEIDAT et al. 2004)

Little is known about factors that governs the temporal and spatial fine-scale distribution within an area. Several studies indicate a north-south gradient of harbour porpoise densities along the German Wadden Sea (BENKE et al. 1998, SONNTAG et al. 1999). Baseline observations on Horns Reef showed that harbour porpoises are abundant in that area, including the area now covered by the wind farm.

It has been suggested that harbour porpoises are associated with estuarine frontal systems. The hydrography of the area west of the Wadden Sea is dominated by a large influx of freshwater, predominantly originating from the rivers Rhine and Elbe. The mixing zone of the estuarine water bodies with more saline North Sea water runs along a frontal zone running offshore from the Wadden Sea, with Horns Reef marking the northern edge of this frontal system (Tougaard et al. 2005b).
Piscivorous birds – e. g. divers (*Gavia* sp.) - are often associated with estuarine frontal systems German Bight (SKOV & PRINS 2001). A recent study from the Bay of Fundy, Canada (JOHNSTON et al. 2005) confirms a strong association of porpoises tagged with radio transmitters with hydrographical fronts and eddies formed by strong tidal currents.
A significant correlation in abundance with tide was also observed when analysing the line transect data collected in our study.

As similar complex hydrographical features with fronts and eddies are present in the Horns Reef area, it is likely that they also play a major role in determining the fine-scale distribution of harbour porpoises in the area, including the wind farm. It is believed that the gradients and

frontal systems are important for concentrating nutrients and plankton and porpoises probably respond to an increased concentration of prey, which itself aggregates in the frontal regions due to the higher production and/or availability of planktonic prey (JOHNSTON et al. 2005).
In the area west of Sylt/D BIOCONSULT & GfN (2002) and DIEDERICHS et al (2004) showed a consistent marked seasonal distribution pattern with declining densities in the winter months.

3.5.2.2. Nysted

The harbour porpoise is the only cetacean that is regularly found in inner Danish Waters and the western Baltic. It is very common in inner Danish Baltic Sea waters, with a total population in Kattegat, Belt seas and western Baltic estimation of around 40.000 animals (HAMMOND et al. 1995, HAMMOND et al. 2002). In the Baltic Sea, varying densities of harbour porpoises occur: whereas the species is abundant in the western part, the density is strongly decreasing in central or eastern Baltic Sea. SCHEIDAT et al. (2004) described decreasing sighting rates in arial surveys and VERFUß et al. (2004) showed decreasing echolocation activity with the help of T-PODs within the expansion of the German Baltic Sea from west to east.
The species reaches the south-eastern limit of its main distribution range in the area south east of the islands Lolland/DK and Falster/DK. The Danish part of the Baltic south of Gedser/DK was previously believed to be an unimportant area for harbour porpoises, as only very few porpoise observations were made before the EIA framework studies. Now it is known that the area has a medium density of porpoises and is considered to be a relatively important area as calves are observed regularly.

Baseline observations have shown that harbour porpoises regularly use the Nysted Offshore Wind Farm area. Satellite tracking of 60 animals in Danish waters has shown that some of the tracked animals regularly visited the Rødsand area but not for very long periods (TEILMANN et al. 2003).

On the basis of porpoise positive days, BENKE et al. (2003) described a significant decline of harbour porpoise echolocation activity in the German Baltic Sea during the winter months.

3.6. Methods

3.6.1. Principle of operation and characteristics of T-PODs

The responses of harbour porpoises to offshore wind mills were monitored by continuous registration of echo-location clicks in the wind farms using passive acoustical hydrophones with data logger (Porpoise Detectors, T-PODs, version 4 with the associated software T-POD.exe v7.41). T-PODs are self-contained automated echolocation sound logger with click timing manufactured by N. Tregenza, www.chelonia.demon.co.uk.
The housing of a T-POD is made of PVC pipe of 730 mm in length and 88 mm in diameter. A screwing lid closes the device at one end and a vinyl encapsulated hydrophone

(piezoceramic transducer) is attached on the other end (Fig. 3-1). The vinyl material has the same impedance as seawater.

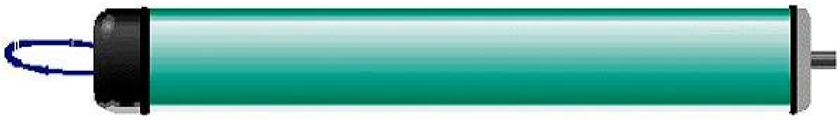


Fig. 3-1: The housing of the T-POD with external hydrophone.

The T-POD is linked to a specialised signal processing system that recognises the very distinctive trains of clicks produced by harbour porpoises and produces computer files with details of detection.

The device processes the recorded signals with specialised software in real-time and logs the time and duration of each click with a resolution of ten microseconds on a PC. Overall click timing accuracy is lower due to clock drift, but would be sufficient for logged events to be correlated with timed visual data.
Specific acoustic values are set by the user. The click train detection allows the T-POD to achieve a higher specificity of cetacean detection than is possible using any method based purely on single click characteristics. The T-POD is equipped with a 128 MB non-volatile memory (up to 30 million clicks can be stored) and is powered by two bundles of six 1.5 volt D-cell alkaline batteries. Data logging stops when the voltage drops to 5.2 volts. The standard alkaline batteries ensure a logging period of more than six weeks. The memory is filled in highly variable times depending on echolocation activity, ambient noise and specific software settings.

In this study, data were downloaded to a laptop on the ship for storage and future analysis (Fig. 3-2). This procedure handling did not cause any considerable interruption of the total the deployment period.

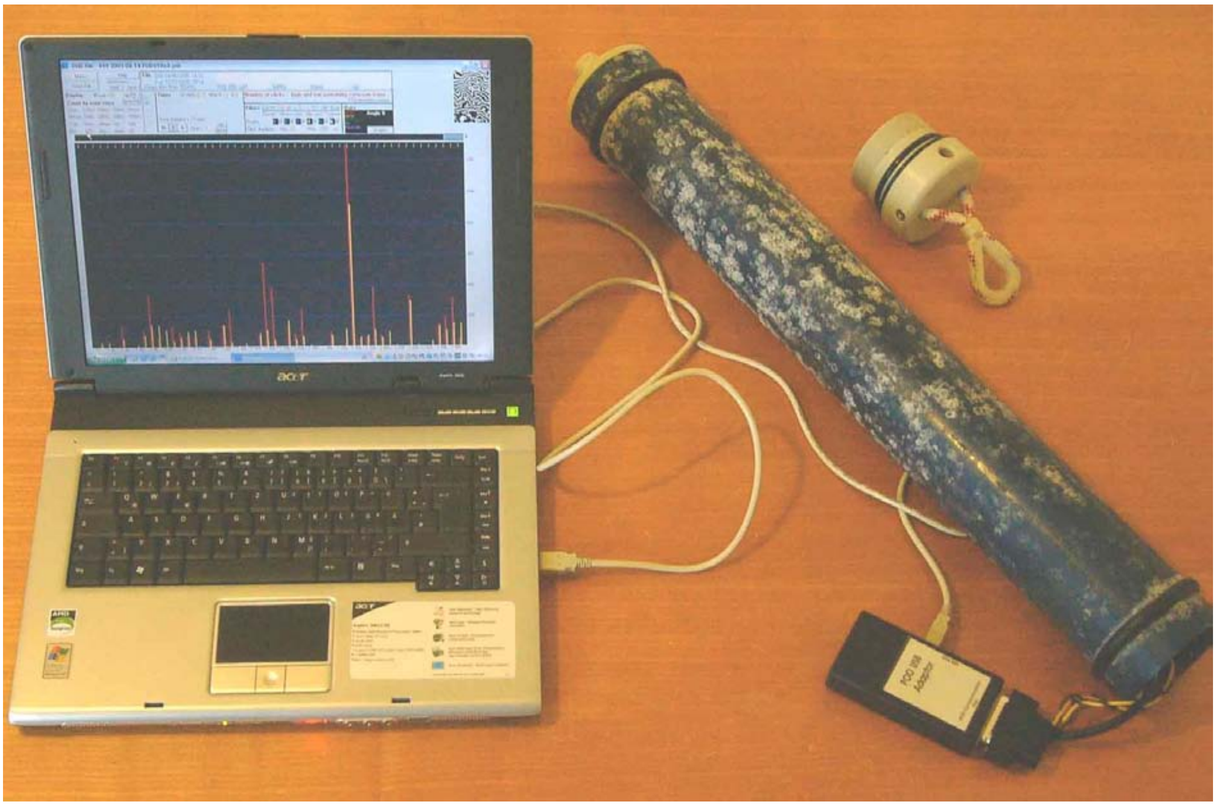


Fig. 3-2: Communication of laptop and opened T-POD via USB for settings or data storage.

Furthermore, the T-POD consists of a hydrophone, an amplifier, analogue electronic filters, a digital and a memory to store click times. Potential aging of the ceramics forming the active part of the hydrophone is negligible Static pressure has - especially in the onsite shallow waters - no influence on the sensitivity of the hydrophones The hydrophones are omnidirectional (2.5 calibration) in the horizontal plane with the highest sensitivity at 120 kHz, but especially tidal currents cause inclination of the T-POD and may influence the sensitivity to an unknown extent In the range of normal onsite water temperatures the hydrophone is insensitive to temperature. The digital and filter settings can be set to a range of different click duration, centre and reference frequencies, signal bandwidth and signal strength that are characteristic for harbour porpoise echolocation clicks in order to distinguish them from noises from boat sonars and other sources (propeller cavitations, shifting sediments in tidal areas like Horns Rev).

The T-POD detects harbour porpoise sonar clicks by the continuous comparison of the output of two bandpass filters. Each filter blocks all frequencies except those around its centre frequency. The start of a click is defined by the output level of the target frequency filter exceeding the reference level by some selected factor. The logger can scan through six sets of settings each minute to enable the detection of species using different frequencies. In each scan the T-POD logs for 9.4 seconds using the set of chosen values.

Click detection by the T-PODs is followed by train detection and classification using the software T-POD.exe (v.7.41). This software makes use of an algorithm to discriminate cetacean trains from other sources. The difficulty of train classification is to distinguish between “false positives” and “true negatives”. False positives are click trains from other

sources than porpoises but the algorithm identifies this train as porpoise click trains. Respectively true negatives are real porpoise click trains which are not identified by the algorithm. The T-POD.exe software deals with that problem by distinguish between different click train classes with different probability to derive from porpoises.
The software puts clicks into the following train classifications:
"CetHi" – (Cetaceans high): click trains with very high probability of coming from harbour porpoises.
"CetLo" – (Cetaceans low): less distinctively harbour porpoise click trains, but still with a high probability of porpoise origin.
"?" – (Cetaceans doubtful): trains, which in noisy environment are likely to have a non-cetacean origin.
"??" – (Cetaceans very doubtful): trains, which include trains that may have come from porpoises but cannot be reliably identified as having that origin. These trains have often been subject to multiple reflections and may contain multiple clicks in clusters.
"Boat sonars" – these noise sources are inevitably logged because boat sonars can be at the same pitch as echolocation clicks of harbour porpoises.
All other clicks which occurred not in trains or do not fit into the scheme above are rejected and will not be shown.
The software presents the different train classifications in different colours of the clicks on the screen (Fig. 3-3). Red = CetHi; yellow = CetLo; green = doubtful; white = very doubtful.

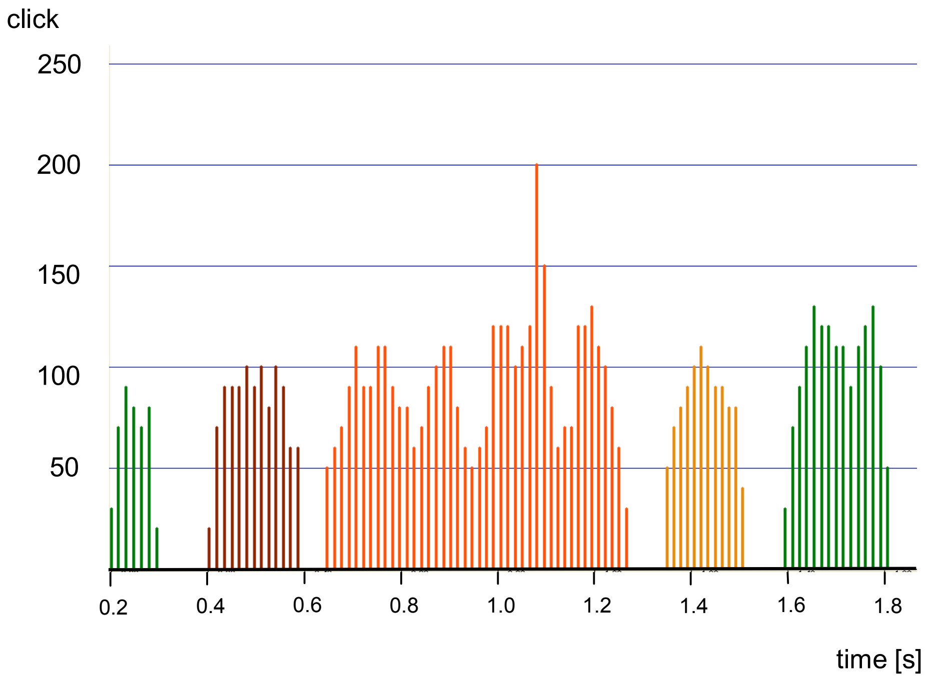


Fig. 3-3: Example of registered porpoise click sequences, shown as series of vertical bars, whereas the time [s] is shown on the X–axis and the duration of a click is shown on the Y-axis.

Special attention must be addressed to the classification "doubtful" click sequences. In relatively quiet environments like in the Nysted area most of the trains classified as "doubtful" were neighboured by trains of higher classification categories. It is therefore obvious that in this area click trains of this classification were also produced by harbour porpoises and should be included into data analysis.

In the Horns Rev area we met a lot of ambient noise clutter, caused possibly by moving sediments during periods of high current speeds. Especially grains of sand hit the hydrophone and produced high frequency noise which passed the filter and caused thousands of clicks within few seconds. In these periods a lot of click trains classified as "doubtful" are likely to have a non-cetacean origin. In order to cope with this ambient noise clutter we identified threshold values to define times when harbour porpoise click sequences are possibly masked. The thresholds were set arbitrarily and need to be tested in future.
When no scan limit was set, we skipped logging periods with more than 14,000 clicks per minute (equivalent to 233 clicks per scan). Later we introduced a scan limit and excluded periods with more than 4,000 clicks per 10 minutes (Fig. 3-4). To keep both areas comparable we decided to use within this report only "CetHi "and "CetLo" click trains which is in common with data analysis of our Danish colleagues (TOUGAARD et al. 2005, 2004, TEILMANN et al. 2001, 2002).

It is apparent, that in times with high wind speeds and thus ambient noise clutter of braking waves and/or moving sediments harbour porpoise echolocation sequences are masked (Fig. 3-4). These times were identified referring to threshold values of noise clutter and omitted from the logging effort.

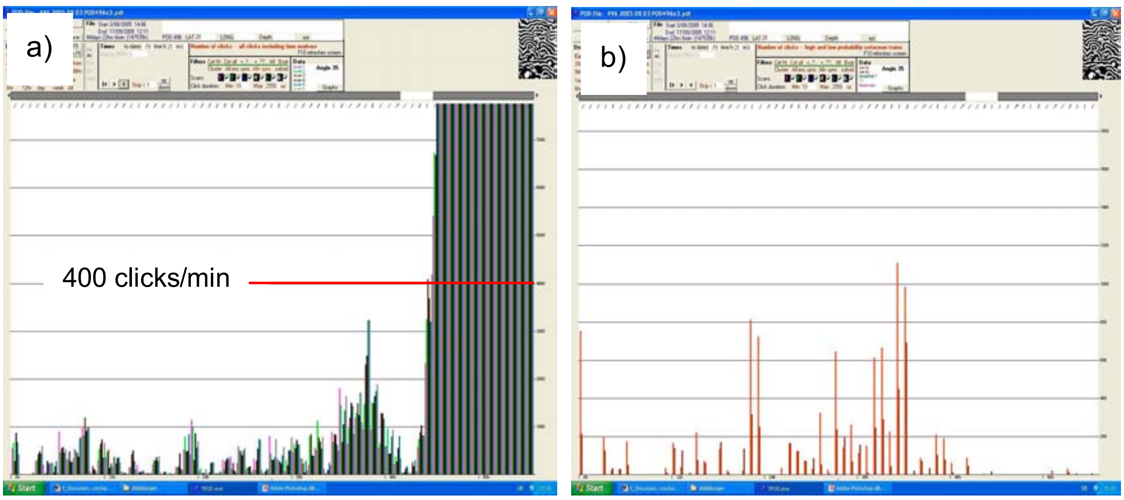


Fig. 3-4: Example of empirical identification of threshold assessing the logging effort: a) all clicks b) identified harbour porpoise clicks. Ambient noise clutter mask harbour porpoise echolocation click sequences and logging periods with more than 4,000 clicks per ten min were deleted. Be aware of different scale in Y-axis in a) and b).

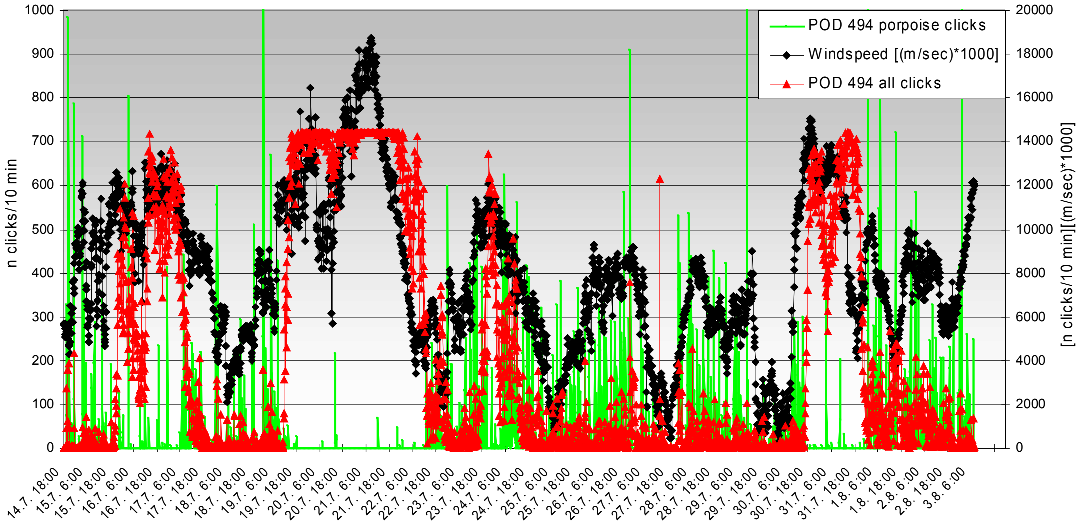


Fig. 3-5: Wind speed, all recorded clicks and harbour porpoise click trains identified by the algorithm of T-POD 494 in the time period July, 14th to August, 3rd.

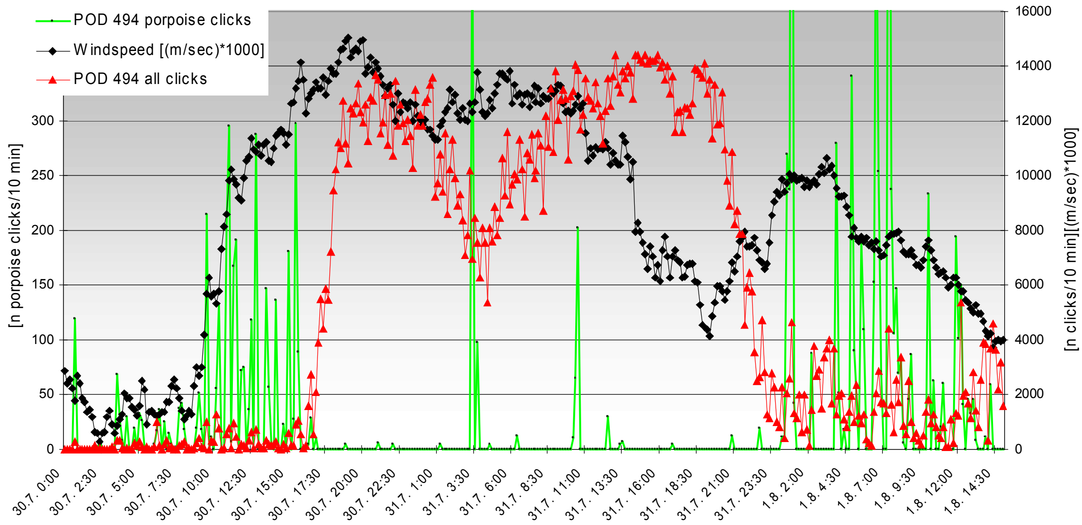


Fig. 3-6: Wind speed, all recorded clicks and harbour porpoise click trains identified by the algorithm of T-POD 494 in the time period July, 30th to August, 1st (extraction of fig. 33)

Specific T-PODs settings

The TPOD.exe software offers the opportunity to choose specific settings to cope with different target species and environments (Fig. 3-1):

For each 9.4 second interval of each minute the following operational parameters can be set by the user:

- Target frequency (16 steps from 9 kHz to 170 kHz)
- Reference frequency (same)
- Bandwidth (8 steps)
- Sensitivity (16 steps)
- Noise adaptation. This reduces the maximum bandwidth logged when the ambient noise level (reference filter output) is high. Two settings ++ = on, + = off.
- Maximum number of clicks logged in each scan in any minute. This helps to make memory use more predictable.
- In addition the minimum click duration logged can be set for all scans and the number of minutes OFF following each minute ON can be set.

To focus on harbour porpoises we set the target (A) filter to 130 kHz and the reference (B) frequency filter to 92 kHz and the click bandwidth to 5 kHz.

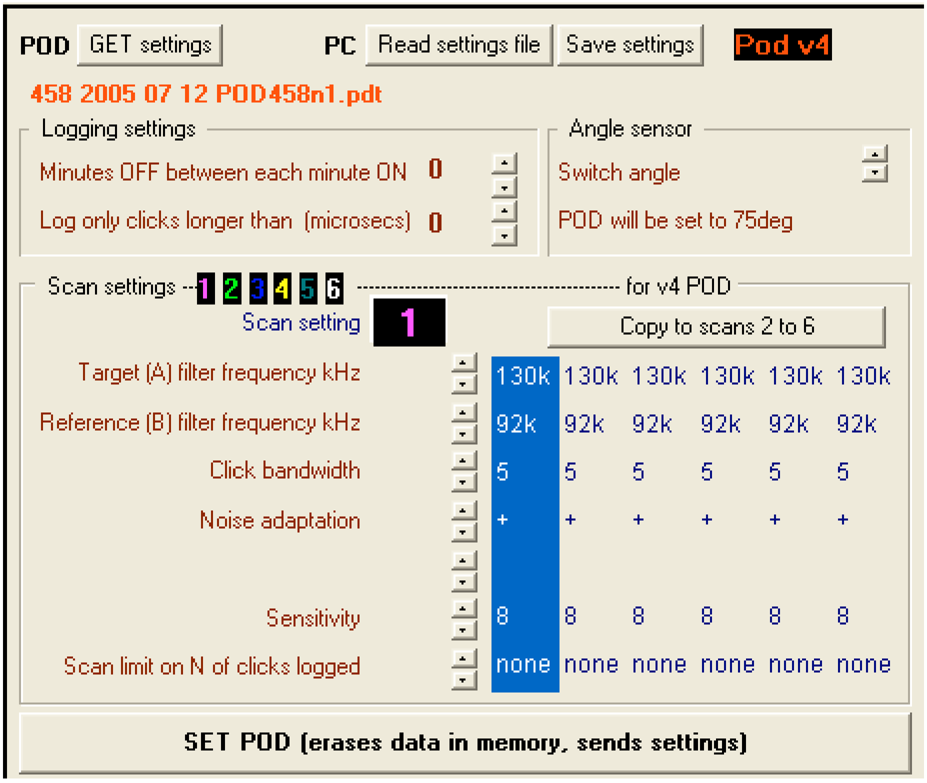


Fig. 3-1: Scan settings of the T-PODs. With the exception of the scan limit the settings were identical in the two wind farm areas Horns Rev/DK and Nysted/DK.

The noise adaptation facility has been developed recently and has not been approved so far. It was therefore not used here in order to keep the data set coherent and comparable. The influence of the perception of different intensities of echolocation clicks under variable ambient noises has not been addressed by now. (The screenshot of the settings show a single + for noise adaptation off, instead of ++ for noise adaptation on.)
The sensitivity was set to "8" (the medium value within the range from 1 to 16) in order to reduce overlapping recording ranges of single T-POD devices.
The T-Pods were operating only when floating in a more or less upright position. The logger switched off when the angle of inclination range was between 75 and 295° (Fig. 3-2).

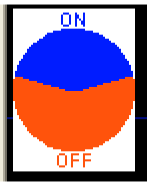


Fig. 3-2: Switch angle was set to 75°.

Due to a considerable ambient noise at Horns Rev caused probably by moving sediments (see above) we changed the settings in this area during the investigation period. To avoid replenishment of memory within a few days due to millions of click clutter we set a scan limit of 240 clicks within a scan of 9.4 s at row South1 between July, 13th and September, 5th. The same setting was used during the second time period from September, 10th to December, 5th at both rows. In the Nysted area the environment is much calmer and no scan limit was activated ("none" in Fig. 3-1).
As we cut off times with a lot of disturbance by noise in the Horns Rev area, this difference in settings has no influence on the data analysis as long as we only look to the echolocation activity parameter used in this report.

3.6.2. Mooring of T-PODs at sea

Within both wind farms, we used each two arrays consisting of five T-PODs to investigate the principal question, if harbour porpoises do react either to single wind mill power plants or to the entire wind farm (Fig. 3-1). One array consists of a row with five T-PODs placed 400 m apart from each other. Two of the T-PODs within a row were moored inside the wind farm approximately 150 m close to single wind turbines, a third T-POD inside the wind farm was positioned in between two wind mills. The last two T-PODs were moored outside the wind farm up to a distance of approximately 1,200 m away from the outer line of wind turbines.
During the study period in 2005 in both wind farms the two row arrays were changed once to new positions (Fig. 3-3). Over the whole study period of two years it is planned to deploy multiple linear arrays of T-PODs in several transects leading from the inside of wind farm to its surroundings to reveal potential gradients in habitat use of harbour porpoises in relation of the distance to the wind farm. Row positions will be changed subsequently, approximately

every eight weeks in the course of the project in order to avoid site-specific gradients in the echolocation activity of harbour porpoise.

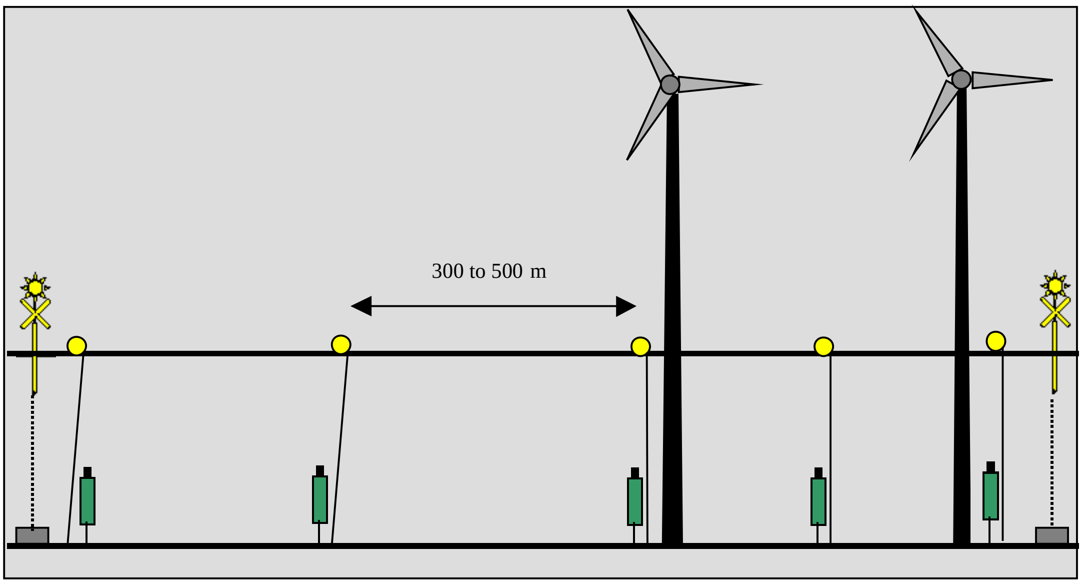


Fig. 3-1: Linear array of T-PODs (transect) from outside (left) to inside the wind farm (right). T-PODs inside the wind farm with different distances to the wind mill power plants.

The exact detection range of a T-POD is not accurately known. However, if the lowest sound pressure is known that a T-POD needs to detect a porpoise signal (called "T-POD sensitivity") a theoretical maximum detection distance can be assessed (Fig. 3-2).
When starting the project, only few results of T-POD sensitivity measurements were available (VERFUß et al. 2004, TREGENZA pers. comm.). VERFUß et al. (2004) suggested a maximum detection range of 100 to 260 m (version 3 T-PODs). Referring to the manufacturers instructions, the latest T-POD version 4 logs porpoise echolocation clicks up to a distance of 270 m when the sensitivity is set to "8" and 380 m at the maximal sensitivity level of "16". As the porpoise signal is highly directional with a beam width of approximately 16° at 3-dB (AU et al. 1999), the maximum detection distance can only be received when the sonar of the harbour porpoise points towards the hydrophone of the T-POD. Therefore the detection range is supposed to decrease significantly if the sonar beam is not directed to the hydrophone.

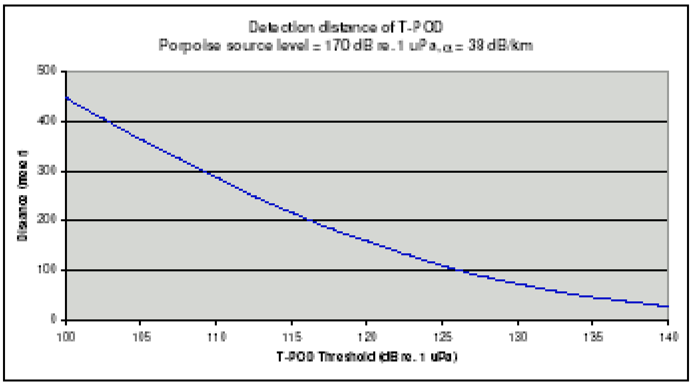


Fig. 3-2: Theoretical maximum detection distance at which a porpoise can be detected by the T-POD at different T-POD sensitivities. α = sound absorption coefficient of sea water. Figure from Tougaard et al. 2005.

Field experiments indicate that the effective detection range of T-PODs is less than the theoretical detection distance measured by test tank calibration. For version 3 T-PODs a detection distance of 200-250 m is assumed by different authors (TREGENZA pers. com., HENRIKSEN et al. 2003, BENKE et al. 2003, KOSCHINSKI & CULIK 2001, DIEDERICHS et al. 2002).

In order to minimise the overlap between neighbouring positions, and to avoid that one animal can be detected by two T-PODs during the same minute we employed the T-PODs at a medium sensitivity and located the PODs with a minimum distance of 400 m from each other. When handling the T-PODs under rough sea conditions, it was not always possible to deploy the T-PODs systems at exactly equal distances from each other (Fig. 3-3).

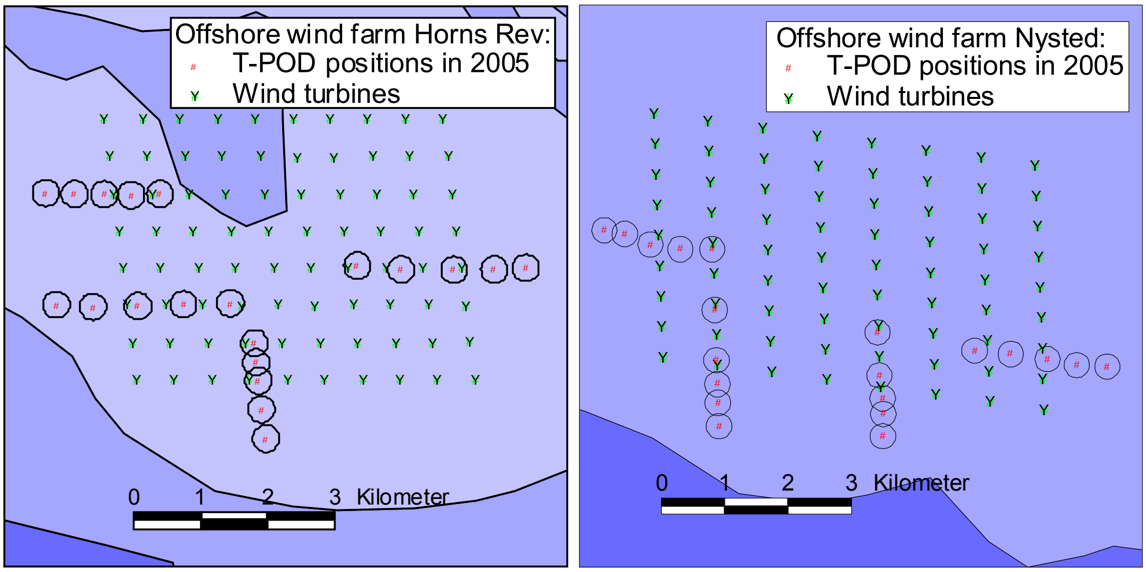


Fig. 3-3: All positions of T-PODs in the wind farms Horns Rev and Nysted in the study period of 2005 with 200 m diameter around each T-POD.

In both wind farm areas we placed the T-PODs in the water column approximately one meter above the sea bottom (Fig. 3-4).

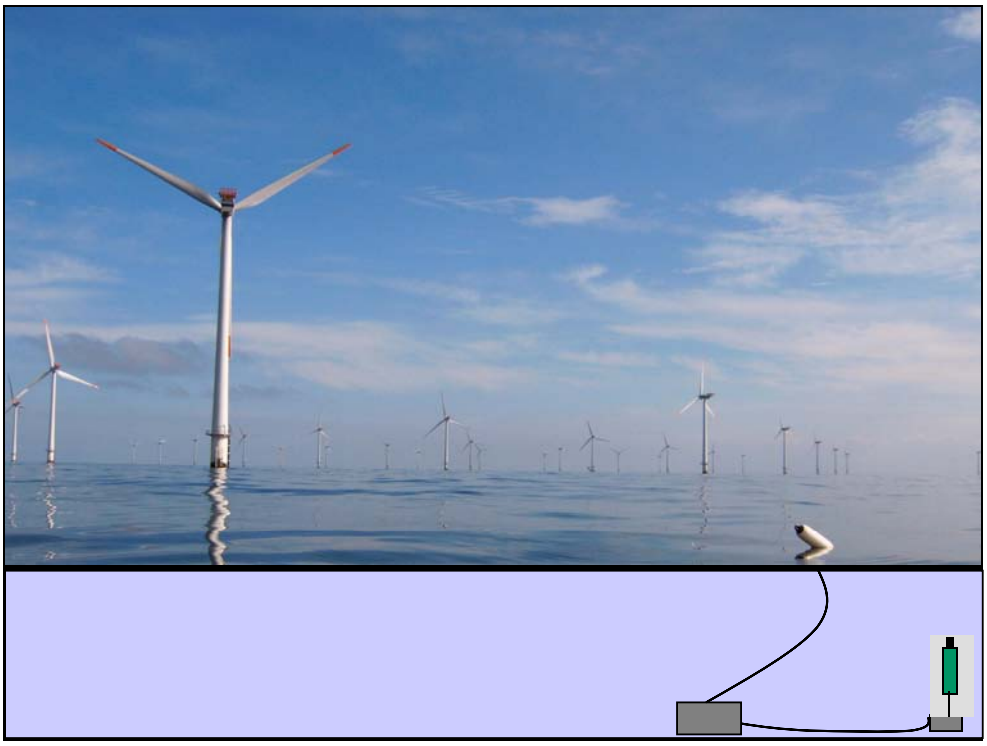


Fig. 3-4: Deployment of a T-POD at sea.

The T-POD normally has a sufficient buoyancy to stay in an upright position, but considerable inclination may occur with strong currents – especially in the North Sea. Inflatable yellow buoys indicate the position of the T-POD. A row of five hydrophone positions is marked by two official yellow warning buoys in the Baltic and three in the North Sea respectively.

The locations of the T-PODs were stored with the ships GPS system with approximately five meter accuracy. We lost some yellow inflatable buoys but were able to recover the hydrophones with a dredged anchor which got entangled with the rope between the anchor blocks attached to the T-POD systems (Fig. 3-4 and
Fig. 3-5).

Fig. 3-5: T-POD mooring system with two anchor blocks.

3.6.3. Parameter of measuring harbour porpoise echolocation activity

After downloading the porpoise signals from the T-POD memory to a PC the data were processed by the algorithm of the software T-POD.exe. All click sequences falling within the two highest classes of probability to originate from a “true” porpoise (CetHi, CetLo, chapter 1.1.1) were stored in an access database together with the time of origin. Further analysis were made using different parameters.

3.6.3.1. Porpoise positive time per time unit (PPD/PPH/PPM)

Different parameters of T-POD signals have been proposed to describe porpoise echolocation activity. The T-POD logs the single clicks with a micro second resolution. In this report, the smallest time unit used for analyses is a minute.
Analyses on basis of a minute consist of many observations of zero (minutes without porpoise click sequences) and a few minutes with a minimum of one click sequence.
The parameter “porpoise positive time” means the proportion of time units (minutes/hours/days) with porpoise activity logged compared with the total number of time units in which the T-POD was active (equation 1-1, x_t = number of clicks during time unit)

1-1

$$\text{Porpoise positive time per time unit} = \frac{\text{Number of time units with clicks}}{\text{Total number of time units}} = \frac{N\{x_t > 0\}}{N_{total}}$$

The parameter “porpoise positive time” has already been identified as powerful tool to describe harbour porpoise click activity (TEILMANN et al. 2001, 2002, 2003, TOUGAARD et al. 2004, 2005, DIEDERICHS et al. 2004).
The different time units from days to minutes give different information about the echolocation activity of harbour porpoises. The number of porpoise positive days (PPD) as the roughest unit gives information about the utilisation of low density areas. It answers the question: on how many days are porpoises present in this area? This unit is useful to describe seasonal attendance patterns in areas with low densities like the eastern German Baltic (VERFUß et al. 2004). In high density areas when porpoises are present nearly every day it is recommended to apply a higher resolution. The more detailed unit porpoise positive hours (PPH) expresses the utilisation of a specific area more precisely

For an area west of Sylt, DIEDERICHS et al. (2004) showed a high similarity between seasonal attendance patterns of porpoises derived from PPM/day with those basing on densities calculated from observations during monthly aerial surveys. A relation of harbour porpoise density and PPM/day is therefore very probably.

Through the comparison of PPH and PPM it is possible to draw some conclusions about the activity of porpoises in an area. A high value of PPH in combination with a low value of PPM may indicate a high turn over rate with short duration of stay. In contrast, a low value of PPH in combination with a high PPM may describe a longer duration of stay and a low turn over rate.

We analyzed the diurnal rhythm of echolocation activity in considering different time resolutions as hours or specific daylight conditions. Dawn and dusk are defined as periods of 90 min before and after sunrise and sunset respectively and thus totalling in 180 min (three hours). It is evident, that day and night times vary with seasons and day time periods range e. g. in Nysted from 256 to 856 min and night time periods range from 224 to 824 min. The extracted click statistics (e. g PPM per hour) is referred to the varying time spans and thus directly comparable.

3.6.3.2. Encounter

A different approach of analysing T-POD signals is to consider their temporal pattern and to separate periods with click activity of periods without click activity. In this sense, a click event or encounter is defined as a period with click activity separated by a silent period of at least minimum of ten minutes without any click activity (Fig. 3-1).

In consequence, two click sequences separated by a silent time of nine minutes do per definition still belong to the same encounter and thus the maximal number of encounters within one hour is five. The interval of ten minutes for separating events or encounters was suggested by TEILMANN et al. (2002) and was found to be an appropriate choice after inspecting high-resolution graphs of POD signals.

Two parameters can be extracted to describe porpoise activity on the basis of encounters:

Encounter duration = number of minutes between two silent periods longer than ten minutes.

Number of encounter = number of encounters per day.

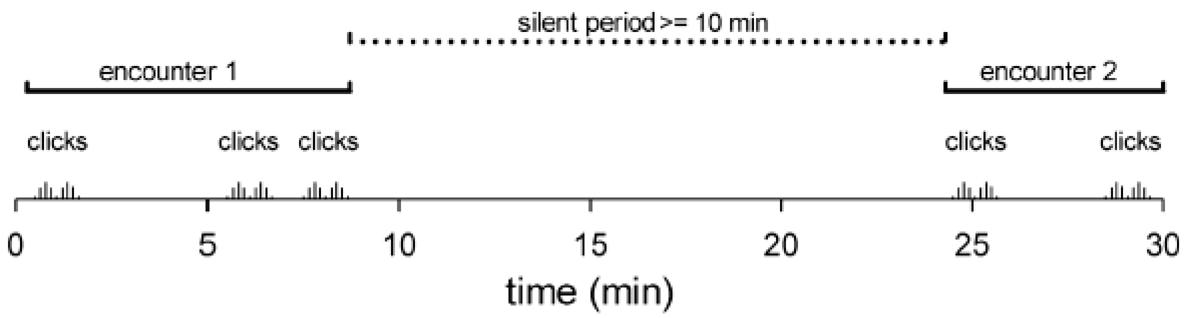


Fig. 3-1: Definition of “encounter” and “silent periods (waiting time)” (of Benke et al. 2003).

3.6.3.3. Waiting time

The time period between two encounters is called waiting time and is to some extent related to the parameter encounter. The waiting time is the time interval in minutes between two encounters and is per definition not shorter than ten minutes (Fig. 3-1). This parameter gives information about the timing of encounters and thus offers some hints the utilisation and turn over rate of animals in the vicinity of the hydrophone.

3.6.4. Calibration of T-PODs

The sensitivity of single hydrophones differs as a result of the production process (N. Tregenza pers. comm.). Different authors therefore recommend T-POD calibrations (TEILMANN et al. 2001, BENKE et al. 2002, DIEDERICHS et al. 2002, TOUGAARD et al. 2005). Especially for our study which focuses on comparisons between single locations on a small temporal and spatial scale it is necessary to calibrate every hydrophone.
The absolute sensitivity of individual T-PODs was measured in a laboratory environment (tanks in Roskilde/DK and Stralsund/D). Additionally, we carried out in-situ measurements of the relative sensitivity of single hydrophones in deploying T-PODs close together during the time we spent in both wind farm areas for investigations of bird migration.

3.6.4.1. Test tank calibration in Roskilde/DK (NERI)

NERI calibrated 17 out of 24 T-PODs used in the two wind farm areas in a laboratory test tank in order to measure the absolute sensitivity.
Even though the small tank is a highly reverberant environment, it is suitable for threshold measurements, as echoes from the tank sides and the water surface are always weaker than the directly transmitted clicks and thus were not detected at sound pressure levels close to the threshold. Specific filter settings were identical in the tank and in the field. The testing routine followed a set-up implemented by NERI and we refer to the description of TOUGAARD et al (2005).

In short, 18 artificial porpoise signals per nine seconds (corresponding to the duration of one scan of the T-POD) were pulsed for each one minute into the water by a waveform generator. The sound level of these signals was stable in this minute. Calibration was started with sound levels well above the threshold of the T-POD hydrophone. The sound level of these signal sequences was then decreased stepwise by 1 db each.

T-POD files were inspected and the signal threshold was defined as the sound level where less than 50 % of the 108 clicks/minute were recorded. This level is referred to as the absolute sensitivity of the T-POD.
Settings of the T-POD filters during calibration were identical to the settings used for deployment. The horizontal directionality of T-PODs was measured by sequentially measuring the T-POD sensitivity at four different angles of incidence in steps of 90 degrees.

3.6.4.2. Test tank calibration in Stralsund/D (DMM)

Due to a co-operation agreement with the German Oceanographic Museum in Stralsund, we calibrated all 24 T-PODs which had been used in the area in 2005, in a test tank at the Museum in Stralsund. The concept of this test tank calibration was very similar to that what was done by the NERI in Roskilde. As the measurements have been performed quite recently in February 2006, the results are not yet available and will be presented in the final report in 2007.

3.6.4.3. Field calibration

Up to now, it has not been possible to analyse the results of the test tank calibration with respect to potential differences in recorded echolocation activity parameters as for instance, “porpoise positive time per time unit”.

To be able to compare data from T-PODs of different sensitivity, we performed in-situ inter-calibration experiments of bundled T- PODs in both wind farm ares. The aim of the experiment was to test for a correlation between the parameter recorded by different devices, allowing the calculation of correction factors to compare the results of different T-PODs despite varying sensitivities.

These experiments at sea are always a trade off between length of deployment time to get sufficient data and the potential danger of T-POD losses in case of unforeseen incidences. We therefore performed field calibration experiments only for the duration of several days simultaneously to counts of migrating birds at sea. We deployed seven to 14 T-PODs bundled close together (Fig. 3-1) in the vicinity of our ship up to 500 m away. The calibration arrangement was similar to the general deployment, as we fixed the T-POD bundle 1.5 m above the sea bottom to a concrete anchor block. From this anchor two 25 m ropes were fixed to a second and a third anchor block. These blocks had ropes to the sea surface where they were marked by small yellow buoys.

Fig. 3-1: Bundle of T-PODs for inter calibration purposes.

Before a field calibration session we fixed together up to 7 T-PODs in the way shown in Fig. 3-1. For technical reasons we could not calibrate every T-POD during every session. Also the composition of T-PODs within a bundle changed from survey to survey.

The total calibration time was divided in six-hour-blocks and for every T-POD the number of porpoise positive minutes (regarding the algorithm setting of “CetAll”, chapter 1.1.1) during these six hours was counted.

The first six-hour-block of a day was defined to last from 0:00 am to 5:59 am, followed by the next block from 6:00 am to 11:59 am etc. For each of these time blocks, we calculated the average number of PPM. The difference between the average number of PPM of a certain T-POD within a bundle and the average number of PPM of the whole bundle showed the difference in sensitivity and could be given as a percentage.
By calculating the average of all differences to the average of all time blocks for one T-POD, we generated a relative value of the sensitivity of a single T-POD referring to the parameter PPM. Regarding this specific parameter it is now possible to adjust all instruments to the same level by applying individual correction factors. For further comparisons, we decided to use the T-POD with the smallest difference to the overall average, the longest calibration recording time and the smallest standard deviation as a ‘reference T-POD” which was set to one.

3.6.5. Choice of dataset

Because of water absorption, the ceramic transducer of the T-POD takes up to three hours of soaking before reliable data are recorded. Therefore all data recorded during the first three hours after deployment of the last T-POD within a row were omitted from the analysis. In the same way, all data recorded from the last hour before the recovery of the first T-POD onwards were omitted in order to avoid biases caused by the noise of the ship motor at the end of the observation trip.
Frequent maintenance intervals assured a continuous power supply to the T-PODs and no data were lost due to potential misbehaviour near the power shortage caused by flat batteries.

In this small scaled study, we generally do not consider the influence of hydrography parameters (e. g. temperature, salinity) on harbour porpoise echolocation activity pattern, as we do not have to deal with significant differences in hydrography parameters between the neighbouring rows of hydrophones.
Further covariates of harbour porpoise click sequences as boat traffic, turbine performance and water depth will not yet be considered in this stage of the project, but in the final report in 2007. In a first approach in this first report, wind speed data of both wind farms are analysed as potential co-variates of harbour porpoise echolocation activity.
Furthermore, diurnal or seasonal rhythms will be revealed and inter- and intra row comparison of the data of single T-PODs are presented.

3.6.6. Statistical analysis

All statistical treatment was performed using SPSS 9.0.
Prior to all statistical tests, data were tested for normal distribution and equality of variances performing the Kolmogorov-Smirnov-test of goodness of fit and the F-test, respectively. When necessary, we (-log) transformed the data in order to achieve a normal distribution. To test for differences between two samples, e. g. for differences in PPH between two POD rows deployed within a wind farm, a T-test was conducted in case that data were normally distributed. The Mann-Whitney-U-test was performed in case of deviation.

To reveal the potential occurrence of differences between several groups, e. g. between hours or other time units within a day, the Kruskal-Wallis-test was performed if data deviated from a normal distribution. If significant differences between groups were found, we applied the Mann-Whitney-U-test to identify between which groups the differences existed. To correct for the growing probability to achieve a significant result at random, results were Bonferroni-corrected. To perform a Bonferroni-correction, the quotient was made from the significance level assumed (e. g. 0,05) and the number of tests conducted with the sample concerned. E.g., when comparing one of the four day light phases with each of the three remaining units, the term 0,05/3 = 0,01667 described the Bonferroni-corrected level of significance.
In case of normal distribution of data, an ANOVA was calculated. To test for variance homogenity, the Levene-test was performed. Significance limits for all statistical treatments were defined as follows (Tab. 1):

Tab. 3-1: Definition of significance levels:

Error probability p	Level of significance
≥ 0,05	not significant
< 0,05 (*)	significant
< 0,01 (***)	highly signifikant

3.6.7. Harbour porpoise high-frequency vocalisation patterns in relation to their behavioural activities

So far, we refer to PPM as the most fine-scaled time unit of harbour porpoise echolocation activity. As the T-PODs log click sequences with a resolution of microseconds, a more detailed approach will be feasible. In order to comprehend behavioural aspects and biological meanings of specific click sequences, our collegue Sven Koschinski reviewed the existing reports and publications. In this report, we include his review in the results. In the final report, we expect to be able to present not only data of harbour porpoise presence (porpoise positive times), but behavioural aspects as well.

3.7. Results

3.7.1. Calibration of T-PODs

3.7.1.1. Test tank

The results of the test tank calibration are shown in Tab. 3-1. Using an empirical average detection threshold, a theoretical maximum detection distance for single T-PODs could be determined, as described in TOUGAARD et al. (2005). The average detection distance was 300 m and ranged from approx. 280 m (110 dB re. 1 µPa) to approx. 340 m (107 dB re. 1 µPa).

However, in the field, the theoretical detection distance can only be achieved if a harbour porpoise is pointing the echolocation beam directly towards the hydrophone. Due to the very narrow angle of the echolocation beam of 16° (Au et al. 1999) it is evident that the detection distance will drop dramatically once the porpoise does not emit sounds in the direction of the T-POD. The mean detection distance in the field will therefore be much shorter and it can be safely assumed that a harbour porpoise cannot be detected from two T-PODs separated by more than 250 m.

Tab. 3-1: Calibration data for T-PODs tested by NERI in Roskilde, DK. Treshold values in dB SPL RMS.

POD No.	Threshold 0°	Threshold 90°	Threshold 180°	Threshold 270°	Threshold mean	st. dev.
412	108.4	107.7	107.6	109.4	**108.28**	0.830161
450	111.1	110.9	108.7	110.2	**110.23**	1.087428
452	108.7	108.6	107.2	108.3	**108.20**	0.687992
454	109.5	109.9	109.7	111	**110.03**	0.670199
458	107.9	107.4	107	107.5	**107.45**	0.369685
474	109.9	108.5	111.9	110	**110.08**	1.396126
476	110.4	108.3	108.5	108.1	**108.83**	1.062623
477	108.5	109.9	110.2	110.4	**109.75**	0.858293
478	110.7	110.5	109	110.9	**110.28**	0.865544
479	108.7	109.5	112.2	109.8	**110.05**	1.506652
480	110.2	110.2	110.6	109.9	**110.23**	0.287228
482	108.9	108.8	108.8	109.9	**109.10**	0.535413
492	107.6	111.6	111	108.5	**109.68**	1.927650
493	107.4	108	110.3	108.7	**108.60**	1.251666
494	109.3	108.9	109.2	110.7	**109.53**	0.801561
495	111.8	109.4	110.8	109	**110.25**	1.289703
497	108.9	109	109.5	109.4	**109.20**	0.294392

The differences between the T-PODs used in our study were rather small (2.8 dB re. 1 µPa) compared to other test tank calibrations (TOUGAARD et al. 2005, VERFUß et al. 2004).

3.7.1.2. Field calibration

In 2005 we carried out five field calibration experiments in the offshore wind farms. In total, 24 T-PODs logged 3.952 hours of data. All T-PODs deployed during the study period were calibrated at least in one experiment (Tab. 3-1).

Tab. 3-1: Details of the field calibration (calibration period, T-POD ID and logging time).

Calibration period 2005	**Pack 1**		**Pack 2**		**Pack 3**	
	POD ID	no. of hours	POD ID	no. of hours	POD ID	no. of hours
12.-16. May	412, 474, 475, 480	84				
5.-10. Sept.	452, 454, 477, 480, 495	103	458, 474, 481, 492, 497	103	475, 478, 490, 501	86
17.-20. Sept.	412, 451, 479, 481, 482, 492, 496	53	458, 474, 476, 493, 494, 498, 499	53		
11.-14. Oct.	451, 454, 477, 478, 480, 495	56	452, 475, 490, 497, 499, 501	56		
3.-6. Sept.	458, 482, 490, 493, 496, 498	69	412, 479, 481, 492, 494, 501	69		

On the basis of PPM per six hours the results of the T-POD field calibration experiments showed some differences in the sensitivity of the T-PODs. Fig. 3-1 demonstrates the results of the calibration period October 11th to 14th, when two bundles with six T-PODs were deployed for 56 hours.

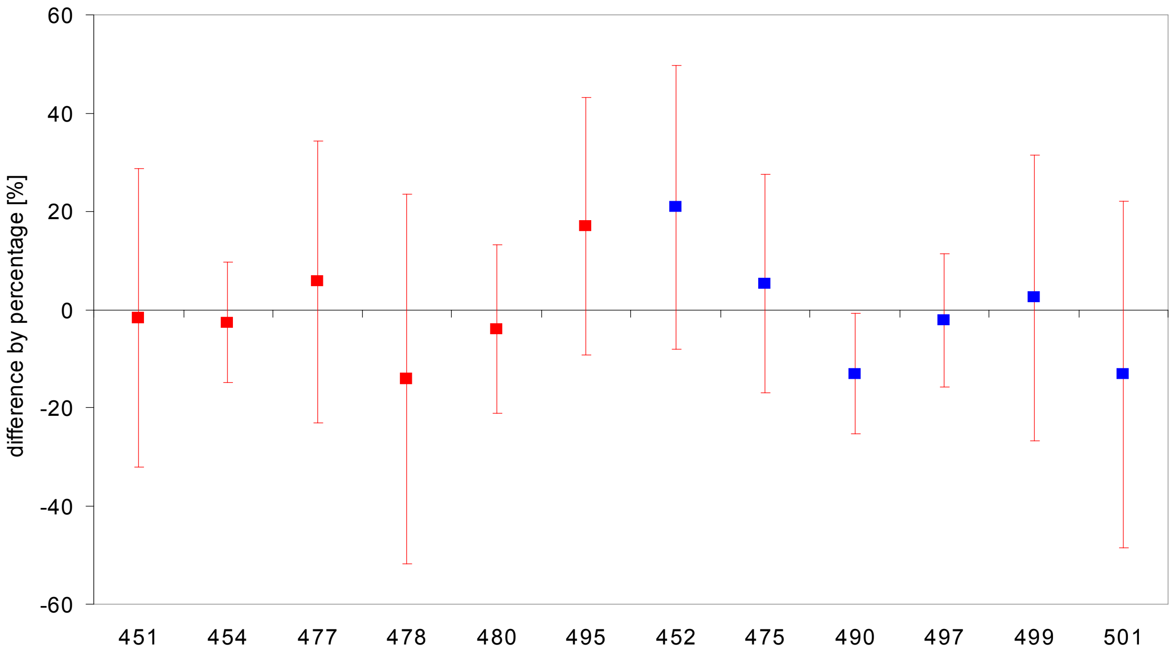


Fig. 3-1: Deviation of individual T-POD sensitivity from overall average (two bundles indicated in red and blew) from Oct 11th to Oct 14th.

Some T-PODs as 454 or 497 differed very little from the overall average whereas other T-PODs like 495 or 452 deviated about 20 % in mean.
The wide span of standard deviations for most of individual T-PODs is remarkable because it indicates that a change in sensitivity of individual T-PODs occurred from time block to time block.

Fig. 3-2 shows that the number of PPM per six h were closely correlated between PODs. It can be seen that T-POD 475 differed only very little from the bundle average. The PODs 412 and 452 appeared to be more sensitive than average.
To be able to apply a correction factor, it is important that no significant difference occurs between the PPM/time unit for the T-PODs deployed together within one bundle. In order to test if the T-PODs which were deployed within one bundle belong to one population we applied after the Kolmogorov-Smirnov-test for normal distribution an analysis of variance for normal distributed data and the Kruskal-Wallis-test for not normally distributed data. Tab. 3-2 shows that for all bundles the p-value was well enough over 0.05 so that we can assume that there is no significant variance between the statistical spread of the PPM/six-hours of the single T-PODs. The sample size N indicates the sum of all six-hour time blocks of all the T-PODs within one package.

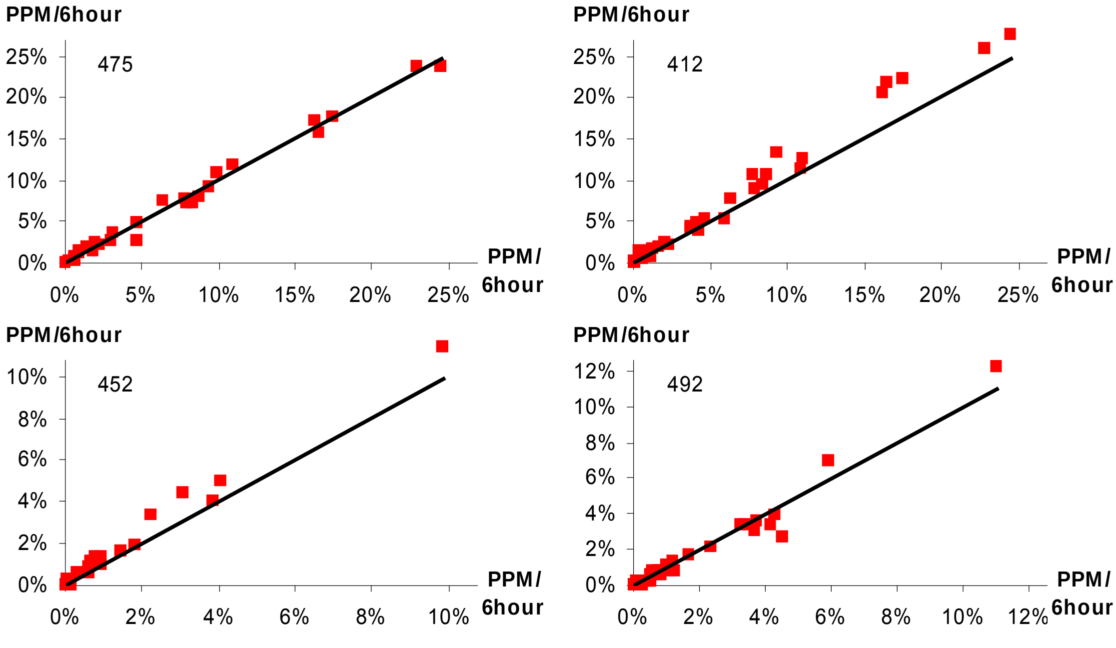


Fig. 3-2: Deviation of PPM per six-hour time intervals from the overall bundle average (black line) in percent.

Tab. 3-2: All T-PODs within a bundle belong to one population. Data were tested for normal distribution applying a Kolmogorov-Smirnov-test and ANOVA (normally distributed) or a Kruskal-Wallis-test (not normally distributed) was used. All P-values are above 0.05.

Distribution	bundle	N	Levene, p	F-value	ANOVA p
normal distributed	1	56	0.329	1.118	p = 0.35
Distribution				Degr. of freedom	Kruskal Wallis p
not normally distributed	2	90		4	p = 0.948
not normally distributed	3	90		4	p = 0.998
not normally distributed	4	60		3	p = 0.995
not normally distributed	5	63		6	p = 0.985
not normally distributed	6	63		6	p = 0.992
not normally distributed	7	60		5	p = 0.999
not normally distributed	8	60		5	p = 0.994
not normally distributed	9	72		5	p = 0.985
not normally distributed	10	72		5	p = 0.974

Comparing the variance of all T-PODs with the average it is possible to evaluate different sensitivities of single T-PODs (Fig. 3-3). Two T-PODs (412, 452) with the highest deviation differed more than 30 % from the bundle average. These T- PODs were clearly more sensitive than the others. To compare the results of the parameter PPM per time unit from different T-PODs it was now possible to adjust the recorded number of PPM to a comparable level for all T-PODs.

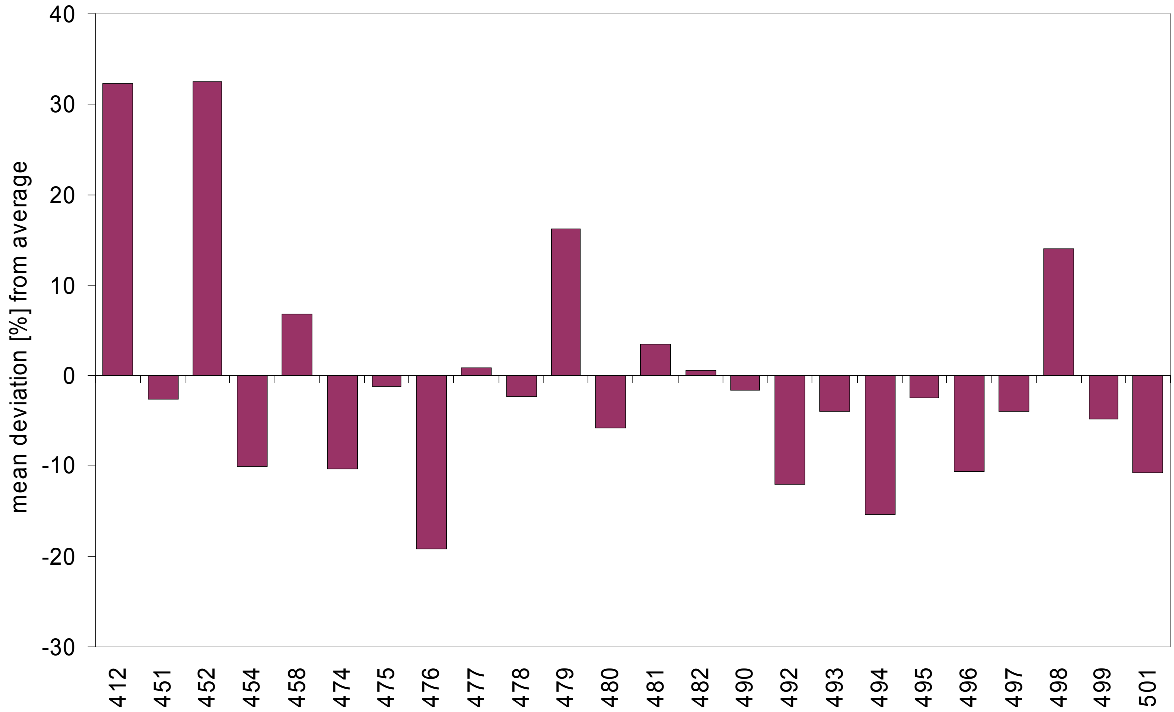


Fig. 3-3: Mean deviation of single T-PODs from the bundle average.

We decided to use a T-POD with a small difference to the overall average, a long calibration recording time and a small standard deviation as a reference device to adjust the data of all other PODs. T-POD 475 met these requirements with 234 hours of data recording and a mean difference of 1.2 % and a standard deviation of 18 %. In a next step the performance of T-POD 475 was set to 1 and all other devices were adjusted to this level by calculating correction factors (Tab. 3-3).

Tab. 3-3: Correction factors for PPM per time unit based on the sensitivity of T-POD 475.

T-POD ID	Correction factor	T-POD ID	Correction factor
412	0.75	481	0.96
451	1.01	482	0.98
452	0.75	490	1.00
454	1.10	492	1.12
458	0.93	493	1.03
474	1.10	494	1.16
475	**1.00**	495	1.01
476	1.22	496	1.10
477	0.98	497	1.03
478	1.01	498	0.87
479	0.85	499	1.04
480	1.05	501	1.11

3.7.2. Nysted

3.7.2.1. POD deployments

Exposure times of single T-PODs in the Nysted area in 2005 are shown in Fig. 3-1. Altogether ten T-PODs recorded data during 1.563 days, which was 90 % of the exposure time. All T-PODs collected useful data and no longer periods with disturbing noise clutter occurred.

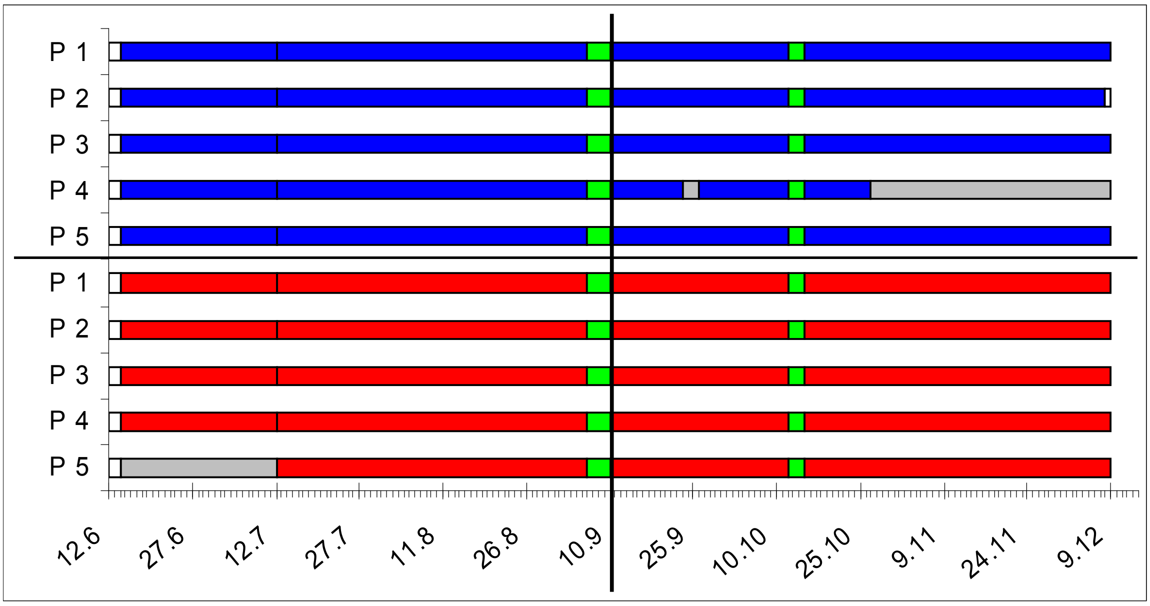


Fig. 3-1: Deployments of T-PODs in the Nysted area from June, 14th to December, 7th. Blue bars: useful data in row west (left from the black line) and east (right from the black line). Red bars: useful data in row south1 (left) and south2 (right). Green bars: useful calibration data. Grey bars: POD deployed but no data. P1 to P3 = positions inside the wind farm; P4, P5 = positions outside the wind farm.

The presence of harbour porpoises was recorded continuously and as porpoise positive hours or minutes per time unit (half month/pentade/day/hour or daylight phase) were calculated from the data. All data were adjusted by POD-specific correction factors (chapter 1.1).

3.7.2.2. Temporal distribution pattern

Porpoise positive days

During the first time period (June, 14th to September, 5th) ten T-PODs recorded data in two rows totalling 781 days. 772 days showed at least one porpoise positive hour (99 %), which indicates, that porpoises were almost continuously present throughout the study area. During the second period (September, 10th to December, 7th) ten T-PODs recorded altogether 782 days. In 752 days at least one porpoise positive hour was logged (96 %).
During the entire investigation period, porpoises were detected during 97 % of the days.

Porpoise positive hours (PPH)

To describe the presence of harbour porpoises on a finer temporal scale than days, we calculated in a second step the average values of PPH per day for each row and time period (Tab. 3-1).

Tab. 3-1: Mean PPH/day fort two rows in two different time periods (south1 and west1: June, 14th to Sept. 5th; south2 and east1: Sept. 10th to Dec. 7th)

south1	west1	south2	east1
24 %	33 %	27 %	22 %

On average over all rows and time periods porpoise positive hours occurred in 27 % of total exposure time which means that on every day in more than six hours harbour porpoises were recorded by the T-PODs.

Porpoise positive minutes (PPM)

The smallest scaled parameter calculated to describe porpoise activity is porpoise positive minutes (PPM, Tab. 3-1). PPM occurred averaged over all in 1.7 % of total exposure time. This corresponds to 24 min with porpoise clicks per day.

Tab. 3-1: Mean PPM/day fort two rows in two different time periods (south1 and west1: June, 14th to Sept. 5th; south2 and east1: Sept. 10th to Dec. 7th)

south1	west1	south2	east1
1.0 %	2.7 %	1.3 %	1.7 %

It appears that ,in most cases, harbour porpoises were recorded only for few minutes once they were detected by the hydrophones. On average, over all positions harbour porpoises were present during three to four minutes within six hours of the day.

PPM per day of the five T-PODs of the row south1 averaged 1.0 % (0 to 4.2 %) - according to 14.4 PPM per day -, whereas the average of row west1 was significantly higher with 2.7 % (0 to 16.6 %; M-W U, $P < 0.001$).

PPM per day of the five T-PODs of the row south 2 reached 1.7 % (0 to 14.4 %) and did also differ significantly to the average of row east1, which was 1.3 % (0 to 14.6 %) PPM per day on average (M-W U, $P < 0.001$).

As porpoise presence at the T-PODs was apparently short and resulted in 1.7 % PPM/day as compared to 27 % of PPH per day and 97 % of PPD, we assume that the parameter PPM gives the best information and we will use it therefore predominantly to describe harbour porpoise presence in the study area.

3.7.2.3. Seasonal distribution pattern

The daily PPM statistics are shown for four different rows (south1 and 2, west1, east1) in two consecutive periods (June 14th to September 5th and September 10th to December 7th). Harbour porpoises were present almost every day, but no persistent pattern of click activity occurred which would allow to separate regular periods with high activity from periods with low activity. PPM values per day varied considerably and high and low values of click activity alternated irregularly (
Fig. 3-1 and
Fig. 3-2).
The average daily proportion of PPM per interval of five days (pentade) illustrates the overall temporal pattern of click activity (Fig. 3-3, Fig. 3-4). Recordings of porpoises within a row were positively correlated indicating that porpoise presence fluctuated at a somewhat larger scale.
No trends in porpoise presence could be detected during the summer month but from early October recordings decreased markedly (
Fig. 3-5).

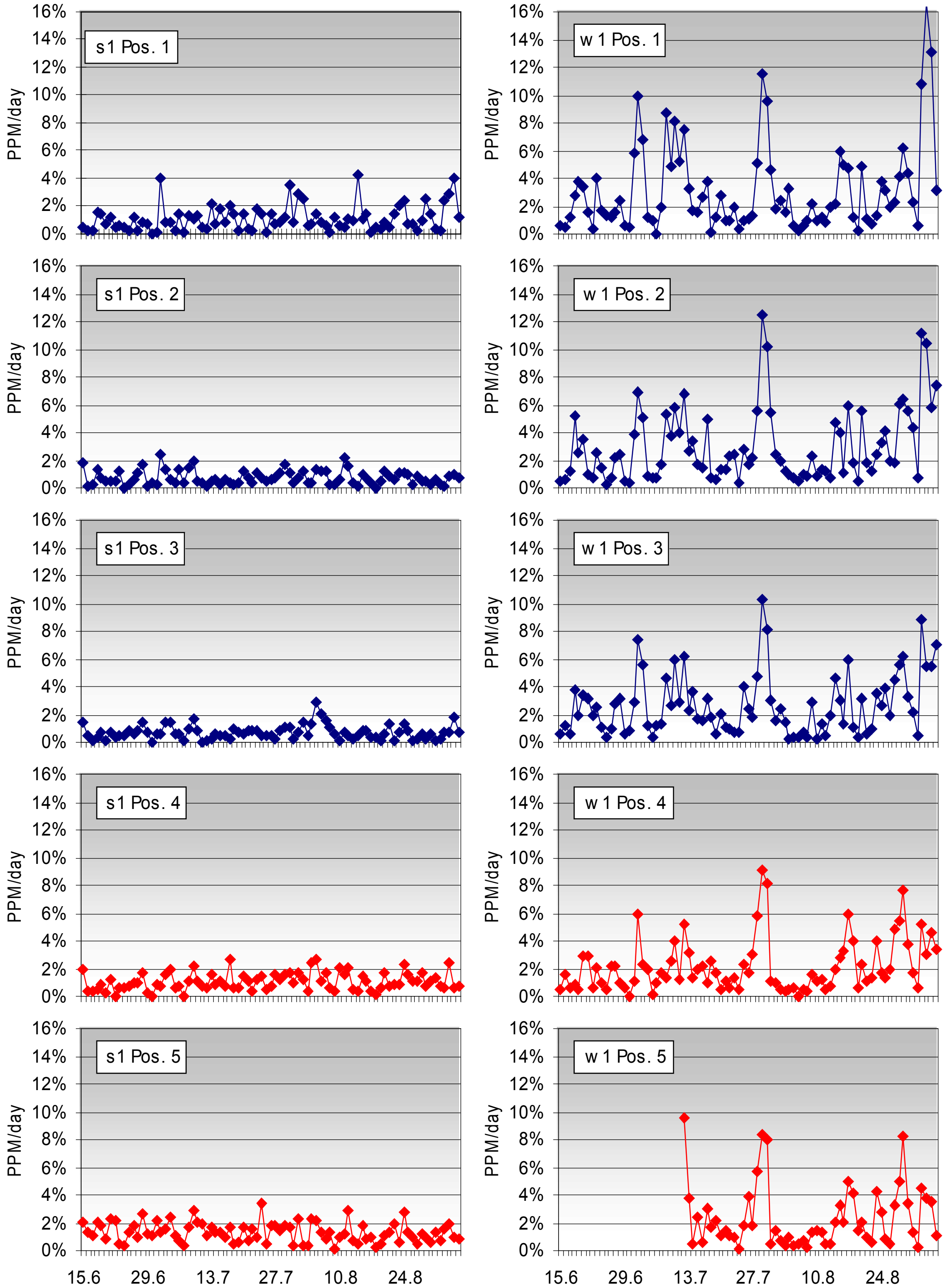


Fig. 3-1: PPM per day from all positions in the Nysted area during the first period from June 14th to September 5th. Left panel: row south1; right panel: row west1. Position 1 to 3 was located inside the wind farm and spanned to position 4 and 5 outside the wind farm.

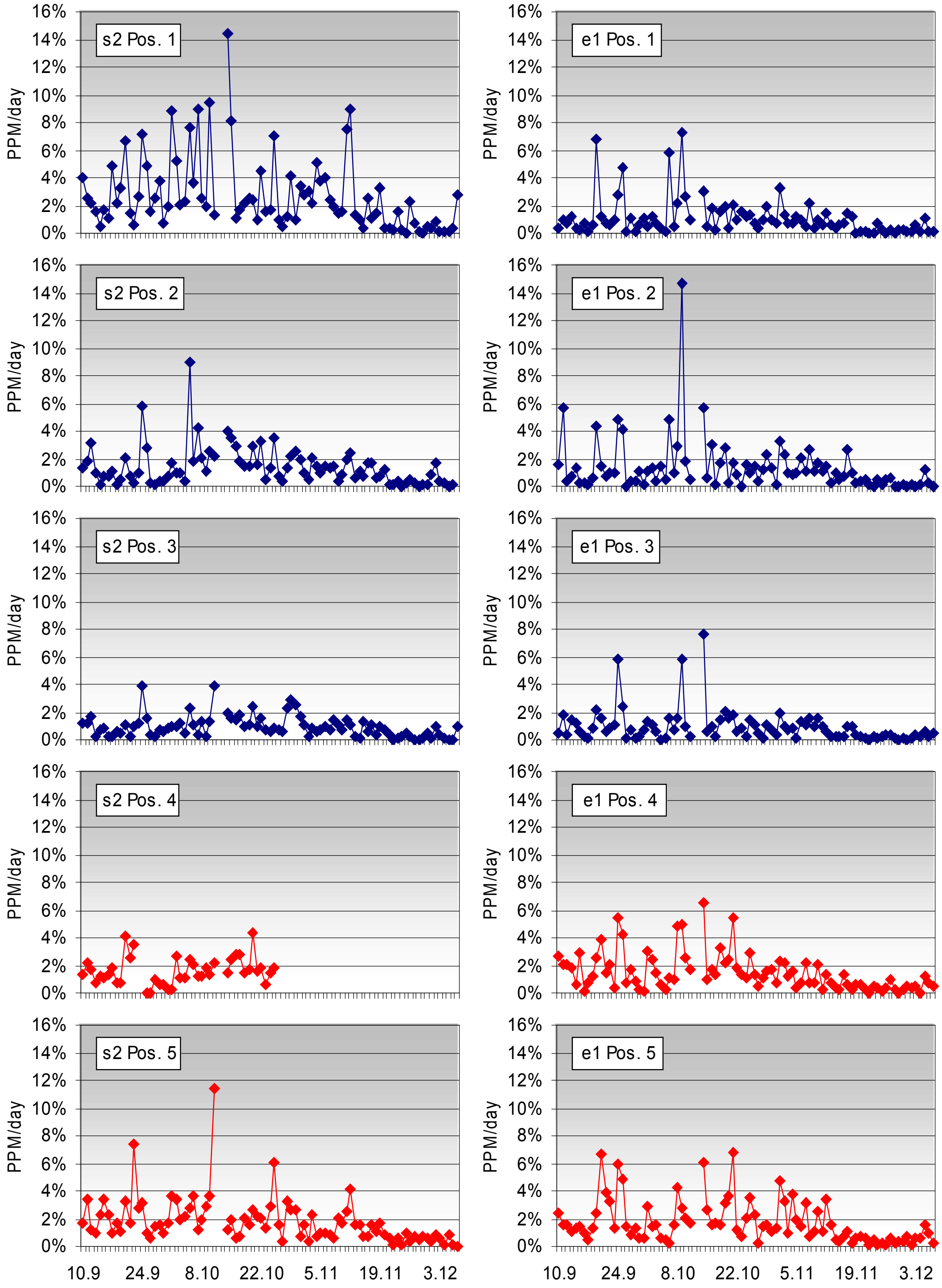


Fig. 3-2: PPM per day from all positions data collected in the Nysted area during the second period from September 10th to December 7th. Left panel: row south2; right panel: row east1. Position 1 to 3 was located inside the wind farm and spanned to position 4 and 5 outside the wind farm.

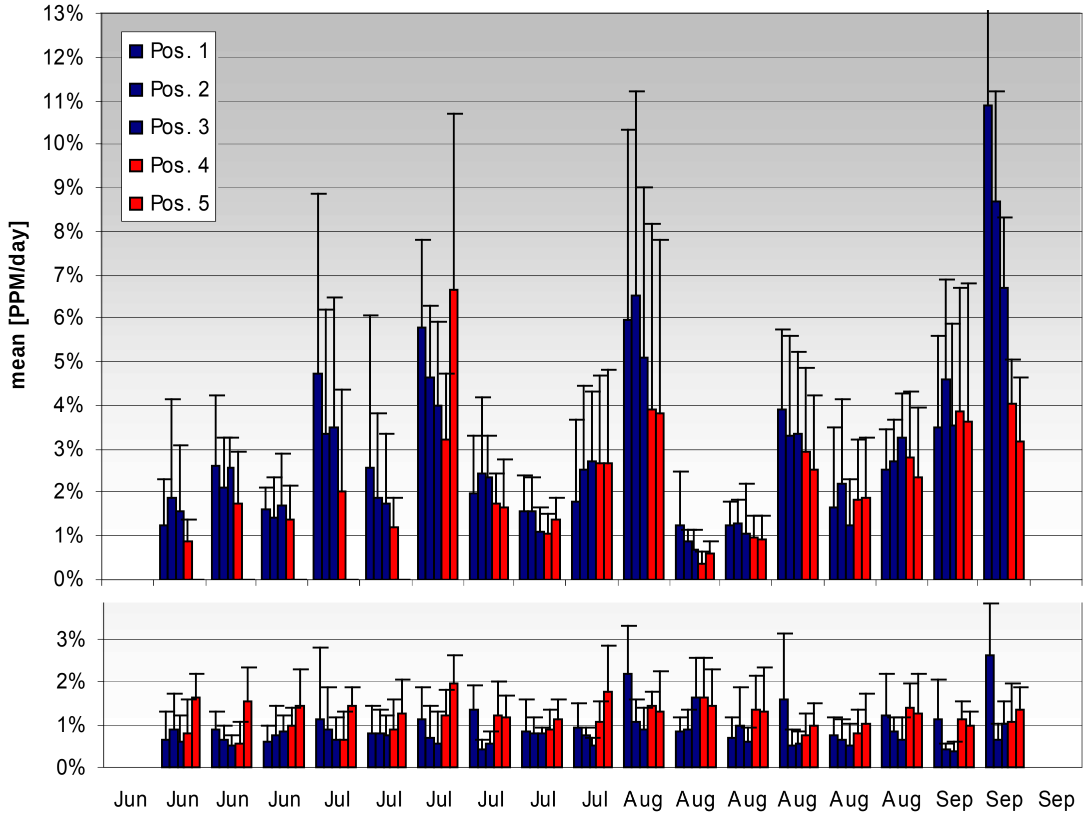


Fig. 3-3: Mean PPM per pentade with standard deviation from positions at Nysted during the period June, 15th to September, 5th in row west1 (above) and row south1 (below).

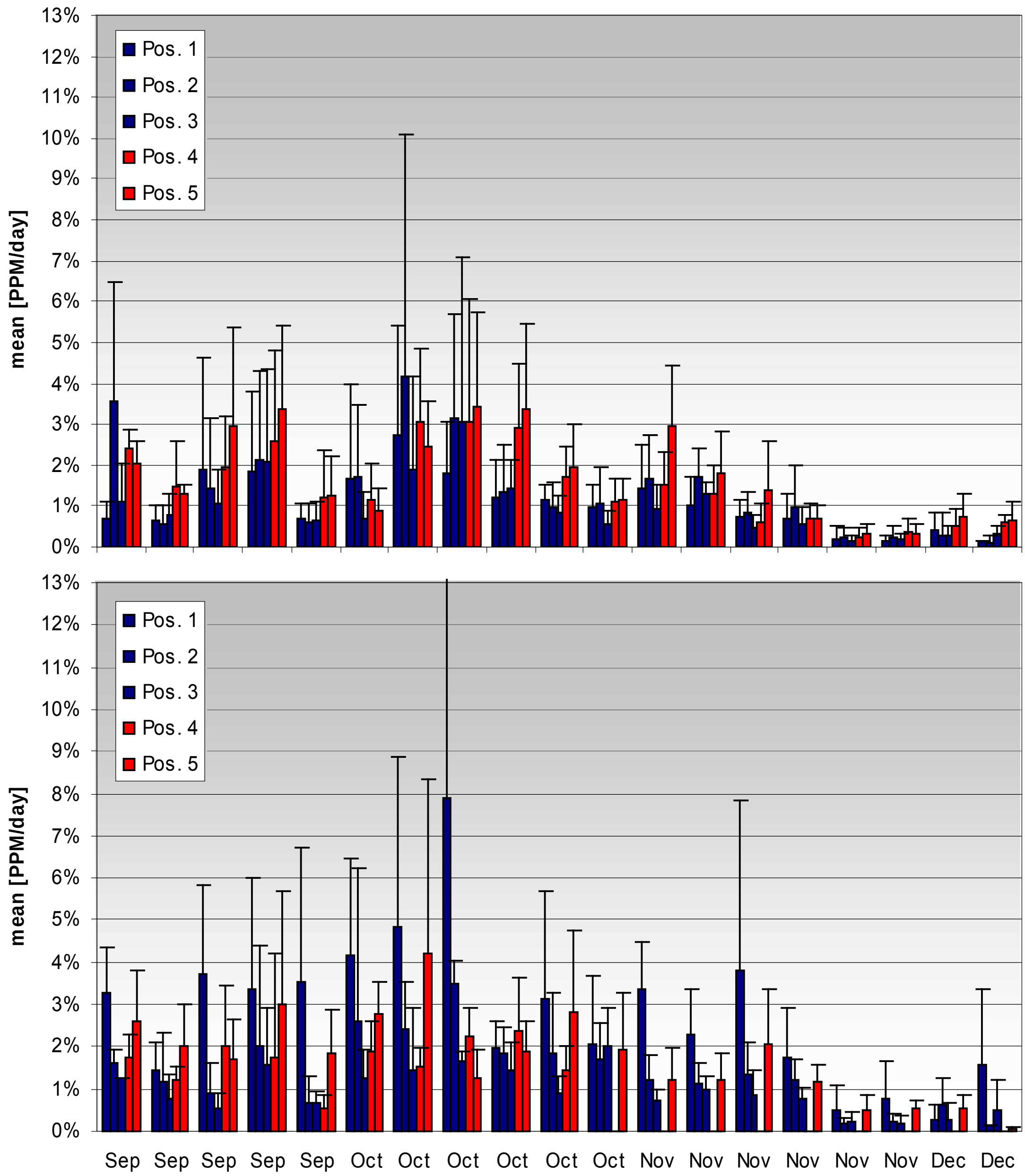


Fig. 3-4: Mean PPM per pentade with standard deviation from all positions at Nysted during the period September, 10th to December, 7th in row east1 (above) and row south2 (below).

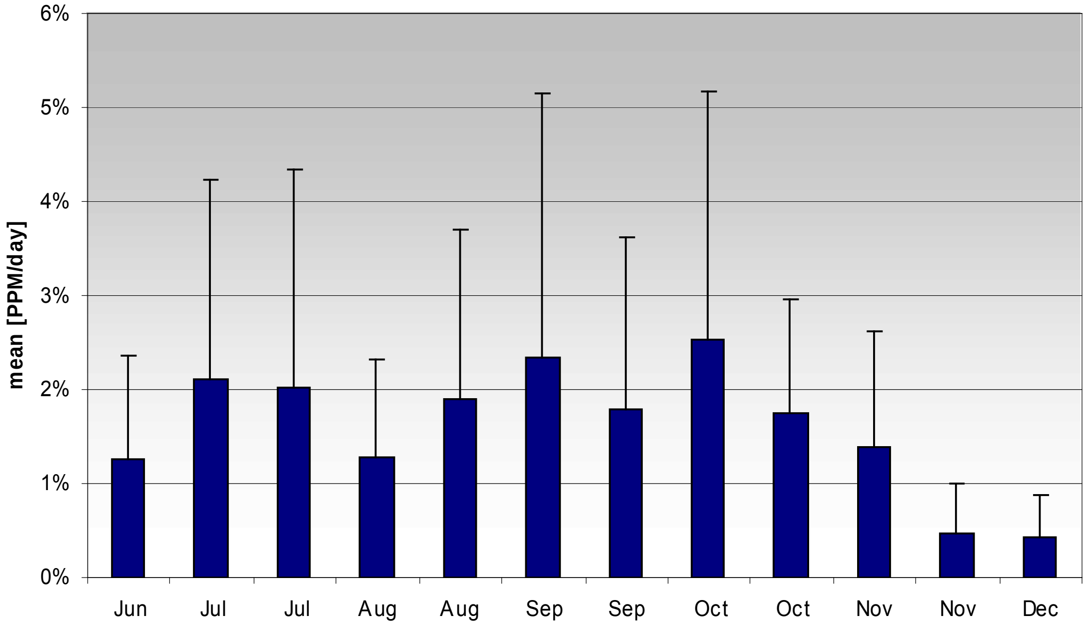


Fig. 3-5: Seasonal mean (half months) for PPM per day from all positions in the Nysted area. Whiskers indicate the standard deviation.

Additionally to PPM we calculated the waiting time from logged T-POD data. Mean daily waiting times for specific positions are illustrated for the two investigation periods (Fig. 3-6 and Fig. 3-7). Similar to the parameter PPM per day no consistent pattern occurred and the values alternated irregularly from day to day. The duration of waiting times covered a wide range of times from 10 minutes up to 3,579 minutes (about 2.5 days).

Referring to the first time period a similar pattern with a slight decrease in waiting time during the last four weeks occurred at all ten positions in both rows. The waiting time between two porpoise encounters averaged in row south1 168 minutes (N = 3,421) compared to significantly fewer 145 minutes in row west1 (N = 3,575; M-W U; P < 0.001). In row west1 all 5 positions showed a minimum in daily mean waiting time at July 29th and 30th which was not found in row south1. In the second investigation period the mean duration of waiting time was 136 minutes for row south2 (N = 3,835) which was significantly shorter than 193 minutes for row east1, respectively (N = 3,092; M-W U; P < 0,001). During the last four weeks the mean daily waiting time increased (

Fig. 3-7). This replicated the declining autumnal click activity pattern measured by PPM per day. When calculating the average waiting time of half month periods, November and December were obviously characterised by increasing waiting times (Fig. 3-8).

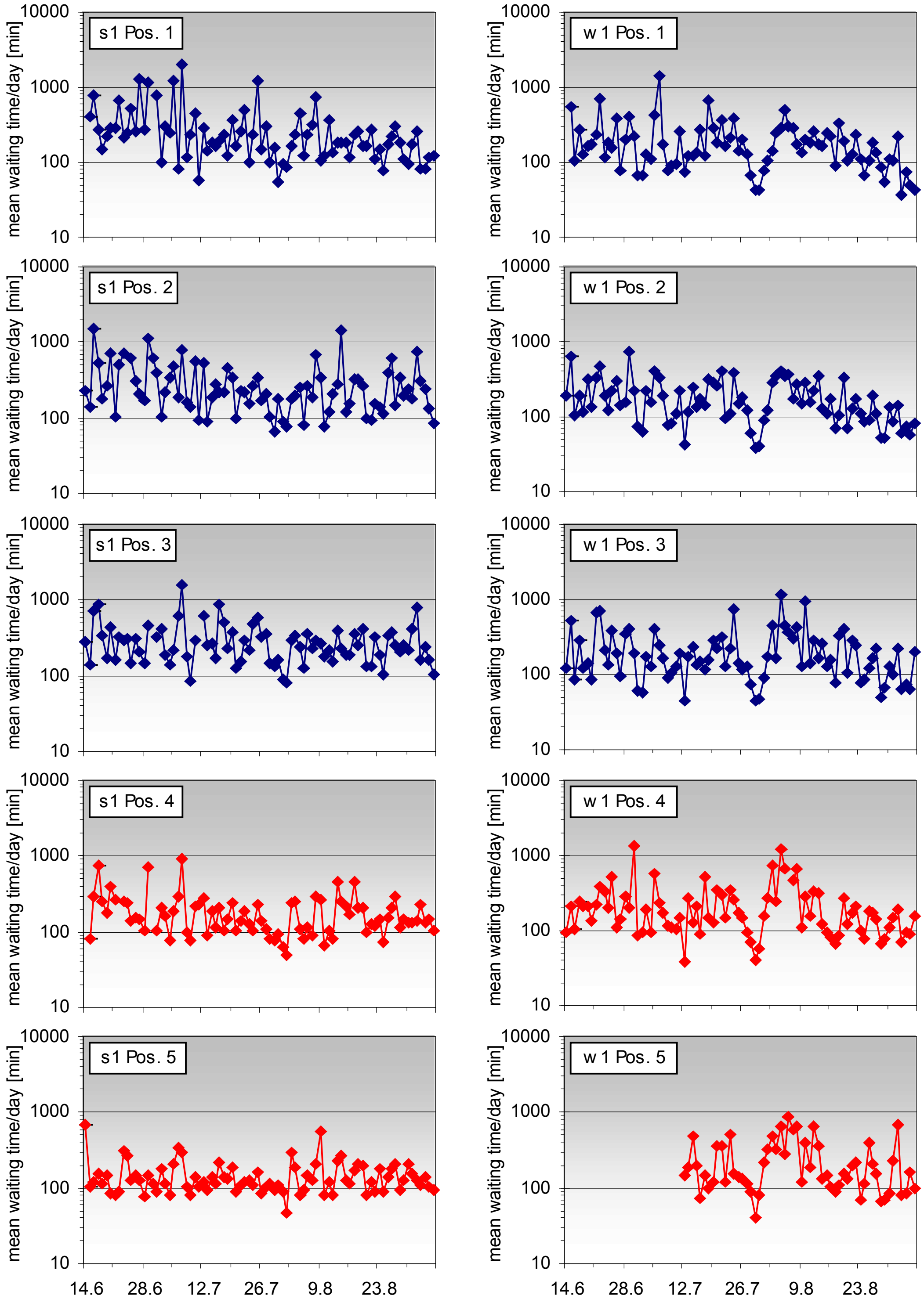


Fig. 3-6: Mean daily waiting time extracted from T-POD data collected in the Nysted area during the investigation period from June 14th to September 5th. Left panel: row south1; right panel: row west1. Position 1 to 3 was located within the wind farm and spanned to position 4 and 5 outside the wind farm.

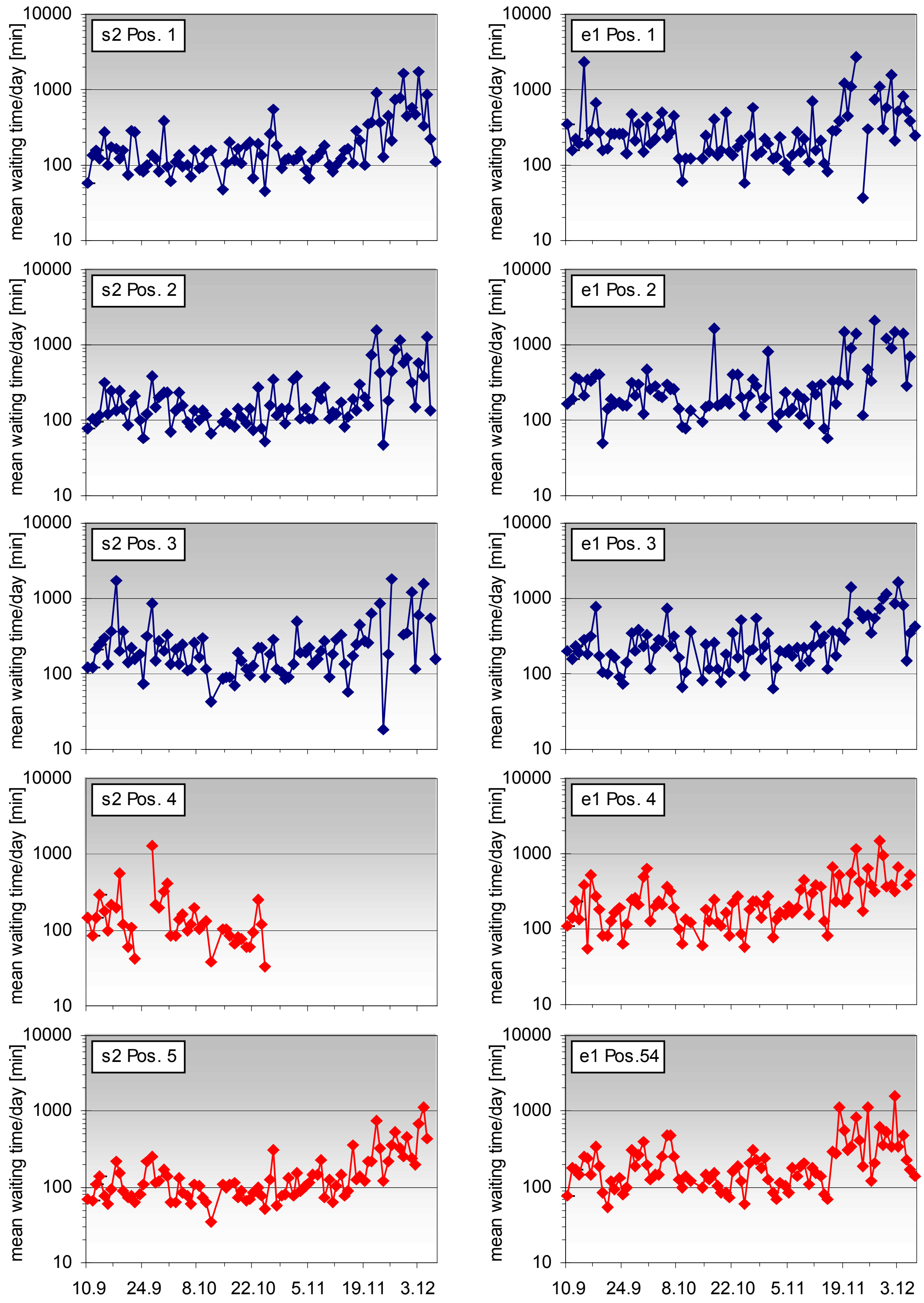


Fig. 3-7: Mean daily waiting time extracted from T-POD data collected in the Nysted area during the investigation period from September 10th to December 7th. Left panel: row south2; right panel: row east1. Position 1 to 3 was located inside the wind farm and spanned to position 4 and 5 outside of the wind farm.

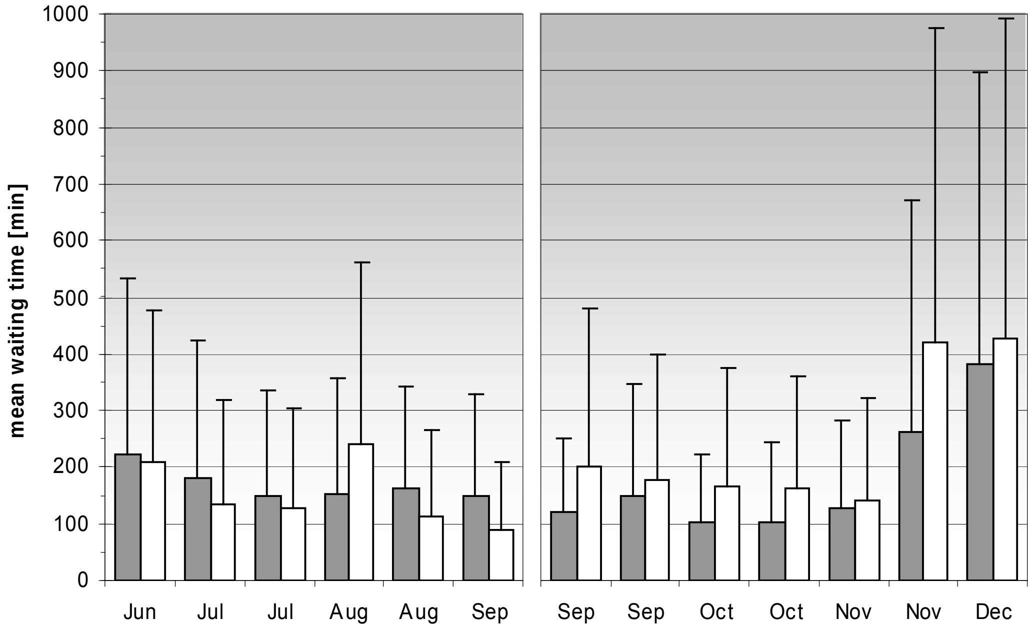


Fig. 3-8: Seasonal average of waiting time in half month periods in the Nysted area of all positions. Left: row south1 (blue) and row west1 (red) for the time period June, 14th to September, 5th. Right: row south2 (blue) and row east1 (red) for the time period September, 10th to December, 7th. Whiskers give the standard deviation.

3.7.2.4. Diurnal rhythm in different time intervals

The data recorded in the study area allowed to analyse whether or not the porpoise activity followed diurnal patterns which might be relevant to understand porpoise behaviour in and near the wind farm.

The diurnal pattern of PPM/hour recorded with the T-PODs is shown for four different rows (south1 and 2, west1, east1) in two consecutive periods (June 14th to September 5th and September 10th to December 7th) by the Fig. 3-1 and Fig. 3-2. At all positions the distinct difference in measured porpoise echolocation activity between the two rows during the first period was also persistent regarding the 24-hour cycle: Mean maximum values in row west1 were threefold higher than in row south1.

Looking at the 24-hour echolocation pattern, mean values per hour differed both between and within single rows. However, positions inside the wind farm area (blue coloured) showed pronounced elevated activities mostly at night or at the early morning hours consistently for all rows. Outside the wind farm the pattern was rather unclear and often no diurnal pattern appeared.

In row west1 the highest porpoise click activity was measured and all five positions showed a small peak with slightly more PPM during midday (10 a.m. to 1 p.m.).

Although a pronounced difference between the five positions within one row occurred we pooled the data to check roughly if the 24-hour cycle was persistent over time periods of 14 days (Fig. 3-3 and Fig. 3-4). The results show that in all rows the pattern changed over time. In row west1 a distinct diurnal rhythm in echolocation activity occurred during summer until the end of July with highest PPM/hour during night time (Fig. 3-3). In August the pattern changed to a slightly higher activity during the day. In row south1 no consistent pattern could be seen. During the second investigation period the whole echolocation activity decreased so that the pattern with highest activity during early morning in September and October disappeared, probably due to too few porpoise signals during the 14 day period.

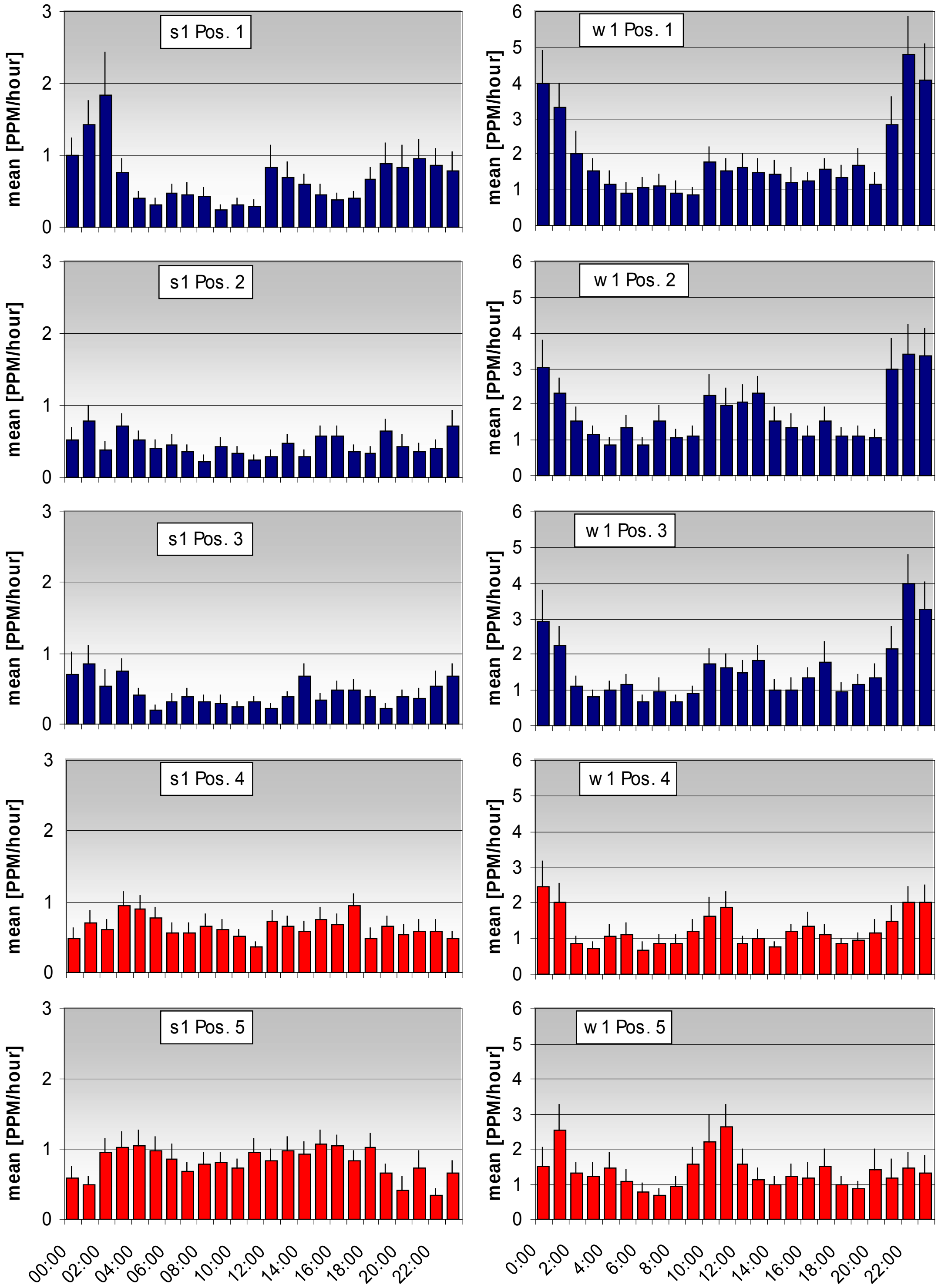


Fig. 3-1: 24-hour cycle of mean harbour porpoise click activity per hour (with standard error) extracted from T-POD data collected in the Nysted area during the investigation period from June 14th to September 5th. Left panel: row south1; right panel: row west1. Position 1 to 3 was located inside the wind farm and spanned to position 4 and 5 outside of the wind farm. Be aware of different y-axis scale between both rows.

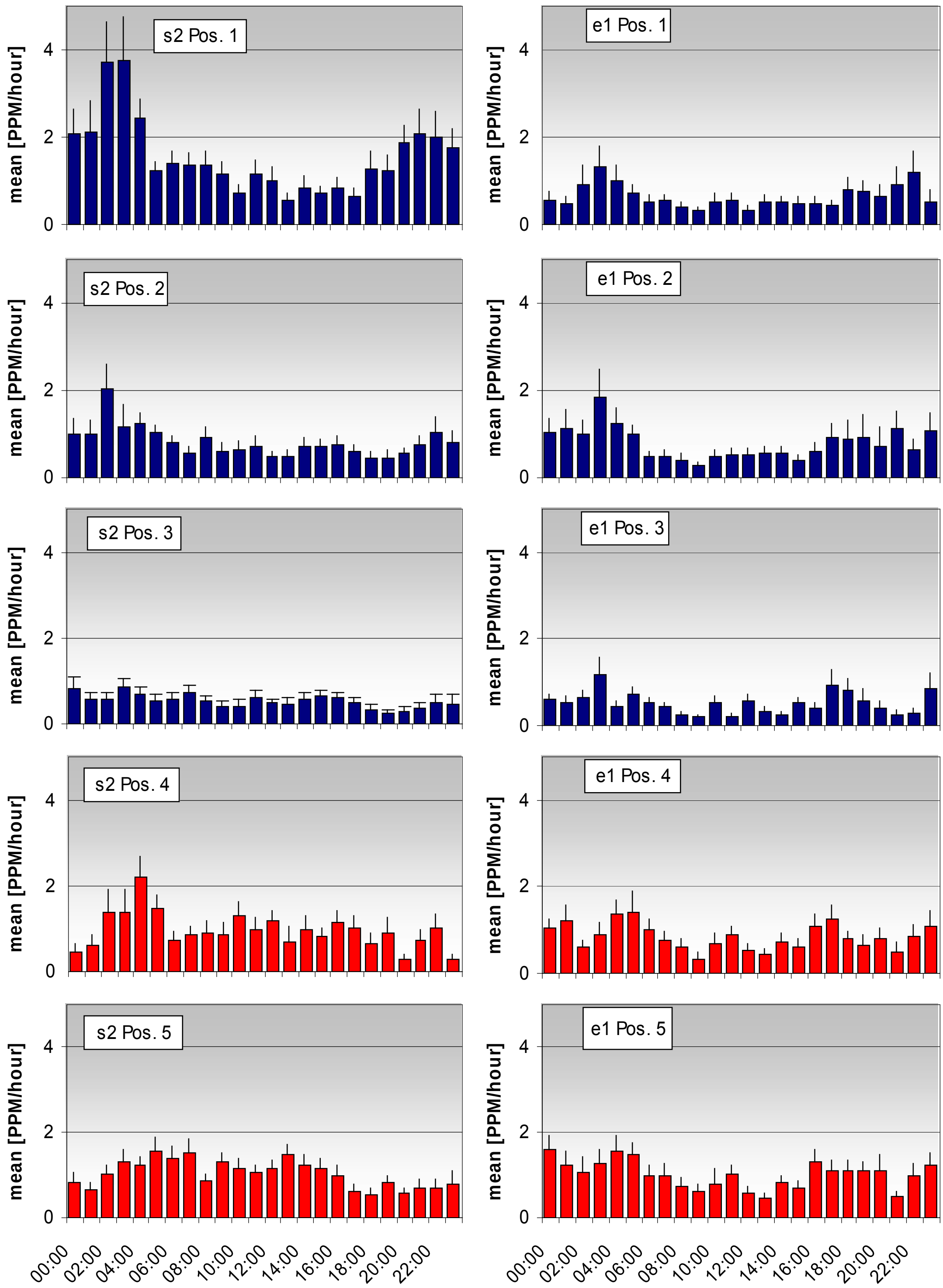


Fig. 3-2: 24-hour cycle of mean harbour porpoise click activity per hour (with standard error) extracted from T-POD data collected in the Nysted area during the investigation period September, 10th to December, 7th. Left panel: row south2; right panel: row east1. Position 1 to 3 was located inside the wind farm and spanned to position 4 and 5 outside of the wind farm.

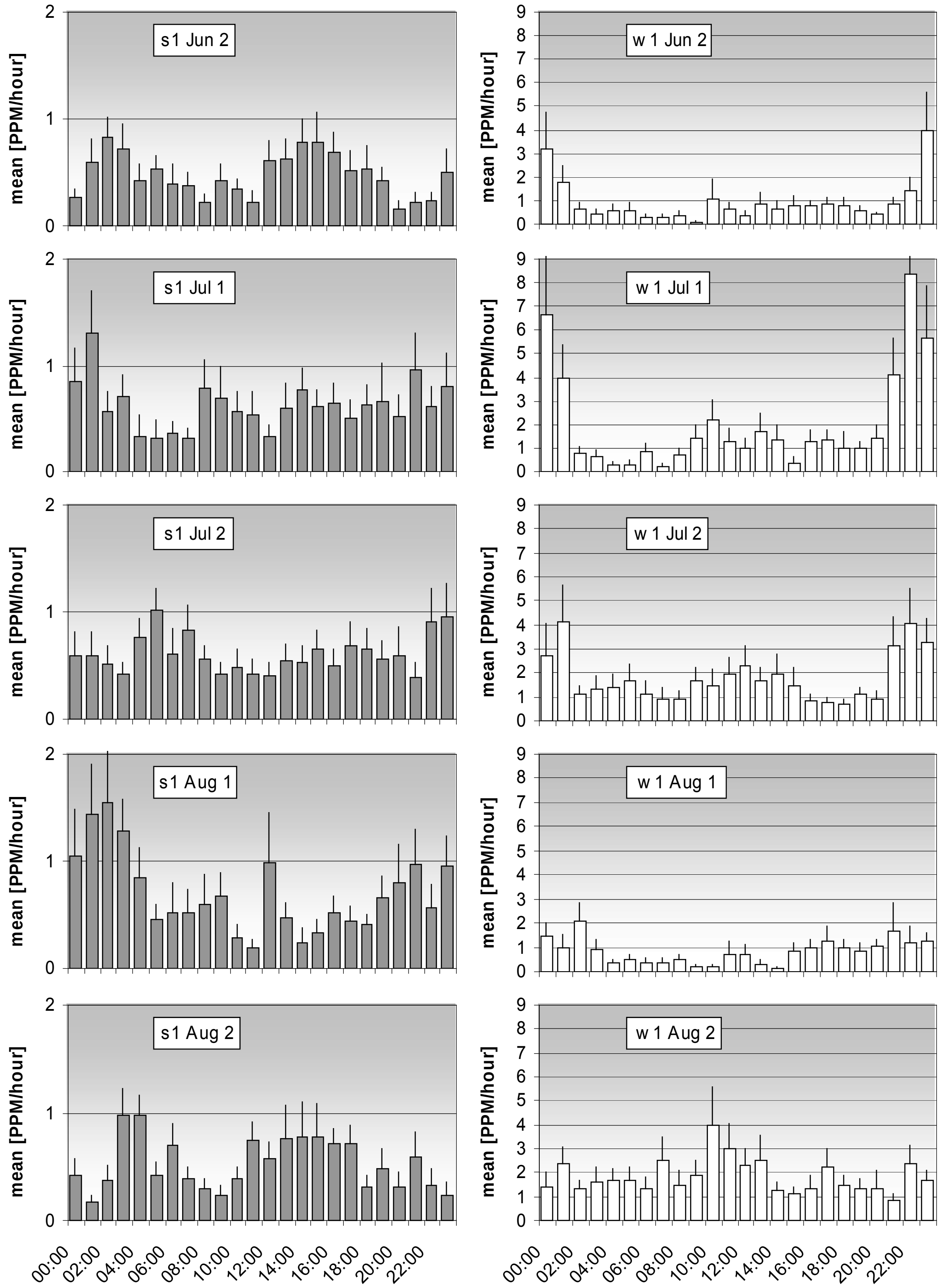


Fig. 3-3: 24-hour cycle of mean harbour porpoise click activity per hour (with standard error) extracted from T-POD data collected in the Nysted area during the investigation period from June 14th to September 5th. Left panel: row south1; right panel: row west1. Data from all five T-PODs within one row were pooled for half month intervals. Be aware of different y-axis scale between both rows!

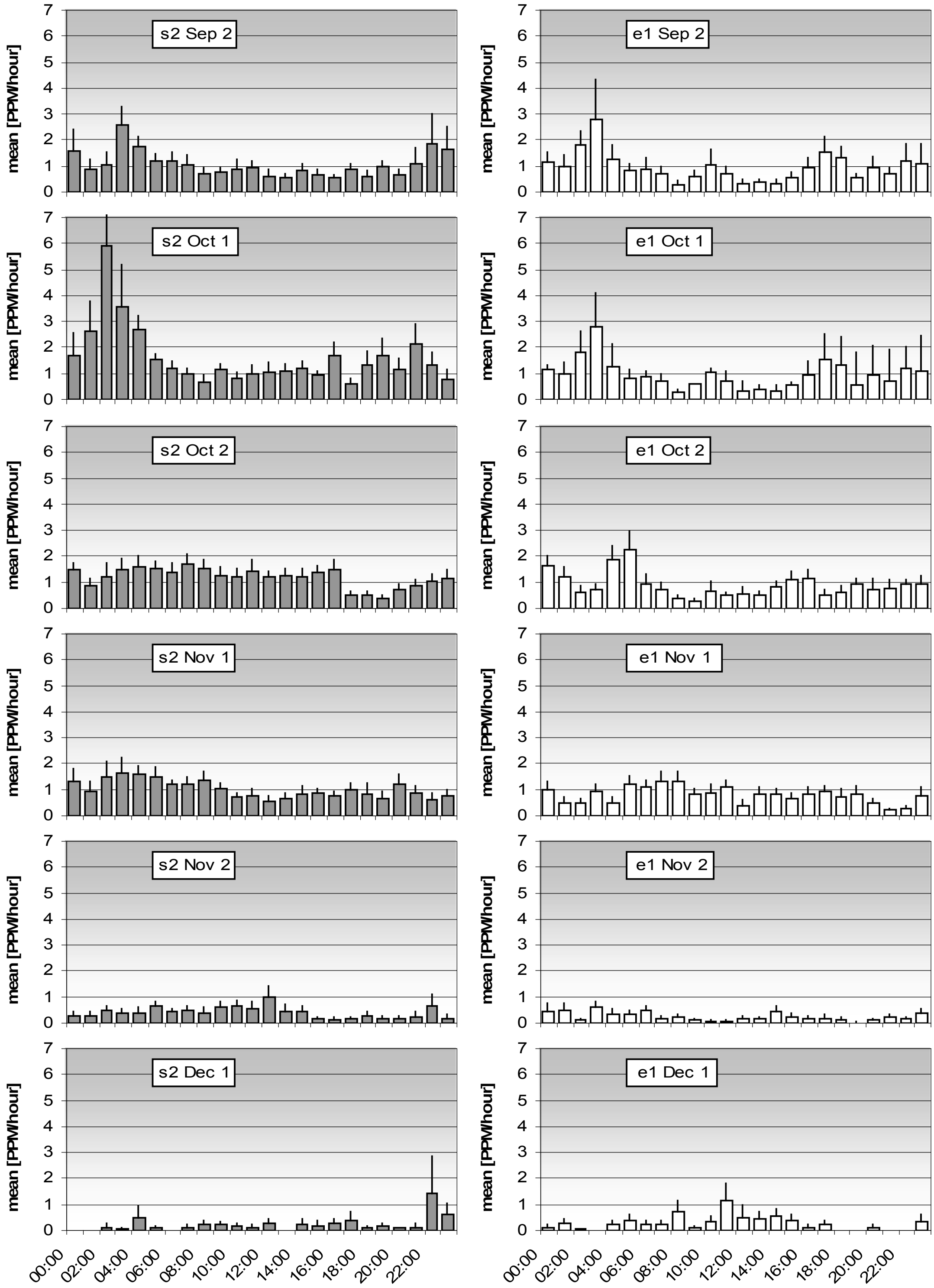


Fig. 3-4: 24-hour cycle of mean harbour porpoise click activity per hour (with standard error) extracted from T-POD data collected in the Nysted area during the investigation period June 14th to September 5th. Data from all five T-PODs within one row were pooled for half month intervals.

During the investigation period from mid of June to beginning of December sunrise and sunset moved for several hours. To check if harbour porpoise echolocation activity was influenced by day light we calculated in a next step PPM for the four different light phases dawn, day, dusk and night (Fig. 3-5 and Fig. 3-6). Considering these different times of day –

as already shown in the diurnal rhythm above – the T-POD positions 1 to 3 (inside the wind farm) of the row west 1 showed a significant increase in PPM per hour at night (K-W; $P < 0.01$; Fig. 3-5). In position 4 the night-time maximum in echolocation activity was still present but on a lower significant level (K-W; $P = 0.02$) and at position 5 no difference between different light phases occurred (K-W; $P = 0.3$). In the row south1 the pattern was not as distinct as in the row west1. At all three positions inside the wind farm lowest PPM were recorded during day time even though only at position 1 the differences between the four phases was highly significant (K-W; $P < 0.01$). Outside the wind farm the pattern changes to highest activity during dawn and day which was significant for position 4 (K-W; $P = 0.2$) and highly significant for position 5 (K-W; $P < 0.01$).

In the second investigation period the pattern was more indistinct (Fig. 3-6). In row south2 the alteration from inside to outside the wind farm was still consistent: In all three positions inside the wind farm the T-PODs recorded fewest PPM during day light and most activity during night or dawn. In the first two positions the differences between the phases was significant (pos. 1: K-W; $P < 0.01$; pos. 2: K-W; $P = 0.02$). At position 4 and 5 outside the wind farm fewest PPM were recorded during night and maximum was reached during dawn or day. Differences between phases were significant at position 5 (K-W; $P < 0.01$). In row east1 at all positions lowest PPM were recorded during day and most PPM at dawn. No alteration in this pattern occurred between inside and outside the wind farm. But this pattern did not show any significance in diurnal click statistics beside position 5 (K-W; $P < 0.01$).

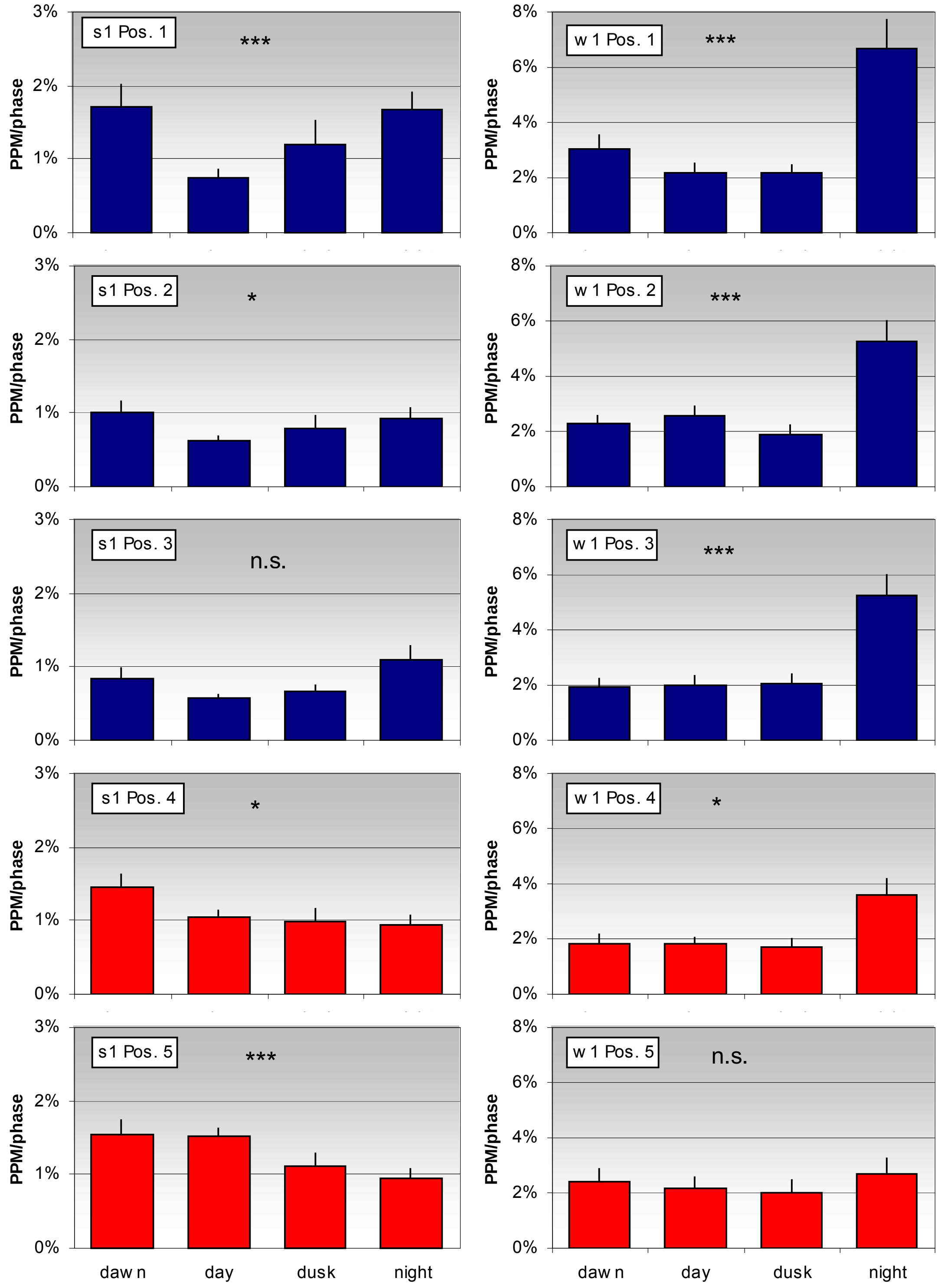


Fig. 3-5: Average PPM/time-phase during four different daylight phases (with standard error) extracted from T-POD data collected in the Nysted area during the investigation period from June 14th to September 5th. Left panel: row south1; right panel: row west1. Position 1 to 3 was located inside the wind farm and spanned to position 4 and 5 outside of the wind farm. Be aware of different y-axis scale.

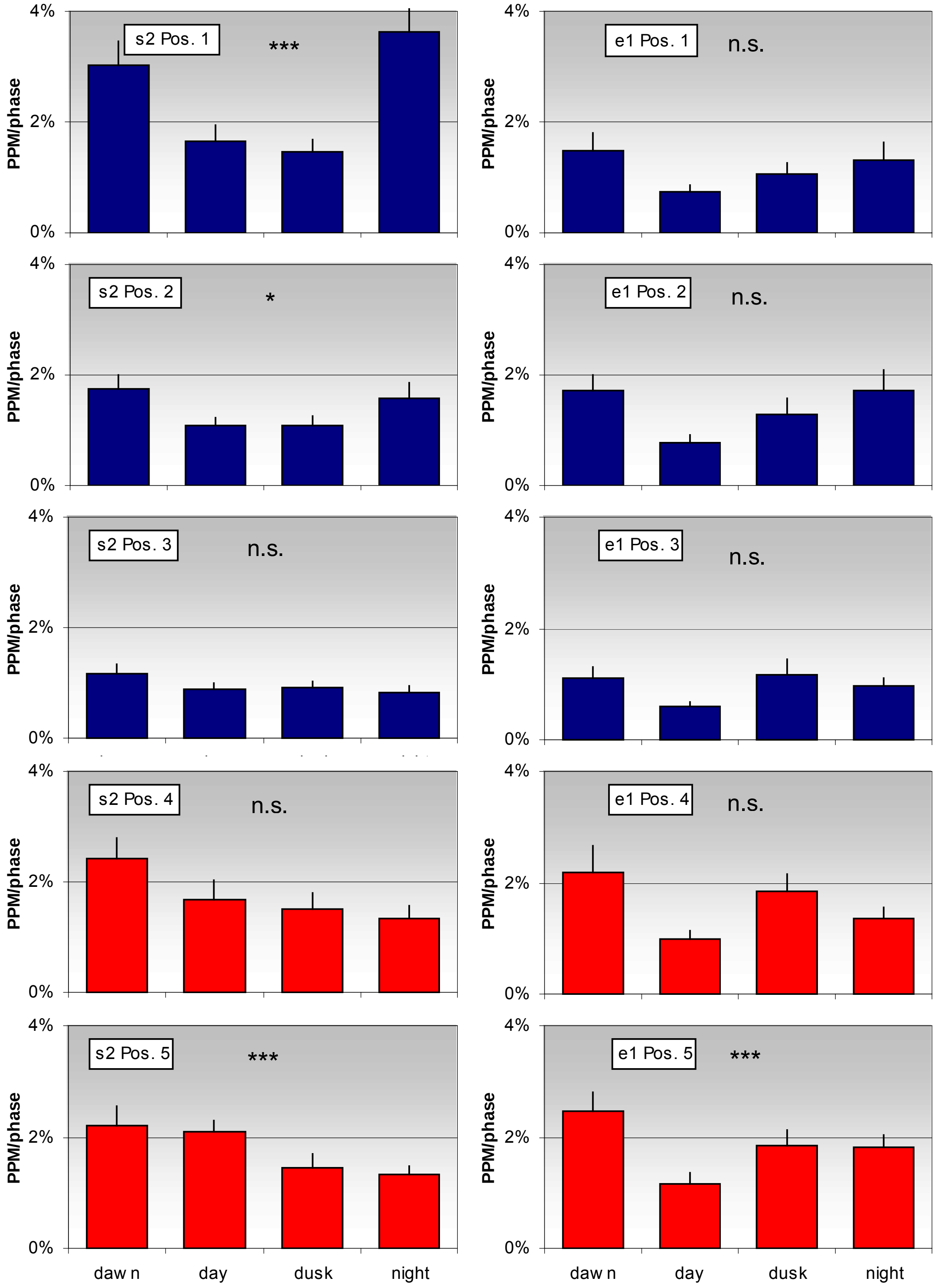


Fig. 3-6: Average PPM/time-phase during four different daylight phases (with standard error) extracted from T-POD data collected in the Nysted area during the investigation period from September 10th to December 6th. Left panel: row south2; right panel: row east1. Position 1 to 3 was located inside the wind farm and spanned to position 4 and 5 outside of the wind farm.

3.7.2.5. Spatial distribution pattern

Inter-row- and intra –row comparisons

Considering potential differences of echolocation activity we took a twofold approach with different time resolutions: PPH per day and PPM per day.

For intra-row comparisons we calculated mean values for each of this parameter for every position during the consecutive time periods. Starting with PPH/day an inconsistent picture appeared with a slight hint on a difference between outside and inside the wind farm (Fig. 3-1, Tab. 3-1). Apart from of row west1, position 5 outside the wind farm differed always significantly from all positions inside the wind farm. One exception showed position 1 in row south2 which was more related to both positions outside the wind farm than inside. In row south1 all three positions inside the wind farm showed no differences in between but recorded significantly fewer PPH per day than both positions outside the wind farm whereas the mean PPH per day at position 5 increased significantly with larger distance from the wind farm. Only row west1 where the highest echolocation activity was measured no differences could be detected between the five positions.

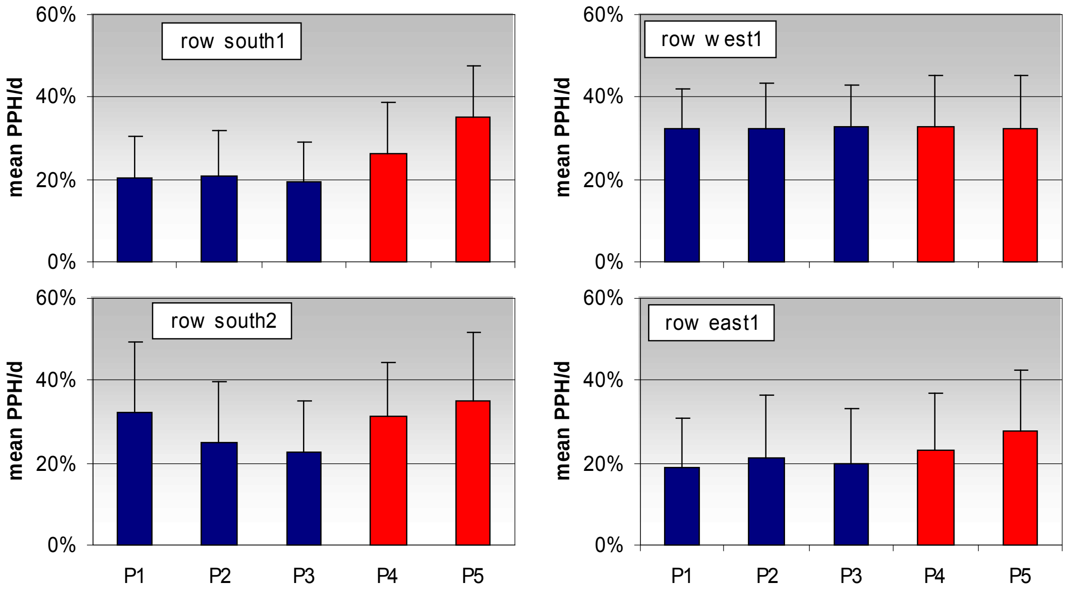


Fig. 3-1: Mean porpoise positive hours per day in Nysted for two different rows in two different time periods (with standard deviation). Blue: inside the wind farm, red: outside the wind farm.

Referring to PPM/day the pattern of echolocation activity did not become more distinct. As data were not normally distributed (even after transformation) a K-W test was applied which showed a significant difference between single positions in all rows with exception of row west1 (Fig. 3-2). Because the two positions outside the wind farm showed consistent values we compared in a next step mean PPM per day values for all positions inside with outside the wind farm (Fig. 3-3).

Tab. 3-1: Significance levels of ANOVA for PPH per day

south1	**Pos. 1**	**Pos. 2**	**Pos. 3**	**Pos. 4**	**Pos. 5**
Pos. 1	-				
Pos. 2	n.s.	-			
Pos. 3	n.s.	n.s.	-		
Pos. 4	*	*	*	-	
Pos. 5	*	*	*	*	-
west1	**Pos. 1**	**Pos. 2**	**Pos. 3**	**Pos. 4**	**Pos. 5**
Pos. 1	-				
Pos. 2	n.s.	-			
Pos. 3	n.s.	n.s.	-		
Pos. 4	n.s.	n.s.	n.s.	-	
Pos. 5	n.s.	n.s.	n.s.	n.s.	-
south2	**Pos. 1**	**Pos. 2**	**Pos. 3**	**Pos. 4**	**Pos. 5**
Pos. 1	-				
Pos. 2	*	-			
Pos. 3	*	n.s.	-		
Pos. 4	n.s.	*	*	-	
Pos. 5	n.s.	*	*	n.s.	-
east1	**Pos. 1**	**Pos. 2**	**Pos. 3**	**Pos. 4**	**Pos. 5**
Pos. 1	-				
Pos. 2	n.s.	-			
Pos. 3	n.s.	n.s.	-		
Pos. 4	*	n.s.	n.s.	-	
Pos. 5	*	*	*	*	-

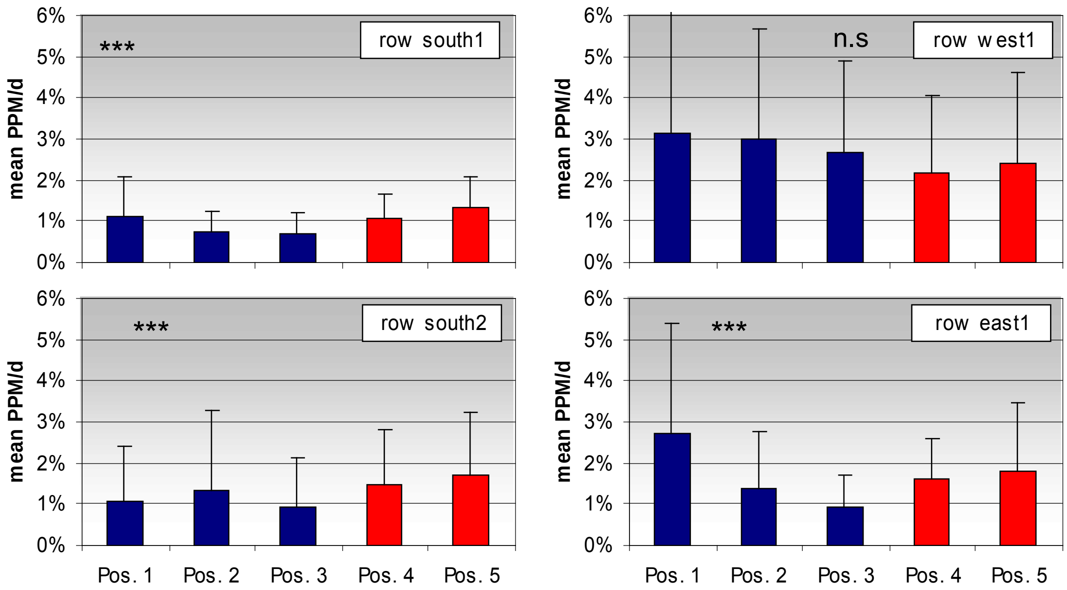


Fig. 3-2: Mean PPM per day in the Nysted wind farm area for two rows in two different time periods (with standard deviation). Kruskal-Wallis-test: south1 $p < 0.01$, south2 $p < 0.01$, west1 $p = 0.14$, east1 $p < 0.01$.

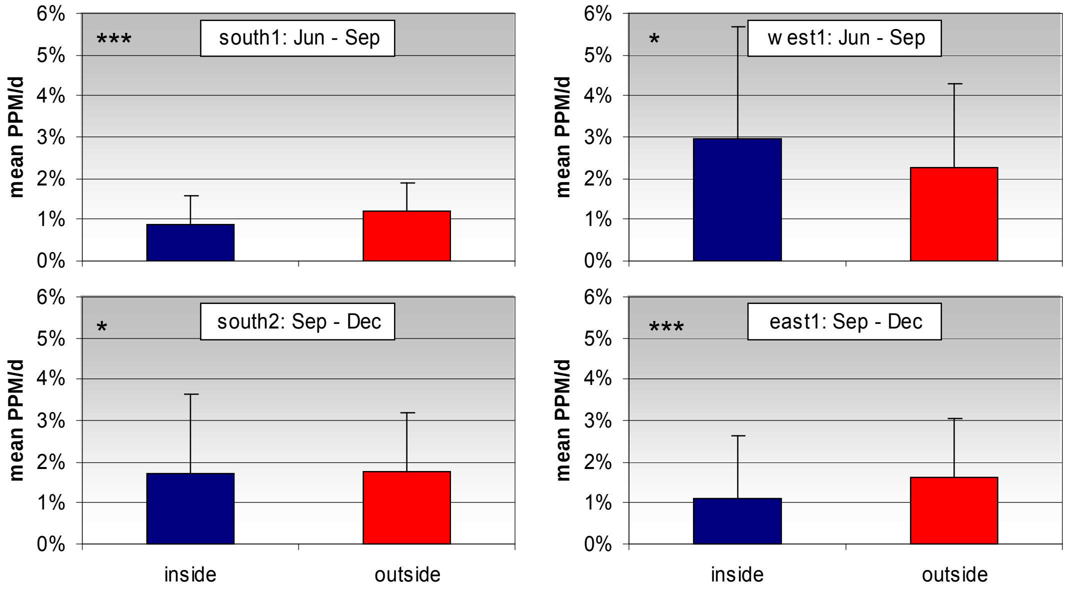


Fig. 3-3: Mean PPM/day inside and outside the Nysted wind farm area for two rows in two different time periods (with standard deviation). Inside: data from pos. 1 to 3 and outside data from pos. 4 and 5 were pooled. Mann-Whitney-U-test: south1 $p < 0.01$, south2 $p < 0.01$, west1 $p < 0.05$, east1 $p < 0.05$.

Fig. 41 confirms the picture seen at the parameter PPH/day. Within three rows (south1, south2 and east1) a significant higher echolocation activity occurred outside the wind farm regarding the parameter PPM per day. Only in row west1 as average more than twofold more PPM were logged, click activity was significantly higher inside the wind farm.
The difference between the two rows is demonstrated in Fig. 3-4. For both time periods the difference between the two simultaneously deployed T-POD-rows was highly significant (M-W U; $P < 0.01$). Especially in the first time period between June and September the difference between the rows was much stronger than the difference inside one of these rows.

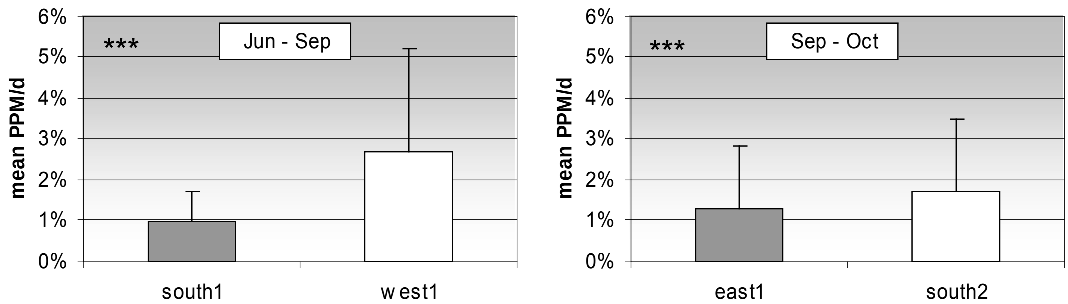


Fig. 3-4: Mean PPM/day in the Nysted wind farm area for two rows in two different time periods (with standard deviation). All data from one row are pooled. Mann-Whitney-U-test: Jun – Sep: $p < 0.01$, Sep – Oct: $p < 0.01$.

The next parameter we tested for intra row comparisons was mean waiting time. Again the pattern indicated by the parameter PPH/day and PPM/day was recognisable: In the rows south1, south2 and east1 the waiting time was longer than inside the wind farm (position 1 to 3). Differences between single positions were highly significant (K-W; P < 0.01). This corresponds to higher echolocation activity outside the wind farm. Only in row west1 no differences between single positions were detectable (K-W; P = 0.2).

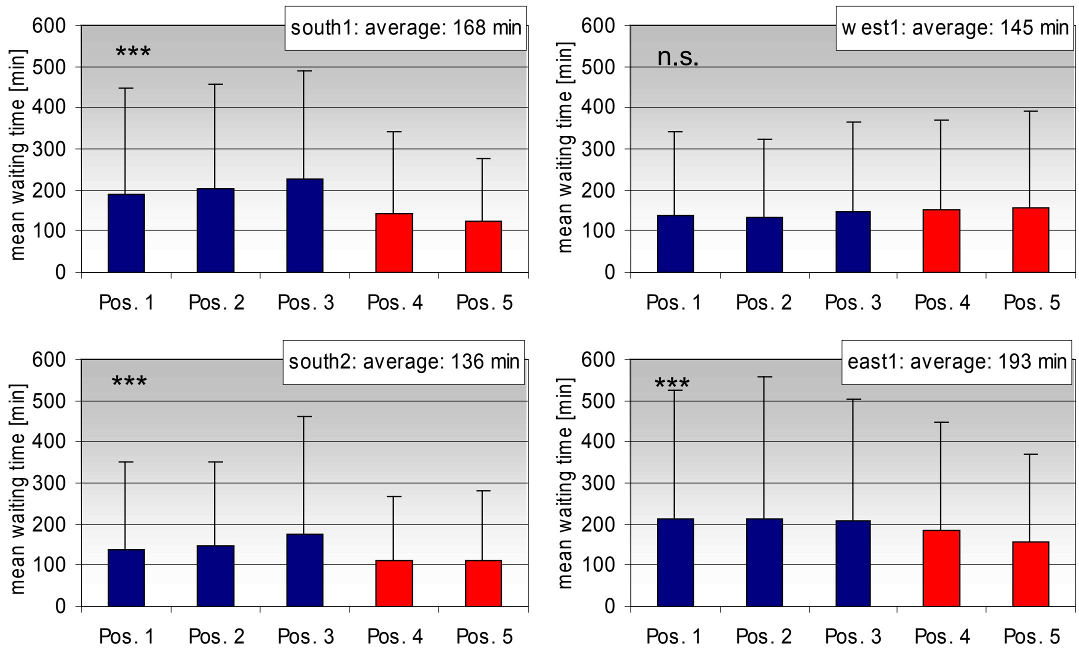


Fig. 3-5: Mean waiting time in the Nysted wind farm area for two rows in two different time periods (with standard deviation). Kruskal-Wallis-test: south1 p < 0.01, south2 p< 0.01, west1 p = 0.2, east1 p < 0.01.

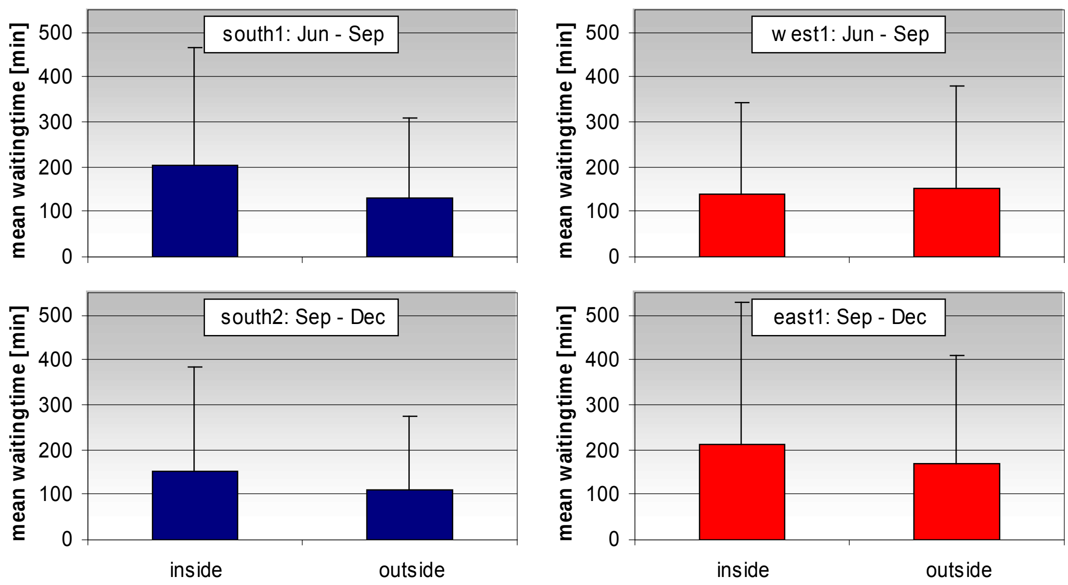


Fig. 3-6: Mean waiting time inside and outside the Nysted wind farm area for two rows in two different time periods (with standard deviation). Inside: data from pos. 1 to 3 and outside data from pos. 4 and 5 were pooled. Mann-Whitney-U-test: south1 p < 0.01, south2 p < 0.01, west1 p = 0.08, east1 p < 0.05.

In Fig. 3-6 the data inside and outside the wind farm were pooled. The conclusion is still present: Apart from of row west1 the parameter mean waiting time showed significantly more porpoise echolocation activity outside the wind farm than inside (M-W U; P < 0.01).

In a last test for differences between inside and outside the wind farm we checked the echolocation activity referring PPM/time-phase during four different day light phases (Fig. 3-7). In this case another difference between the two sides occurred: In three of four rows the echolocation activity shifted from a maximum at night in recorded PPM to a maximum at day (or dawn) or to no distinct difference between the four phases.
The strongest shifts occurred in row west1 where no differences in daily statistics of harbour porpoise echolocation activity could be detected.

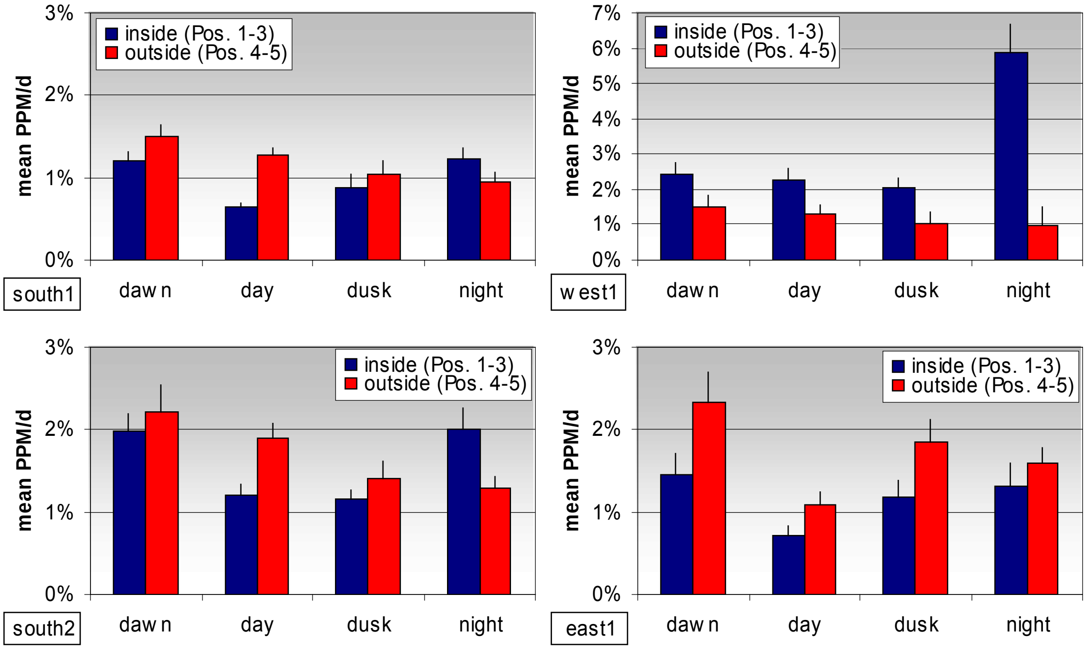


Fig. 3-7: Average PPM/time-phase during four different daylight phases (with standard error) extracted from T-POD data collected in the Nysted area in two rows during two different time periods. Be aware of different y-axis scale. Inside: data from pos. 1 to 3 and outside data from pos. 4 and 5 were pooled. Mann-Whitney-U-test: south1 $p < 0.01$, south2 $p < 0.01$, west1 $p = 0.08$, east1 $p < 0.05$.

3.7.2.6. Abiotic covariates: wind characteristics

Wind speed and echolocation activity did not show a consistent correlation. In the row west1 and east1 T-POD positions within the wind farm logged higher echolocation activity under calm conditions of 0 to 3 m/s. The PPM per hour decreases with increasing wind speed. This pattern was replicated in the row east1 but not in the two southern rows. The figure gives some advice for future investigations.

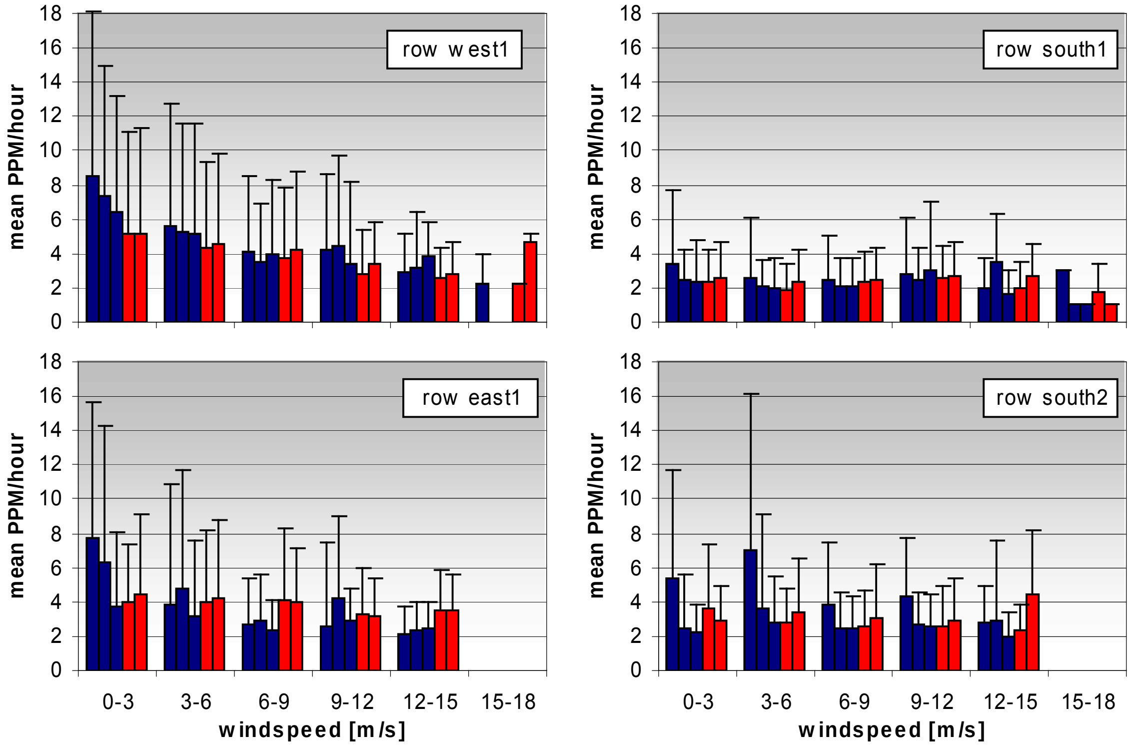


Fig. 3-1: Mean PPM/hour in combination with mean wind speed per hour. T-POD data pooled from 5 positions in two different rows (left/right) in two different time periods (above/below). Blue columns indicate T-POD positions within, red columns outside the wind farm.

3.7.3. Horns Rev

3.7.3.1. POD deployments

Fig. 3-1 shows the exposure times of T-PODs in the Horns Rev area in 2005. Ten T-PODs recorded data on 1,462 entire days. Because longer periods with high ambient noise clutter occurred quite some logging times had to be deleted. 751 entire days of useful data remained (43% of exposure time, 51% of the days with successful data logging).

The presence of harbour porpoises is expressed as porpoise positive time unit (month/half month/pentade/day and hour). All data were adjusted by a correction factor which was calculated for each T-POD during the field calibration data analysis (chapter 1.1).

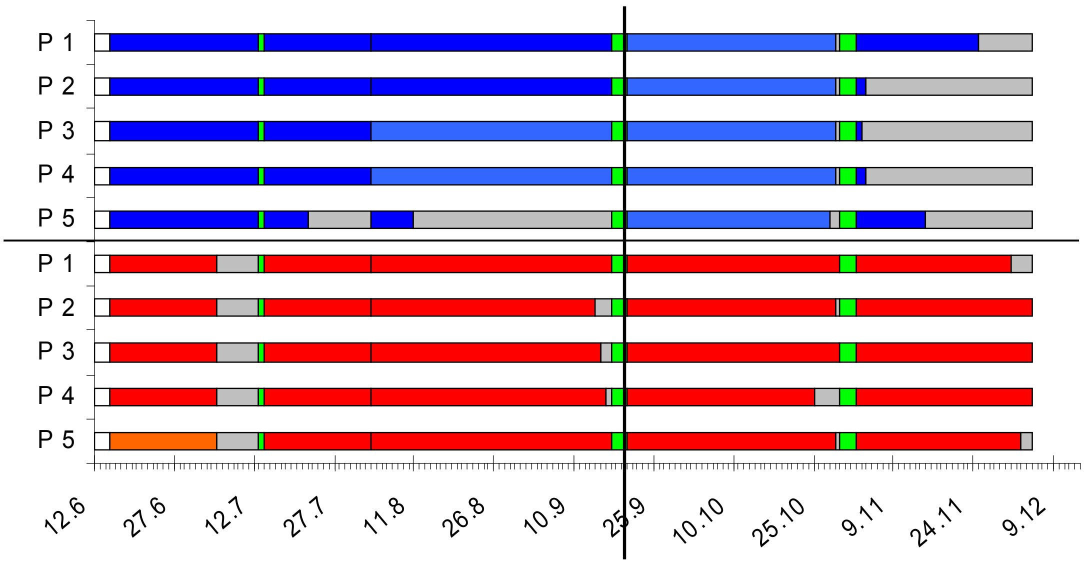


Fig. 3-1: Deployments of T-PODs in the Horns Rev area from June, 15th to December, 5th. Blue bars: times with click sequence logging in row west1 (left from the black line) and west2 (right from the black line). Red bars: times with click sequence logging in row south1 (left) and east1 (right). Green bars: times of calibration. Grey bars: T-POD deployed, but no data. P1 to P3 = positions inside the wind farm; P4 to P5 = positions outside the wind farm.

In Horns Rev ambient noise clutter was a severe problem for data recording. It became apparent, that in times with high wind speeds (and thus ambient noise clutter of braking waves and/or moving sediments) harbour porpoise echolocation sequences were masked and could not be separated from ambient noise. These periods were identified using threshold values of noise clutter and omitted from the data analysis (see chapter methods).

3.7.3.2. Temporal distribution pattern

Porpoise positive days

During the first time period (June, 15th to September, 17th) ten T-PODs logged data in two rows totalling 786 days. There were only three days without any porpoise clicks, and the rate of porpoise positive days was almost 100 % indicating a continuous presence of porpoises in the study area. During the second period (September, 20th to December, 5th) ten T-PODs logged in total 583 days and there were 29 days without any harbour porpoise signal, and 95 % of porpoise positive days. Considering the entire investigation period in 98 % of the days at least one harbour porpoise encounter was logged.

Porpoise positive hours

Considering the entire investigation period, porpoise positive hours occurred in 61 % of the overall logged hours. Tab. 3-1 shows that row south1 recorded the highest mean value for PPH/day with 78 % PPH per 24 hours. This corresponds to more than 18 hours per day. All other rows reached similar values around 55 %.

Tab. 3-1: Mean PPH/day in the Horns Rev area for two rows in two different time periods (south1 and west1: June, 15th to Sept. 17th; west2 and east1: Sept. 20th to Dec. 5th)

south1	west1	east1	west2
78 %	58 %	56 %	52 %

Porpoise positive minutes

In the investigation period PPM/day occurred in 6.6 % of the overall logged minutes. This corresponds to 95 PPM per day, which expresses, that a mean duration of stay of a harbour porpoise was about 9.2 minutes per hour. In Tab. 3-1 the mean values for PPM/day for all four rows are listed. The pattern is similar to PPH/day with highest echolocation activity in row south1.

Tab. 3-1: Mean PPM/day fort two rows in two different time periods (south1 and west1: June, 14th to Sept. 5th; south2 and east1: Sept. 10th to Dec. 7th)

south1	west1	east1	west2
10.8 %	5.4 %	5.5 %	5.4 %

3.7.3.3. Seasonal distribution pattern

We analysed the seasonal pattern of harbour porpoise echolocation activity by calculating porpoise positive minutes (PPM) on a daily basis. The daily amount of PPM is shown for different rows in two consecutive periods (June 15th to September 17th and September 20th to December 5th). Harbour porpoises were present at almost every day, but in rather variable intensities. Daily PPM values varied considerably and high and low values of click activity alternated irregularly (Fig. 3-1 and Fig. 3-2). No characteristic periods of high or low click activity could be identified. In row south1 few days after the start of the investigation a maximum numbers of daily PPM were reached with approximately 40 % PPM/day at the both positions outside the wind farm (4 and 5). The latter investigation period was characterised by frequent off effort times due to ambient noise clutter. Due to these gaps 5-day intervals were only summarised for the first investigation period (Fig. 3-3). The figure shows that recordings of PPM per pentade correlate well in between one row indicating a larger scale for harbour porpoise fluctuation.

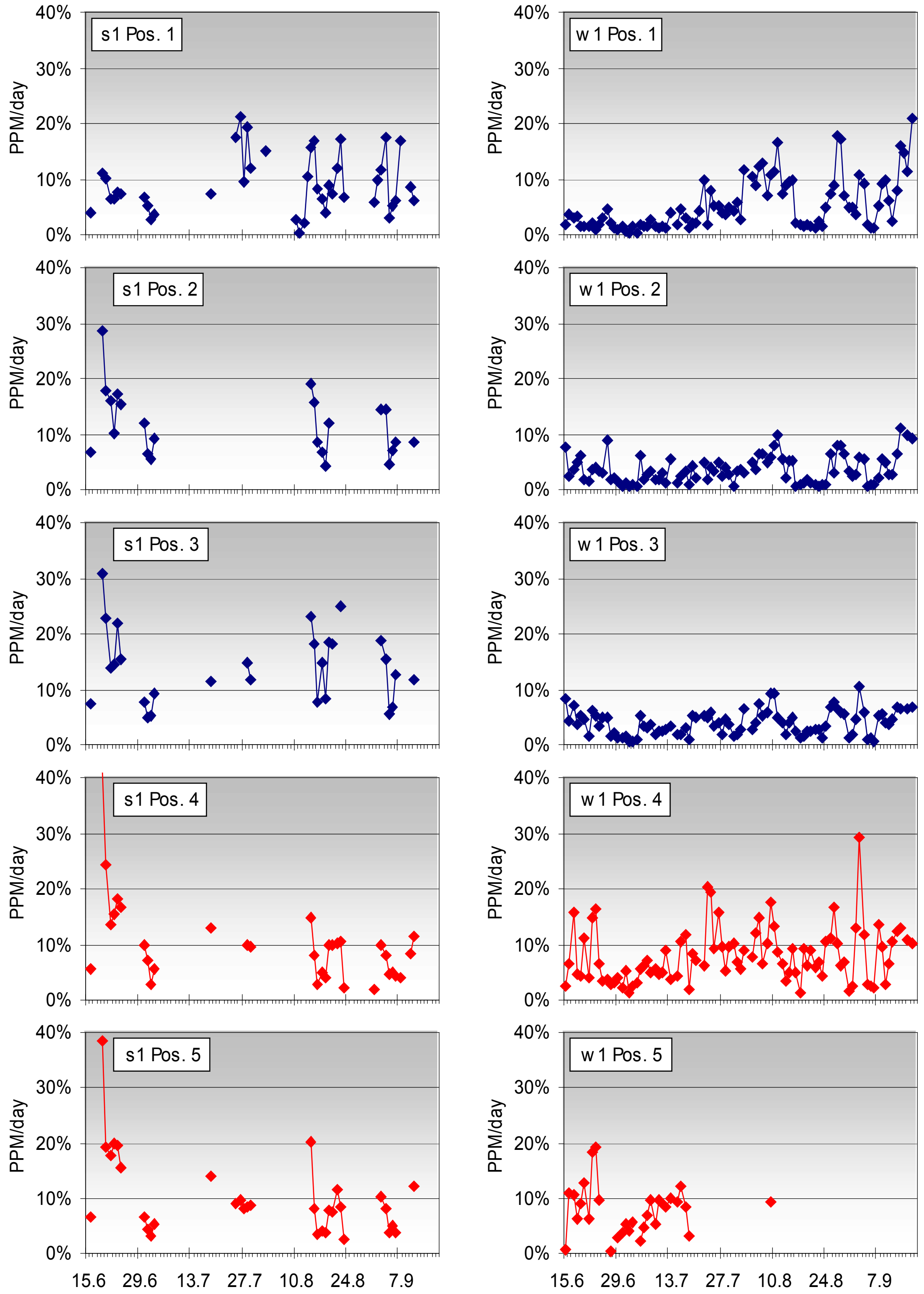


Fig. 3-1: PPM per day from all positions in the Horns Rev area during the first period from June 15th to September 17th. Left panel: row south1; right panel: row west1. Position 1 to 3 was located inside the wind farm and spanned to position 4 and 5 outside the wind farm.

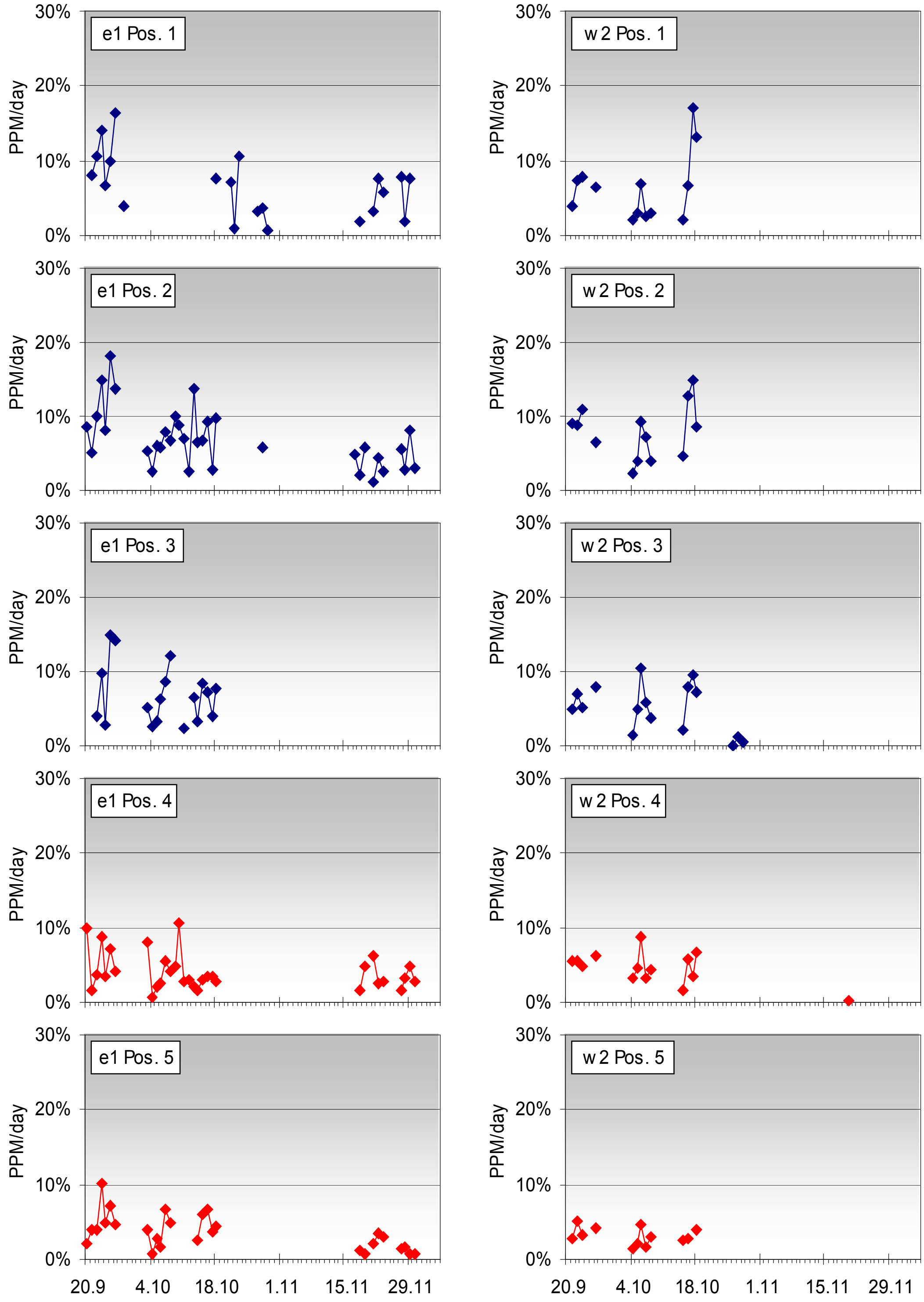


Fig. 3-2: PPM/day from all positions in the Horns Rev area during the first period from September 20th to December 05th. Left panel: row east1; right panel: row west2. Position 1 to 3 was located inside the wind farm and spanned to position 4 and 5 outside the wind farm.

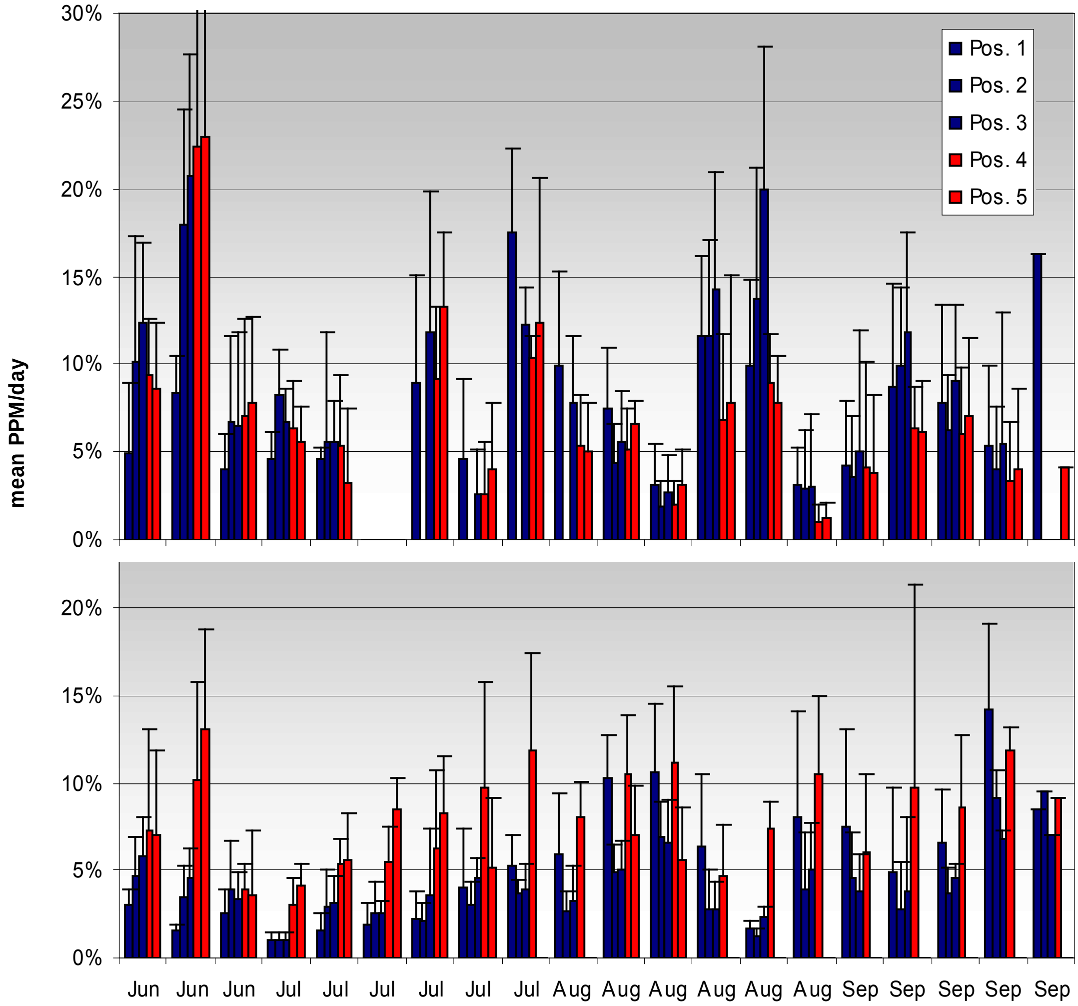


Fig. 3-3: Mean PPM per pentade with standard deviation from all positions at Horns Rev during the period June, 15th to September, 17th in row south1 (above) and row west1 (below).

The average PPM/day referred to half months shows no clear seasonal pattern over the entire study period (Fig. 3-4). A moderate decrease at the end of the campaign in December 2005 could also be caused by fewer days on effort due to a lot of noise clutter in the second part of the investigation.

The frequency of interruptions in recording time prevented the analysis of other parameter like waiting time because this parameter would have often been cut off by this noise clutter.

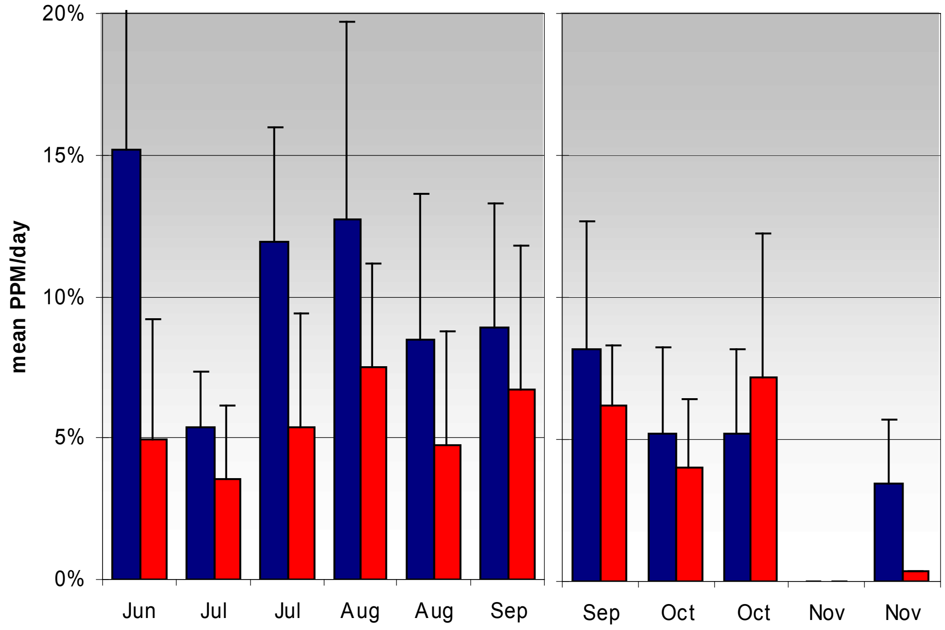


Fig. 3-4: Seasonal mean (half months) for PPM per day in the Horns Rev area from all positions. Left: row south1 (blue) and row west1 (red) for the time period June, 15th to September, 17th. Right: row east1 (blue) and row west2 (red) for the time period September, 20th to December, 5th; with standard deviation.

3.7.3.4. Diurnal rhythm in different time intervals

Due to the low number of data during November/December we present data of diurnal rhythms at different T-POD positions only from the first investigation period between June, 15^{th} and September, 17^{th} (Fig. 3-1). The pattern is distinct but not consistent between the rows. As in Nysted, the data on porpoise presence in row west1 gave some indications that porpoises occurred more frequently at night. This was seen at all 5 positions. In row south1 we could not find a consistent diurnal rhythm of porpoise activity. Inside the wind farm highest numbers of PPM were recorded at dawn, whereas outside the wind farm the maximum number of PPM was reached later in the morning. Inside the wind farm, lowest activity was measured during dusk whereas outside at both positions lowest echolocation was recorded at night.

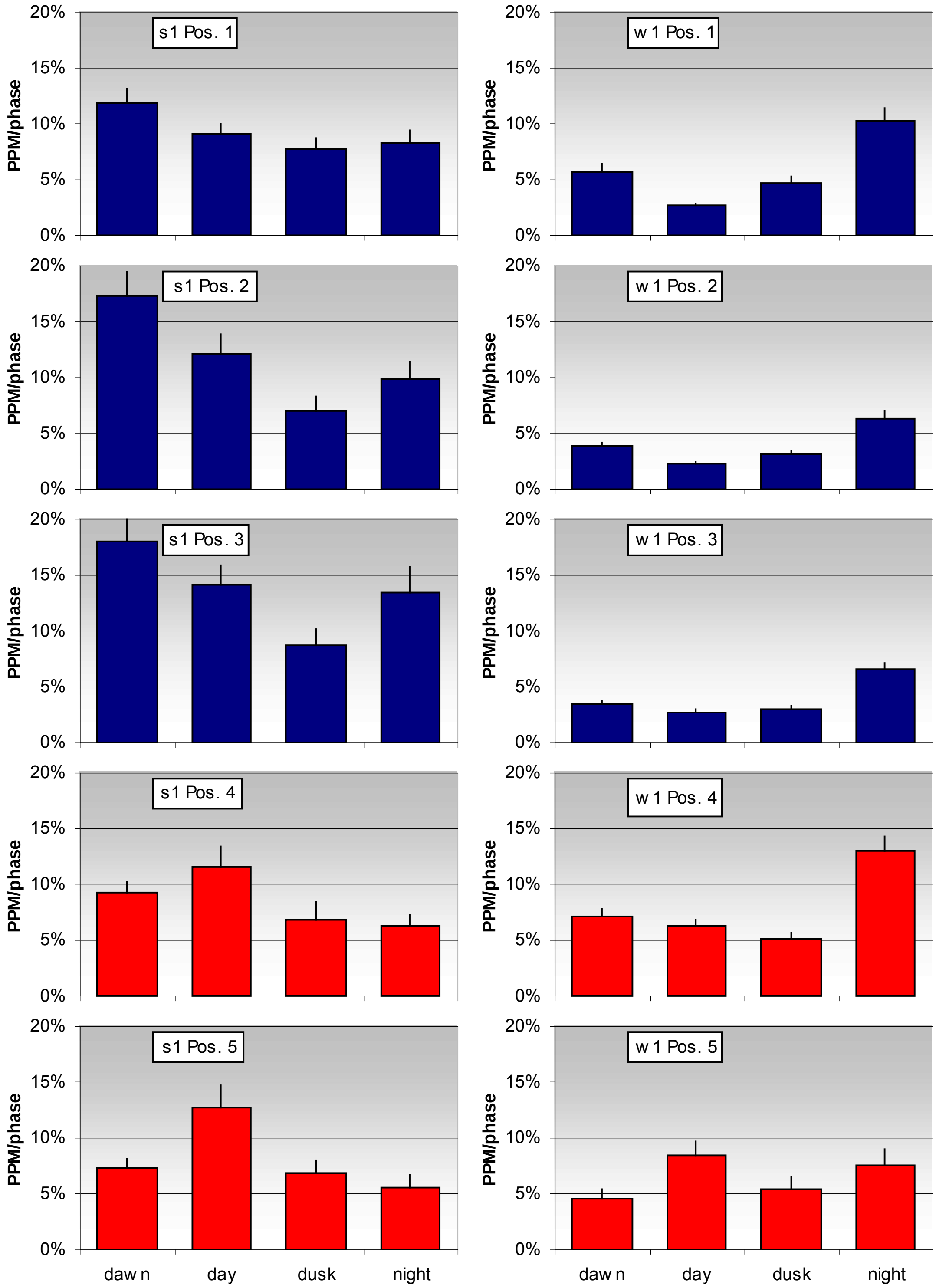


Fig. 3-1: Average number of PPM/time-phase during four different daylight phases (with standard error) extracted from T-POD data collected in the Horns Rev area during the investigation period from June 15th to September 17th. Left panel: row south1; right panel: row west1. Position 1 to 3 were located inside the wind farm and spanned to position 4 and 5 outside of the wind farm.

3.7.4. Spatial distribution pattern

3.7.4.1. Inter-row- and intra–row comparisons

Considering potential differences of echolocation activity we took a twofold approach with different time resolutions: mean PPH per day and mean PPM per day.

In Horns Rev, both parameters draw a similar spatial pattern of porpoise presence (Fig. 3-1 and Fig. 3-2). The differences between some positions within a row were more pronounced when PPM/day were considered.

Tab. 3-1 shows the statistic significance levels calculating an ANOVA (except of row west1 where the data were not normally distributed).

In general, the two positions outside the wind farm were very similar in recorded porpoise activity and differed significantly from at least one position inside the wind farm. The spatial patterns of echolocation activity varied between T-POD rows: In three out of four rows the echolocation activity was significantly lower outside the wind farm than at least at one position inside the wind farm. Actually in row east1 all positions inside the wind farm show significantly higher values for PPM/day than both positions outside. In contrast, only in row west1, where also all positions inside the wind farm were significantly different, more PPM/day were recorded outside the wind farm than inside.

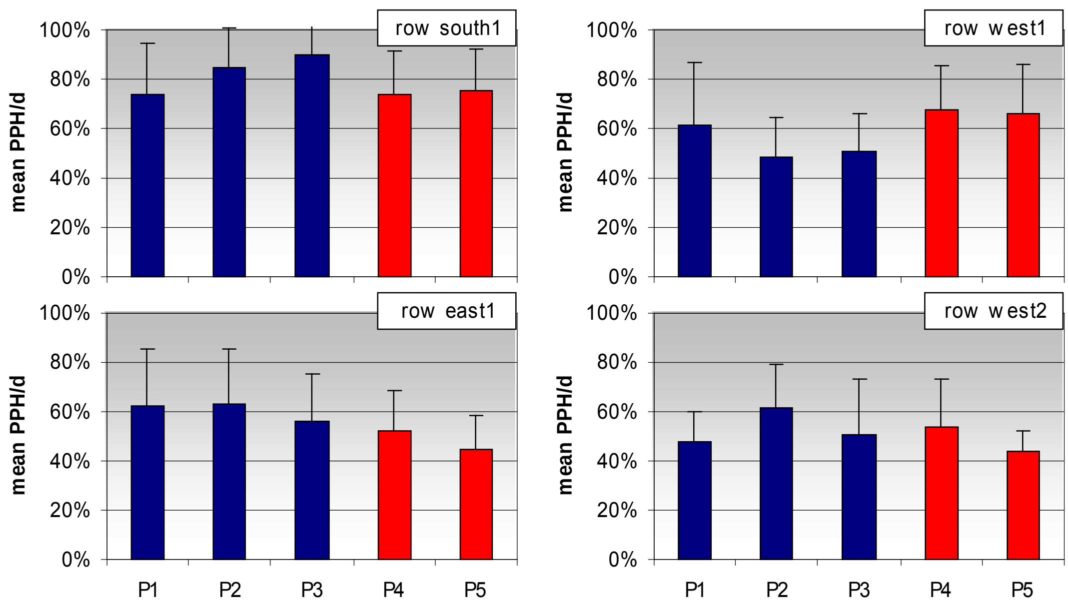


Fig. 3-1: Mean PPH per day in Horns Rev of two different rows in two different time periods.

In order to focus on a possible effect of the fact if PODs were generally located inside or outside the wind farm, we pooled the data for both groups regarding the parameter PPM/day (Fig. 3-3).

The inconsistent pattern was still recognisable: row south1 showed no significant difference between outside and inside whereas both rows east1 and west2 recorded significantly more

PPM/day inside the wind farm. In contrast, the row west1 showed significantly more PPM/day outside the wind farm.

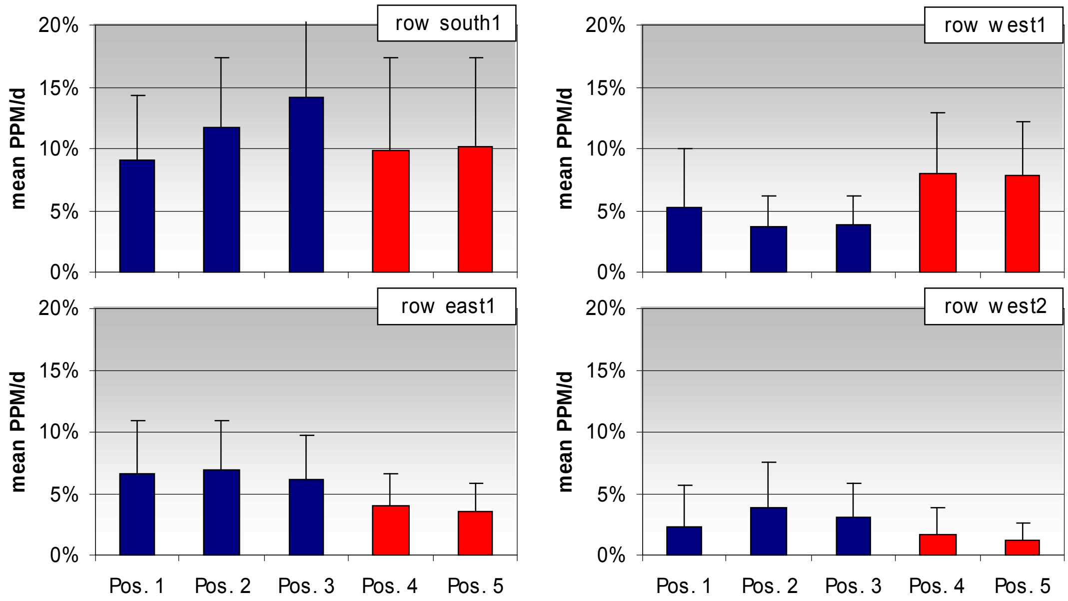


Fig. 3-2: Mean PPM per day in Horns Rev for two different rows in two different time periods. Kruskal-Wallis-test: south1 p < 0.01, east1 p< 0.01, west1 p < 0.01, east1 p < 0.01.

Tab. 3-1: Significance levels of ANOVA for PPM/day. *) row west1 single positions were proved by using a Mann-Whitney U-test with correction according to Bonferroni.

south1	**Pos. 1**	**Pos. 2**	**Pos. 3**	**Pos. 4**	**Pos. 5**
Pos. 1	-				
Pos. 2	n.s.	-			
Pos. 3	*	n.s.	-		
Pos. 4	n.s.	n.s.	*	-	
Pos. 5	n.s.	n.s.	*	n.s.	-
west1*)	**Pos. 1**	**Pos. 2**	**Pos. 3**	**Pos. 4**	**Pos. 5**
Pos. 1	-				
Pos. 2	n.s.	-			
Pos. 3	n.s.	n.s.	-		
Pos. 4	*	*	*	-	
Pos. 5	*	*	*	n.s.	-
west2	**Pos. 1**	**Pos. 2**	**Pos. 3**	**Pos. 4**	**Pos. 5**
Pos. 1	-				
Pos. 2	n.s.	-			
Pos. 3	n.s.	n.s.	-		
Pos. 4	n.s.	*	n.s.	-	
Pos. 5	n.s.	*	n.s.	n.s.	-
east1	**Pos. 1**	**Pos. 2**	**Pos. 3**	**Pos. 4**	**Pos. 5**
Pos. 1	-				
Pos. 2	n.s.	-			
Pos. 3	n.s.	n.s.	-		
Pos. 4	*	*	*	-	
Pos. 5	*	*	*	n.s.	-

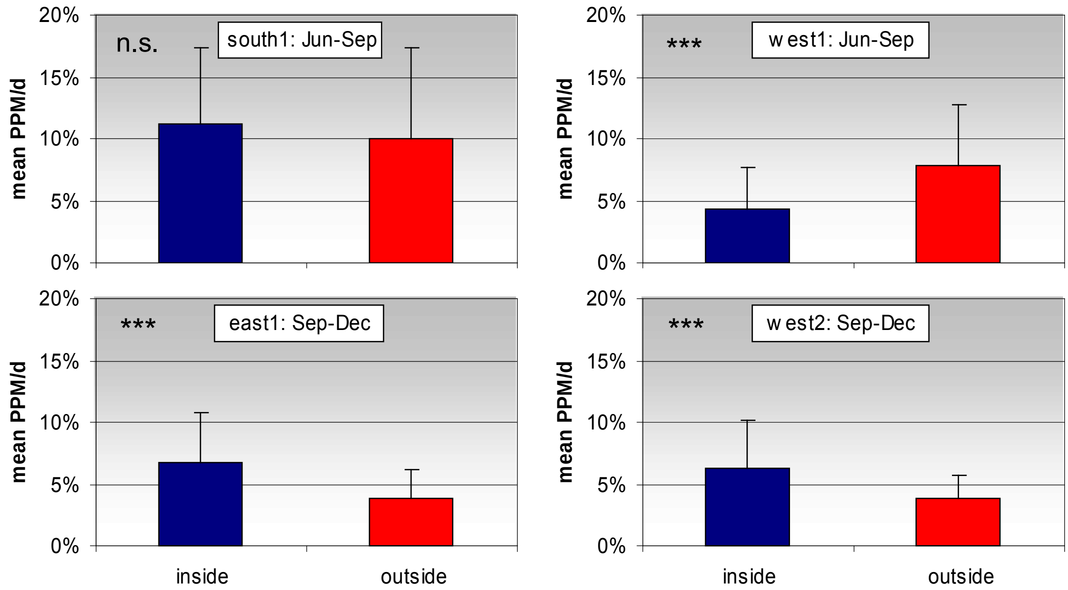


Fig. 3-3: Mean PPM per day inside and outside the Horns Rev wind farm area for two rows in two different time periods (with standard deviation). Inside: data from pos. 1 to 3 and outside data from pos. 4 and 5 were pooled. T-test: south1 $p = 0.1$, west2 $p < 0.01$, east1 $p < 0.01$; west1: M-W U: $p < 0.01$.

In a last test for differences between inside and outside the wind farm we checked the echolocation activity referring to PPM/time-phase during four different day light phases for the first time period (Fig. 3-4). Compared to the Nysted area in row south1 a contrary shift in recorded PPM/time between different light phases occurred. Outside the wind farm most activity was measured during night which was significantly different from other day light phases. Inside the wind farm most PPM were recorded during day. In row west1 a distinct pattern occurred with highest PPM recordings during night and lowest at day or dusk. This pattern was consistent from inside to outside the wind farm.

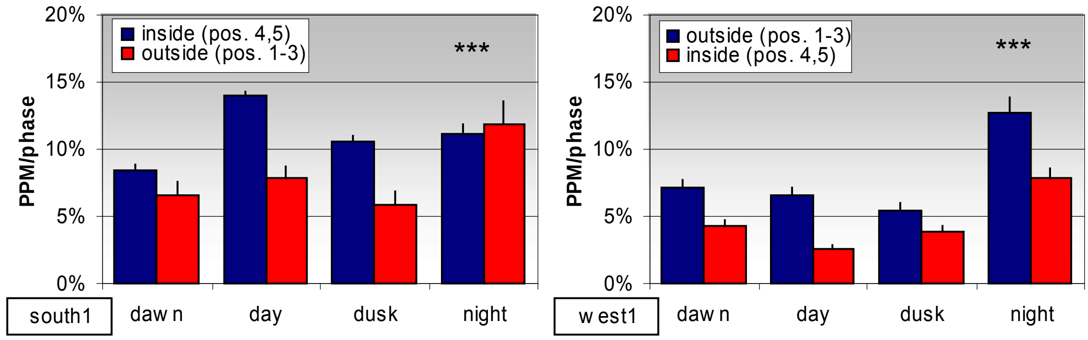


Fig. 3-4: Average PPM per time-phase during four different daylight phases (with standard error) extracted from T-POD data collected in the Horns Rev area in two rows during between June, 15th and Sept, 17th. Inside data from pos. 1 to 3 and outside data from pos. 4 and 5 were pooled. Mann-Whitney-U-test: south1 $p < 0.01$, west1 $p = 0.08$.

3.8. Behavioural categorisation of harbour porpoise click trains (by Sven Koschinski)

3.8.1. Introduction

Since the discovery of echolocation in odontocetes (MCBRIDE 1956) and the early demonstration of their echolocation abilities in detection tasks (e. g. Kellogg 1958) numerous studies have addressed the function and performance of the biosonar of dolphins and porpoises. For echolocation, a variety of click sounds with different properties is used by different odontocete species. Further, the use of frequency modulated low-frequency whistles is well documented for communication in some dolphin species (e. g., AU 1993)

In contrast to delphinids, harbour porpoise sound signals are almost exclusively built up of click trains. All click sounds appear to have a high-frequency component with frequencies between 110 and 150 kHz (e. g., AMUNDIN 1991b, VERBOOM & KASTELEIN 1997). A low-frequency (2 kHz) component is not always present (KAMMINGA & WIERSMA 1981, VERBOOM & KASTELEIN 1995, VERBOOM & KASTELEIN 1997, VERBOOM & KASTELEIN 2003). Further broad band components have been described of which the function is unclear (VERBOOM & KASTELEIN 1995, VERBOOM & KASTELEIN 1997).

So far, studies on harbour porpoise vocalisations are mostly descriptive. A high variation in click duration, intervals and frequency spectrum have been described (e. g., VERBOOM & KASTELEIN 1995, VERBOOM & KASTELEIN 1997). The behavioural context in which certain click train patterns are emitted is only addressed in few studies (e. g., AMUNDIN 1991b, VERFUß & SCHNITZLER 2002, VERFUß et al. 2005). All of them took place in a pool or under semi-natural conditions.

The purpose of this literature study is to summarise the current knowledge on harbour porpoise vocalisation patterns and their behavioural context. A meanwhile commonly applied tool to log clicks of free-ranging harbour porpoises is an electronic click detector (T-POD, for details see www.chelonia.demon.co.uk/). This literature study focuses on high-frequency vocalisation patterns since this device only logs high-frequency click sounds. It is intended to use this information as a basis for identifying the significance of typical patterns found within click detector data.

3.8.2. Sources of information

The main sources for this study were the existing peer reviewed and published literature. For some questions no published information was available. In order to obtain additional information some unpublished papers (e. g., theses and internal reports) were included.

3.8.3. Definitions

In the studies referred to in this review, a variety of methods have been used. Some authors (mostly in older studies) recorded the low-frequency component of clicks while others analysed the high-frequency component.

To describe the nature of click series, some authors use the term *pulse repetition frequency* (PRF, given in Hz or clicks per second) while others relate to *interclick intervals* (ICI, given in ms), meaning the time elapsed between two clicks. One is roughly the reciprocal of the other. However, PRF cannot be converted directly into ICI without knowing the pulse duration which is often not specifically given in the references. Further, pulse duration in the low-frequency component can be much longer than in the simultaneously emitted high-frequency component (see below). Therefore the high-frequency interclick interval differs from the low-frequency interclick interval and cannot be compared.

We therefore use the term *click interval* throughout this paper and define it as the period from the beginning of one click to the beginning of the consecutive click (or as interclick interval plus pulse duration). When necessary, we convert *pulse repetition frequency* into *click intervals*.

Some authors use the term *click train* only for click series with certain click intervals (e. g., VERBOOM & KASTELEIN 1995) while others use it for any series of clicks regardless of their click interval (cf. AU 1993). In this study, the term *click train* is used for any series of clicks separated by gradually or cyclically changing click intervals suggesting a unit during an echolocation event or a communication signal. Click trains may be separated from others by distinctly longer intervals. If these are emitted in a certain behavioural context such as navigating focused on a landmark a number of click trains form *click train sequences*.

3.8.4. Results and discussion

3.8.4.1. Source characteristics of harbour porpoise vocalisations

Harbour porpoises produce narrow-band high-frequency clicks, often with synchronous, low- or mid-frequency components (MØHL & ANDERSEN 1973, PILLERI et al. 1980, AMUNDIN 1991a, VERBOOM & KASTELEIN 1995, VERBOOM & KASTELEIN 1997, VERBOOM & KASTELEIN 2003).

VERBOOM & KASTELEIN (1997) identified a **high-frequency** component between 110 and 150 kHz which sometimes has two peaks. In this component, most energy is concentrated around a distinct peak. The 3-dB bandwidth comprises only 16.4 kHz (AU et al. 1999). In juveniles, the peak frequency was shown to be a little higher (around 145 kHz compared to 127.5 kHz) and the bandwidth narrower (12.5 to 14 kHz) than in adults (GOODSON & DATTA 1995, GOODSON et al. 1995, GOODSON & STURTIVANT 1996, AU et al. 1999).

Typical high-frequency pulses used for echolocation have a duration of 75 to 100 µs and the waveform consists of approx. 7 to 14 sinusoidal cycles. These oscillations rapidly increase in amplitude in the beginning and then appear to decay exponentially (PILLERI et al. 1980, HATAKEYAMA & SOEDA 1990, GOODSON & DATTA 1995, GOODSON et al. 1995). However, VERBOOM & KASTELEIN (1997) reported a click duration of 150 to 300 µs, consisting of two or three such oscillations with a decaying amplitude. These may have been results of interference with the acoustic environment in the pool in which they did their measurements.

Source level values measured in a detection task in a semi-natural environment were found between 160 – 165 $dB_{peak\text{-}peak}$ with a highest level recorded at 172 dB (AU et al. 1999). In reverberant conditions, such as in a pool, porpoises may not use maximum possible source levels as emitted by free-ranging porpoises.

High-frequency click sounds are highly directional. The 3-dB bandwidth in the horizontal and the vertical plane was shown to be 16.5° with the beam pointed toward the forward direction (Au et al. 1999).

A **mid-frequency** broadband component between 10 and 100 kHz containing harmonic patterns was identified especially in single, very short clicks. Harmonics around 30 and 60 kHz sometimes were dominant (VERBOOM & KASTELEIN 1995, VERBOOM & KASTELEIN 1997). KAMMINGA & WIERSMA (1981) reported a 20 kHz component which may be identical with the dominant harmonics found by VERBOOM & KASTELEIN.

The narrow-band **low-frequency** component around two kHz has been described by several authors and used for analysis of porpoise vocalisations (e. g., BUSNEL & DZIEDZIC 1967, SCHEVILL et al. 1969, AMUNDIN 1991b, VERBOOM & KASTELEIN 1997). VERBOOM & KASTELEIN (1997) found two more low-frequency components, a noise like component between 1 and 10 kHz with a low amplitude and a 40 to 600 Hz sine wave.

The source level of low-frequency clicks is reported to be about 100 dB (re 1µPa) (SCHEVILL et al. 1969) or some 40 dB lower than the peak source level measured in the high-frequency bands (GOODSON et al. 1995). In contrast to very short high-frequency clicks found during echolocation, the low-frequency component of clicks can have a duration of 2.5 to 14 ms when long click intervals are used or can even be continuous during click trains (Verboom & KASTELEIN 1995, VERBOOM & KASTELEIN 1997). Often, the low-frequency component is lacking (KAMMINGA & WIERSMA 1981, VERBOOM & KASTELEIN 1995, VERBOOM & KASTELEIN 2003).

3.8.4.2. Directivity related artefacts in recordings

GOODSON and STURTIVANT (1996) using an acoustic harbour porpoise detector - converting ultrasound into the human auditory range - found that in most series of clicks observed at free-ranging, presumably foraging porpoises, the intensities of echolocation signal faded very sharply and reappeared strongly in an almost regular pattern, producing the effect of a series of very short click trains (i. e. as fragments of longer trains). They suggest that porpoises were scanning a small sector ahead of their path by body or head movements. AKAMATSU et al. (1992) and VERFUß & SCHNITZLER (2002) also report these scanning movements during echolocation in captive animals. Hence, the directional properties of the sonar beam may influence the sound recordings or clicks logged with stationary equipment such as T-PODs.

3.8.4.3. Echolocation

Harbour porpoise echolocation signals consist of high-frequency (110 to 150 kHz) click trains which can be detected via click detector (e. g., KAMMINGA & WIERSMA 1981, AU 1993; VERBOOM & KASTELEIN 1997). A low-frequency component around 2 kHz is often found and may not have a function in echolocation (VERBOOM & KASTELEIN 1997, VERBOOM & KASTELEIN 2003). The characteristics of such click trains during echolocation can differ in pulse duration, click interval and number of clicks in a train (e. g., VERBOOM & KASTELEIN 1995).

Click intervals within series of clicks are highly variable. In free-ranging porpoises, CHAPPELL & GORDON (1993) described two patterns, i. e. a “slow clicking vocalisation” with click intervals between 13 and 900 ms as well as “buzzes” during which intervals typically start at 3 ms decreasing to 2 ms. The latter are often found during prey capture (see below). In echolocating harbour porpoises in a pool, VERBOOM and KASTELEIN (1995) reported an even greater number of different recognisable time patterns, described as phrase types varying in duration and click intervals.

Single clicks – short clicks separated by very long click intervals.

Click bursts – short series of clicks with short click intervals and a total duration of less than a second (for instance 0.25 s)

Blocked bursts – a series of short click bursts with a total duration of many seconds. Click bursts are separated by longer click intervals

Click series – a long series of clicks with short click intervals and a duration of many seconds (in fact a long click burst). Examples are shown in .

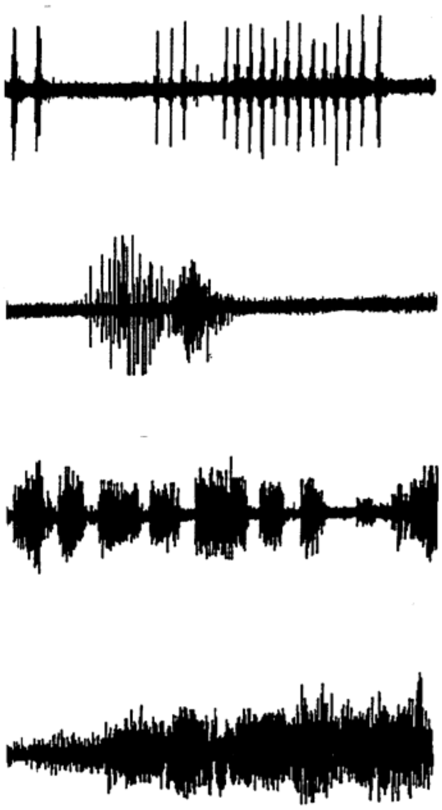


Fig. 3-1: Five different high-frequency echolocation phrase types varying in duration and pulse repetition frequency (redrawn from VERBOOM & KASTELEIN 1995)

Further, there was a tendency in a captive animal to start with a certain click interval, decrease intervals and increase them again (VERBOOM & KASTELEIN 1995). Such u-shaped interval curves can be frequently seen in click detector data (Diederichs et al., unpublished data).

A phenomenon called “jittering” can often be seen within click trains of harbour porpoises and other odontocetes (TEILMANN et al. 2002). By using slight pulse-to pulse changes in click intervals around the range adjusted value odontocetes reduce range ambiguous interference of echoes (e. g., of two targets in close proximity). Some of these interval changes are cyclic while others appear to be at random.

3.8.4.4. Lag time

The lag time is the time required for signal processing after receiving an echo from a target before sending out the next click within a click train (AU 1993). There is inconsistent information what lag time is required by harbour porpoises during navigation and orientation.

The lag time may be influenced by the complexity of a task. During simple navigation tasks, VERFUß et al. (2005) found nearly constant lag times of 14 to 19 ms at distances from 26 to 12 m. The lag time increased to 26 to 36 ms in a more complex spatial situation (with hydrophones, cameras and cables in the water). AU et al. (1999) measured lag times of 20 to 35 ms in harbour porpoises during a detection task of an object at a distance of seven to nine

meter. GOODSON & STURTIVANT (1996) described a lag time of 27 ms which they attributed to highly reverberant conditions of the holding pool and a high SL to reverberation ratio rather than to signal processing.
During the search phase before catching a fish, VERFUß & SCHNITZLER (2002) found a lag time of 23 ms (derived from Fig. 3-2, see below).
In a target discrimination study of TEILMANN et al. (2002) a captive harbour porpoise used nearly constant click intervals of 60 ms rather than adjusting intervals for range. The “experienced” animal may have used a time window that covered all distances tested within its enclosure.

3.8.4.5. Echolocation during prey capture

Click trains with very short click intervals (“bursts”) were suggested to occur when animals in a pool became more vigilant or during prey capture. Immediately before prey capture, click intervals rapidly decreased from 10 to 1.5 ms (BUSNEL & DZIEDZIC 1967,). This pattern has been shown at a distance of about 40 cm from prey. SCHEVILL et al. (1969) found similar click trains with intervals starting at 17 ms, rapidly decreasing to 1.4 ms with the shortest observed click intervals during feeding being one ms.
Similar results were reported by VERFUß & SCHNITZLER (2002) who divided echolocation during prey catch into two phases. During a search phase animals were locked on a target and their click intervals were long and variable around 80 ms, in most cases gradually decreasing. In this phase, target distance can be calculated from the two-way travel time and lag time[1].
A second phase started at short-range when porpoises detected the fish shortly before the catch (usually at five to 1.5 m distance to prey). It is characterised by the “buzz”, a sudden decrease of click intervals to a minimum of about 1.5 ms (Fig. 3-2). These intervals are only scantly longer than the two-way travel time to the prey and hence the observed lag time is too short for processing each single click. Porpoises would have to integrate over a few click-echo-pairs to receive information on the prey. Often, during prey capture, porpoises turned into the opposite direction to catch fish from behind producing directivity related artefacts in recordings. After the catch long click intervals like in the search phase were resumed.

The search phase of captive harbour porpoises before prey capture sometimes started with scanning movements of the head. These were more distinct when animals were blindfolded (simulating turbid waters, darkness or great depths).

[1] $D_{max} = (I - T_{lag})\, v / 2$ (1)
with
D_{max} = maximum detection distance (m)
I = click interval (s)
T_{lag}= lag time (s)
v = sound velocity, ca. 1500 m/s.

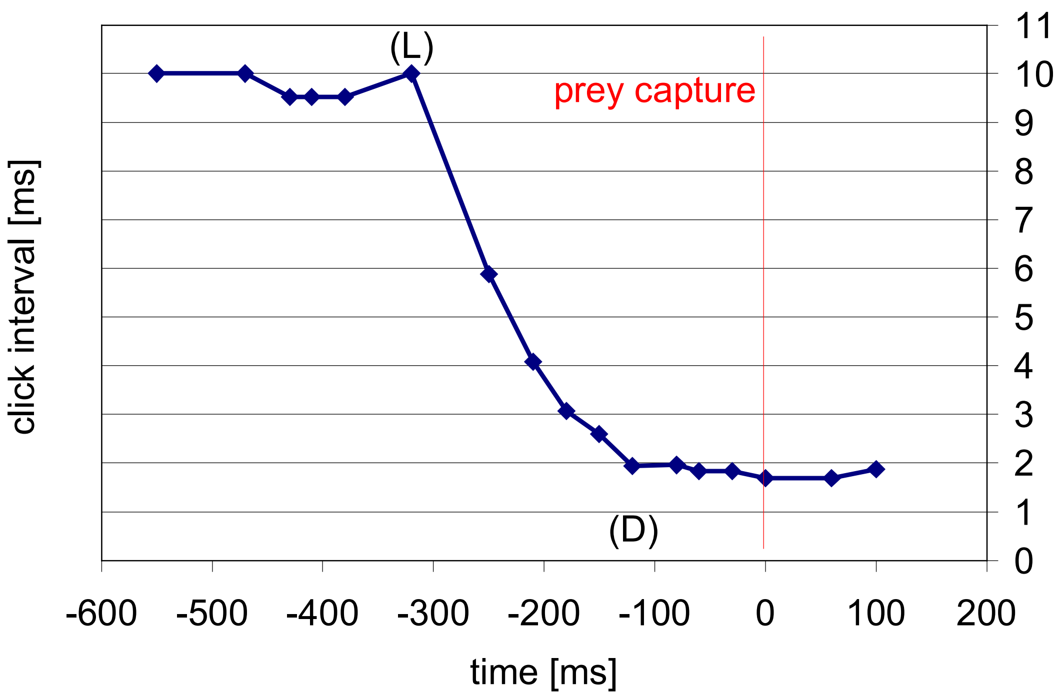


Fig. 3-1: Harbour porpoise click intervals immediately before and during prey capture (redrawn from BUSNEL & DZIEDZIC 1967). (L) indicates the “localisation point”, about 20 to 40 cm from prey, (D) indicates the “decision point”, about 5 cm from the prey

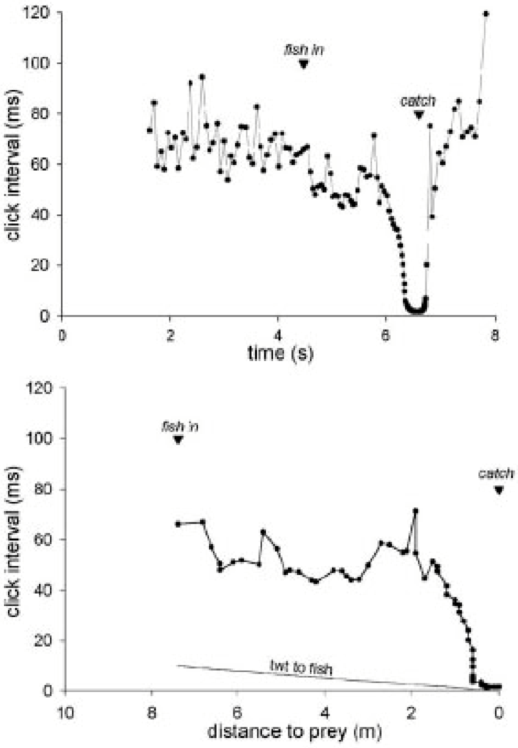


Fig. 3-2: Distance to prey (above) and click intervals (below) before and during prey capture (redrawn from VERFUß & SCHNITZLER 2002).

3.8.5. Observation of objects and dead fish

Several studies report on echolocation behaviour during feeding. Since often dead fish is fed to captive porpoises, this may not be compared to the echolocation of life prey. It may rather be similar to the acoustic behaviour when exploring objects. For example, during feeding KAMMINGA & WIERSMA (1981) noted bursts of about 200 clicks with intervals of 2.6 to 3.3 ms, AKAMATSU et al (1992) reported "pulse intervals" (probably interclick intervals) of 0.6 to one ms, and HATAKEYAMA & SOEDA (1990) recorded four to 23 clicks in a train with intervals between ten and 123 ms.

During feeding of benthic fish in a vertical position ("bottom grubbing") (LOCKYER et al. 2001) echolocation behaviour may be similar to the behaviour shown by captive porpoises exploring objects buried in the sand. During these experiments, porpoises had to discriminate between different objects. They emitted bursts of clicks of less than a second duration with very short click intervals. Unfortunately these were not recorded and hence not analysed (KASTELEIN et al. 1997).

KASTELEIN et al. (1995) found that animals navigating around ropes in a pool used more click trains with intervals > 40 ms and less trains with intervals < 40 ms compared to a situation with floating objects in a pool. They suspect that longer intervals were used during navigation while shorter intervals were used for close investigation. When the porpoises attention was drawn to an object, or when they observed an object at close range, they decreased click intervals from about 30 to 70 ms to about two ms (VERBOOM & KASTELEIN 1995).

3.8.5.1. Navigation, echolocation on landmarks

Captive harbour porpoises often alternate click series with long, relatively stable intervals (29 – 68 ms) with others using much shorter intervals. These slow clicking vocalisations are believed to be emitted during navigation or by porpoises "at ease" and not investigating any particular object (VERBOOM & KASTELEIN 1997).

During navigation tasks, captive harbour porpoises were shown to use landmarks which they locked on during an approach (VERFUß et al. 2005). During click trains their intervals decreased in the same order as two-way travel time decreased during approach. When travelling, captive porpoises switched from one landmark to another. This is incidental to a sudden strong increase of click intervals after a click train with gradually decreasing intervals (VERFUß et al. 2005).

Free-ranging harbour porpoises seem to use underwater structures as landmarks (MEDING 2005). This is expressed by typically over one minute long click train sequences. These are built up of click trains with gradually decreasing average click intervals starting at a mean of 266 ms in deeper waters (water depth approx. 30 m) and 194 in shallower waters (approx. eight m). Using a lag time of 20 ms (VERFUß et al. 2005) for "simple" navigation tasks this translates into maximum navigation ranges of 185 and 131 m, respectively. The end point of such landmark-focused echolocation trains was at a mean of 52 ms (deep water) or 42 ms (shallow water) translating into 24 m and 17 m, respectively.

Further, interpreting long click train sequences with long and stable mean click intervals logged with T-PODs, MEDING (2005) assumes seabed-focused orientation. At a deeper station (30 m) intervals were at a mean of 70 ms and at a shallower station (eight m) they were averaging 41 ms. Using 20 ms as a lag time this would reflect a detection distance of 38 m and 16 m, respectively. This roughly corresponds to the water depth and may take into account that porpoises point their biosonar in a downward slope while travelling along the surface.

3.8.5.2. Number of clicks

The number of clicks used during echolocation tasks is highly variable. It may be dependent on the complexity of the task. E. g., TEILMANN et al. (2002) were able to show that harbour porpoises used significantly more clicks detecting a small water filled steel sphere compared to a large one. KOSCHINSKI et al. (2006) found a higher median number of clicks used by echolocating groups near standard nylon nets compared to more reflective $BaSO_4$ nets (56 vs. 23 clicks).

In an experiment by VERFUß & SCHNITZLER (2002) with captive harbour porpoises, animals used longer echolocation sequences when blindfolded (12 s) compared to normal daylight conditions (six to eight s). This suggests that animals foraging at night or at great depths need more clicks to detect and classify their target.

3.8.5.3. Communication

Communication signals of harbour porpoises usually lack frequency modulated whistles characteristic of many dolphin species (AMUNDIN 1991b, AU 1993). In the present literature, only VERBOOM & KASTELEIN (1995) report whistles with frequencies between 47 and more than 600 Hz with a superimposed low-frequency (two kHz) component. These are believed to be social signals (VERBOOM & KASTELEIN 1997).

Harbour porpoise communication signals are almost exclusively built up of click trains (AMUNDIN 1991b). A low-frequency component found in communication sound always occurs in combination with the highly directional high-frequency component found in echolocation click trains, indicating that both are the result of the same sound production event (AMUNDIN 1991a, AMUNDIN 1991b). The high-frequency component always occurs in the beginning of the low-frequency component which has a longer duration (AMUNDIN 1991a, VERBOOM & KASTELEIN 1997). The low-frequency component can be used as an indicator for the high-frequency component, when repetition rate is concerned (AMUNDIN 1991b). Thus, low-frequency communication sounds could also be found within click detector data by means of their high-frequency counterpart.

AMUNDIN (1991b) recorded a variety of low-frequency and high-frequency social signals, mostly “threat” and “distress” calls. For communication within close range, low-frequency click trains are well suited due to their omnidirectional properties (AMUNDIN 1991b). Strongly directional high-frequency clicks may not be perceived by conspecifics even though their source level is much higher (GOODSON et al. 1995). In some cases, porpoises turned their

melon towards the addressee (AMUNDIN 1991b). In these cases both frequency components may be meaningful.
AMUNDIN (1991b) noted the following call types during low-frequency analysis.
“Sideward threat call” – a call with a duration of approximately 200 ms. Click train with intervals starting at 2.5 ms decreasing steeply to 1.4 – one ms.
“Push threat call” – a call with a duration of over one to 1.5 s. Click intervals used were 1.3 ms with a (sometimes sharp) decrease in the beginning and an increase at the end, sometimes grouped into phrases of several calls. Both calls were used during agonistic behaviour between subadult males.
“S-display sound” – a call with a total duration of sometimes over ten s. The sound consisted of a click train with very long intervals (over 100 ms) interrupted by bursts of somewhat shorter intervals (about 40 ms). This call was used by subadult males during sexual display.
“Signal of dominance” – a call with a duration of 50 to 100 ms and very short click intervals of only 0.8 ms shown during food competition situations.
“Signal of pain” – a call with a duration of 200 ms and decreasing click intervals of 1.7 to 1.2 ms followed by another call, 300 ms long and modulating click intervals between 1.4 and 1.7 ms.
During both, low- and high frequency analysis AMUNDIN (1991b) noted several “distress calls” in situations when animals experienced discomfort. These were calls with varying duration (100 ms to over one s long) and rather even spaced clicks with intervals of between 2 and 3 ms. Some of these click trains showed a slight, others a sharp increase of click intervals followed by a decrease before reaching the steady level. In the beginning of the calls intervals of up to ten ms were found.

Click trains may include a communication as well as echolocation function. The message conveyed may be dependent on the social and ecological context in which it is emitted. The harbour porpoise obviously uses similar click intervals during echolocation and for social communication. However, the main difference is that during prey catch always two very distinct phases occur (one with long intervals followed by another with precipitously decreasing intervals) while in known communication signals often even spaced clicks or decreasing intervals are used.

3.9. Discussion

The project is now entering the second year of investigation and data collection will end in autumn 2006. This report presents a first view to the data set and provides some ideas for subsequent analyses. At the current stage, results are preliminary and any conclusions are drawn very carefully. For general conclusions, we have to refer to results achieved by further analyses in the near future that will be presented in detail in the final report.

3.9.1. Discussion of methods

3.9.1.1. Use of T-PODs

The main objectives of this study are to analyse the effects of an operating off-shore wind farm on the temporal and spatial patterns of harbour porpoise acoustic activity at a much smaller spatial and temporal scale than other existing studies.

So far, the use of T-PODs offers a unique opportunity of continuous remote data logging. Assuring maintenance intervals for data storage and battery change, there is no immanent temporal limitation of data logging. The method assures continuous data logging of harbour porpoise activity irrespective of light or weather conditions, which is impossible in visual surveys requiring daylight and extremely calm sea states (e.g. Teilmann et al. 2003).

We only had to accept a gap of data logging from December to February to account for the risk of material loss during this period due to potential severe gales (North Sea) and additionally potential ice cover (Baltic Sea).

By means of T-PODs it is possible to monitor the harbour porpoise click activity pattern at different time scales such as seasonal presence in the area and diurnal activity rhythms. Due to the high temporal resolution up to micro seconds it is also possible to study click train pattern in a behavioural context.

The main disadvantage of T-PODs is the fact, that density estimates are not feasible. Additionally, the exact detection range is up to now not known even though some experments and calculations make it possible to give theoretical maximum detection ranges (TOUGAARD et al. 2005a). The directionality of the echolocation beam of the harbour porpoise (AU et al. 1999) makes it difficult to determine the range in which the harbour porpoise was swimming once recorded by the T-POD.

The difficult task to distinguish between real porpoise clicks and high frequency signals produced by other sources has recently been solved by the T-POD.exe software. However, VERFUß et al. (2004) give some indications that the software does not always work in a satisfactory way, especially in areas with high ship traffic. Some of the ship noises, especially boat sonar which are very similar in frequency to harbour porpoise click trains, are often categorised as possible or doubtful porpoise click trains.

In our data set of Horns Rev, we observed a similar problem when a lot of data were masked by ambient noise clutter, probably caused by moving sand. Within times of high disturbance the T-POD software found unusually many click trains with the category “?” or “??”. We recognized that this high ambient noise was in close connection with high wind speed. Due to a sandy sea bottom and because the T-POD was positioned at 1.5 m above the ground we assume that sand movements caused this clutter. Due to the fact that T-PODs often

stopped data recording due to an inclination of more than 75° in periods with high wind speed (see methods), we assume that a strong current occurred in these periods.
We decided therefore to truncate times with very high ambient noise (see chapter methods) and to use only the two highest categories of porpoise click train validation indicated by the software.
This procedure reduced the data pool considerably, especially for the Horns Rev area. For the second study year another mooring system is therefore in planning as well as a critical review of the categorised click trains by the algorithm of the T-POD.exe software.
For further investigations of click train pattern in a very high time resolution, all clicks recorded by the T-POD will be analysed. For such an analysis, a further problem linked with the current type of T-PODs has to be resolved, which is a time bias of the internal T-Pod clock . After four weeks, indicated time differed for up to 5 minutes between single T-PODs.

3.9.1.2. Test tank and field calibration

We approached the intrinsic sensitivity differences with calibration experiments in two ways: We performed absolute sensitivity threshold measurements in a test tank, and we compared the relative click sequence parameter output in situ.
So far, we used the first calibration method to determine the theoretical maximum detection range for the T-PODs. The calibration resulted in an average theoretical detection distance of 300 m which is something larger than we expected, but which can only achieved when a harbour porpoise's echolocation beam points directly towards the hydrophone. As the echolocation beam has an angle of only 16,5° (AU et al. 1999), it is evident that the detection distance will drop dramatically if the porpoise does not emit sounds into the direction of the T-POD. The mean detection distance will therefore be much shorter and we exclude that a harbour porpoise can be detected simultaneously by two T-PODs, as they were installed in distances of at least 400 m from each other.
In contrast to former versions of the T-POD (v1 to v3), the differences in sensitivity with respect to angles of incidence are negligible in recent types (VERFUß et al. 2004, TOUGAARD et al. 2005a). By this improvement in manufacturing process, a heavy problem for interpretation of logged data has fortunately been solved.
Up to the start of the project only few results of T-POD sensitivity measurements were available (VERFUß et al. 2004, TREGENZA pers. comm.). VERFUß et al. (2004) suggested a maximum detection range of 100 to 260 m of version 3 T-PODs. Referring to the manufacturer's instructions the most recent instruments of version 4 T-PODs log porpoise clicks up to a distance of 270 m when the sensitivity is set to "8" and 380 m at the highest sensitivity level of "16" respectively.

It is not possible to transfer directly data from T-PODs with different sensitivities into differences in the parameters we analysed in this study (PPD/PPH/PPM). We decided to calibrate the devices in the field to be able to generate correction factors for specific parameters. Hence the field calibrations were scheduled (porpoise positive time (minute, hour, and day) to compare T-POD data on a temporal and spatial scale.

The deployment time had to guarantee a sufficient quantity of logged harbour porpoise click sequences. It is evident that in an area with a high density of harbour porpoises the deployment time of T-POD–bundles can be kept rather short for inter calibration purposes, in order to minimise the time during which the instruments are not available for monitoring purposes. We used several field trips conducted for recording migrating birds into the study area to calibrate the instruments simultaneously in situ. In both wind farm areas Horns Rev and Nysted, the amount of recorded porpoise clicks was sufficiently high for subsequent calibration.

The disadvantages of the field calibration are of biological and technical origin. As mentioned above, porpoise clicks are emitted and focussed on targets with a beam angle of 16.5° (AU et al. 1999). In theory, the beam might hit a hydrophone and fail another one, as they are not at the exact same position. We dealt with that problem in using a bundle of T-PODs so that the difference of position is negligible. However, we are not aware of possible interference of bundled T-PODs, which might influence the data of neighbouring devices. Large data sets are a prerequisite to be able to cope with potential interference, (TREGENZA pers. com).

Single devices of a bundle did not differ significantly in click sequence statistics, but the average difference from the bundle average showed a high standard deviation. Considering the individual differences of a hydrophone of multiple calibration experiments, T-POD 452 showed the highest value (31.9%) and T-POD 451 was characterised by the lowest value (1.7%). These average values enabled us to compare the results of T-PODs in form of porpoise positive time per time unit, even if the T-PODs were not deployed in the same bundle. Determining the difference from an assumed 'ideal instrument' (bundle average) proved to be a valid approach, but the correction factors may change with every additional calibration experiment, as the difference of a single T-POD is a matter of the composition of the bundle and the average sensitivity.

The surprisingly unstable differences in PPM/6-hours of some T-PODs to the bundle average within one experiment indicated that larger data samples are needed for calibration. The data of the campaign in 2005 identified one T-POD (475) with a sensitivity close to the overall average. To avoid that the correction factor will change with every additional field calibration experiment we will use this T-POD 475 in the next field campaign as a reference device, and we will deploy it in a bundle with the other T-PODs for the longest calibration period possible. To avoid possible interference effects. the direct contact of the housings will be avoided. We will test a custom made frame assuring neighbouring deployment with precise separation of single hydrophones.

A rough comparison of field calibration and test tank calibration showed that the sensitivities of individual T-PODs were not consistent in both methods. We did not analyse the differences in more detail due to a further test tank calibration at the Meeresmuseum Stralsund, Germany in February 2006. In a future step we plan to compare the different approaches of T-POD calibration in co-operation with our Danish and German partners.

Explanatory power of different parameter of echolocation activity

All investigated parameters refer to time units of harbour porpoise echolocation and describe therefore the presence of harbour porpoises within the detection radius of the T-PODs. Hence the utilisation of the study areas by porpoises was measured by means of the click sequence statistics: porpoise positive hour, porpoise positive minute and waiting time. The units of porpoise positive time (PPD, PPH or PPM) describe the presence of porpoises within a very small area (up to 0.6 km²) not only at different time scales, but they have through comparisons among each other also different explanatory power as well:

Relatively higher values of PPM compared to PPH reflect a more intense use with a low turnover rate of porpoises at a spot. In a low or medium density area, long waiting times may express continual coming and going of perhaps different animals and give a weak hint of transitional harbour porpoises in the area.

3.9.2. Discussion of results

3.9.2.1. Nysted

Harbour porpoises were recorded nearly every day (97 % of all recording days). This characterised Nysted as an area where harbour porpoises are almost continuously present.

On average the animals were detected by the T-PODs daily during six hours but only for less than four minutes per hour.

The seasonal pattern of PPM/day as well as mean waiting time/day confirmed a highly difference between single days. Days with high PPM/days (low waiting time/day, respectively) were mostly followed by days with low activity. Maximum number of days in connection with higher ratio of PPM was found for only 5 days between July 5th and 10th in row west1. Given that this parameter is correlated with porpoise density it can be concluded that the area is regularly visited by the animals but that number of animals is low and/or time of stay within the area is rather short.

During summer and autumn no pronounced seasonal effect is detectable apart from late autumn when the porpoise echolocation activity drops down.

In the Baltic Sea, VERFUß et al. (2004) report that harbour porpoises frequented their westernmost T-POD positions around the island Fehmarn, Germany, nearly daily in autumn. The ratio of porpoise positive days decreases subsequently in the direction towards the inner Baltic Sea (Kadetrinne 70%, Rügen and Arkona 30% PPD). Based on T-POD investigations, MEDING (2005) describes a pronounced seasonal pattern northwest of Fehmarn, which is in a distance of approximately 20 km from the Nysted wind farm area. The pattern shows increasing PPH/month from a minimum in summer (July) to a maximum in December. A minimum is shown during January and February. This pattern is not exactly replicated by our results. In fact, maximum daily values were reached in the beginning of September and average half month values peaked in October. But from October until December the pronounced decrease in echolocation activity parameters occurred two month earlier.

VERFUß et al. (2004) and MEDING (2005) explain the seasonal pattern north of Fehmarn with movements of harbour porpoises into the Baltic. Historical data confirm this harbour porpoise movement from the western (Belt Sea) to the eastern Baltic following the herring swarms (KOSCHINSKI 2002).
Following this discussion the Nysted wind farm area could belong to a transit area, a view which is also supported by our T-POD data which show a lot of short inconsistent porpoise contacts.
Satellite telemetry studies of porpoises show a high variability in distances the animals swim per day and only few recordings could be made in the vicinity to our investigation area (TEILMANN et al. 2004). This observation suggests that the area is intensively used by porpoises.

First analysis of the results indicates that in Nysted in three out of four rows the echolocation activity was significantly higher at the two T-POD positions outside the wind farm. This pattern has to be replicated in 2006 for reasonable conclusions, but it may give so far first hints of an impact of wind turbines on the spatial distribution pattern of harbour porpoises.

The investigation of diurnal rhythms in echolocation activity shows a significant pattern which, however, was not consistent at all positions.
In the night hours of the 24-hour cycle more PPM were recorded than in daytime hours. Harbour porpoises almost constantly echolocate and do not rely on the sense of echolocation with respect to visibility conditions. An additional small peak at midday underlines the fact, that echolocation does not substitute the optical orientation at night.
Pooling the data of day light phases, a more pronounced picture is recognisable: In all cases when significant differences in activity occurred between different day light phases, the higher activity was always recorded during the night.

Diurnal rhythm in cetaceans has been proved to be highly different and dynamic. For example, the taxon Tursiops is more active at daytime (Mc CORMICK 1969), whereas Hawaiian Spinner Dolphins are inactive in daytime hours and increase prey capture activities at night (NORRIS & DOHL 1980). CARLSTRÖM (2003) showed with the help of T-PODs a higher echolocation activity of harbour porpoises at night in Scottish waters. MEDING (2005) confirmed this diurnal rhythm for harbour porpoises in the Baltic Sea.
The biological reason behind a diurnal rhythm may be caused by behaviour of prey species. Harbour porpoises prey upon the predominating fish species of suitable size in the area. As both bottom fish (flatfish) and pelagic species (e. g. herring) exhibit considerable diurnal rhythms in activity and, in consequence, in their availability as prey for harbour porpoises, the timing of foraging is expected to be highly dynamic in porpoises. Especially the vertical distribution of fish within the water column is known to differ with respect to the hour of the day (for herring: BLAXTER & PARRISH 1965). At moment, we have not referred to details of echolocation sequences indicating certain of behavioural traits. In the final report, we expect to be able to discuss the biological causes and implications of the revealed diurnal rhythms.

3.9.2.2. Horns Rev

We deleted approximately 50% of totally logged data because data were not available due to considerable ambient noise clutter. As the intensity of ambient noise clutter was primarily a function of wind or current speed, we have to keep in mind that we predominantly show results from calm to moderate weather conditions.
Furthermore, the frequent off-effort times caused by current-induced inclination angle of the PODs resulted in very scattered recording times. This was true in particular in the second part of the investigation period, causing difficulties in data analysis. We were thus not able to analyse the data from Horns Rev in the same detail as those from the Nysted area.

Similar to the Nysted area harbour porpoises were almost continuously present throughout the Horns Rev study area (98 % of all days recorded). On average the animals were detected by the T-PODs daily during 18 hours for about 6 minutes per hour. This indicates that the Horns Rev area is part of a larger high density area with porpoises present within 75 % of the hours of a day. The seasonal pattern of PPM per day showed regularly changes of porpoise recordings from day to day although at some positions the number of PPM per day was well above 8 % for a period of up to 7 or even 14 consecutive days (row west, position 1 and position 4, row east1, position 2). These findings indicate that the Horns Rev area plays an important role for the use by harbour porpoises.
We did not find a pronounced seasonal pattern, but fewest number of PPM were recorded in late autumn. A declining porpoise echolocation recordings during winter corresponds to other results of T-POD studies conducted in the Horns Rev wind farm area (SKOV et al. 2002, TOUGAARD et al. 2003, 2004, 2005).
DIEDERICHS et al. (2004), GRÜNKORN et al. (2004) and SCHEIDAT et al. (2004) carried out studies on the distribution of harbour porpoises in the west of the island of Sylt, Germany, and they revealed a pronounced seasonal pattern with high densities recorded during aerial surveys, associated with high numbers of click recordings during early summer, and few sightings associated with a low number of acoustic recordings during winter.
The bias due to the exclusion of data blurred by noise clutter may mask the existence of a potential seasonal pattern. We will therefore wait for the data from 2006 before drawing some conclusions about the year round utilisation. The strong difference in average PPM/day between two rows during the same time period is conspicuous compared to the difference within the positions of one row. This shows a high spatial variance in use of a specific area.
Comparisons of echolocation activity measured as PPM/day within a row of T-PODs give first indications that in some areas of the Horns Rev wind farm, the presence of harbour porpoises may be significantly higher within the farm than outside. As this pattern was not consistent over all rows (only two out of four), we refer to the data of the next campaign before drawing further conclusions.

3.9.2.3. Comparisons of results in the two wind farm areas

The Horns Rev area showed a markedly higher frequency of harbour porpoise occurrence compared to Nysted (factor 2.3 referring to PPH and factor 4.0 referring to PPM). This is in accordance with the differences in abundance derived from aerial surveys in these areas

(SCHEIDAT et al. 2004). In 2002 and 2003, they calculated for 'block C' (adjacent German waters near to Horns Rev) 1.53 and 1.85 animals per km^2 and for 'block F' (including Nysted) 0.13 and 0.06 animals per km^2.

The seasonal distribution pattern of encounter rate and waiting time showed in both wind farms the same - but counter current – pattern as in late autumn the encounter rate decreased whereas the waiting time increased simultaneously. This seasonal distribution pattern is also in accordance with results from aerial surveys (BIOCONSULT SH & GfN 2002, SCHEIDAT et al 2004).

Summarising, we found remarkable differences in harbour porpoise click patterns between the two wind farms. At the Nysted area, we have first indications for a higher echolocation activity outside the wind farm, whereas in Horns Rev, a higher activity was recorded inside the wind farm area – which was in the latter case significant at least in two POD rows. Hopefully, data obtained in the second study year will clarify which of the findings can be generalised.

4. Bird study - Collision risk of flying birds

4.1. Methods

4.1.1. Operation platforms / investigation sites

Data on migrating and other moving birds were obtained by operating from an anchored vessel as working platform using vertical and horizontal radar in combination with visual and acoustic observations.

In Horns Rev wind farm area MV Søløven/Copenhagen, a former buoy-laying vessel of 46 m length was the survey vessel.

In Nysted wind farm area it was MV 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 about 300 m away from the edge of the wind farm. As sea cables run between the single windmills, anchoring closer to the wind farm was not possible. The anchored vessel could be moved by 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. 4.1 - Fig. 4.4.

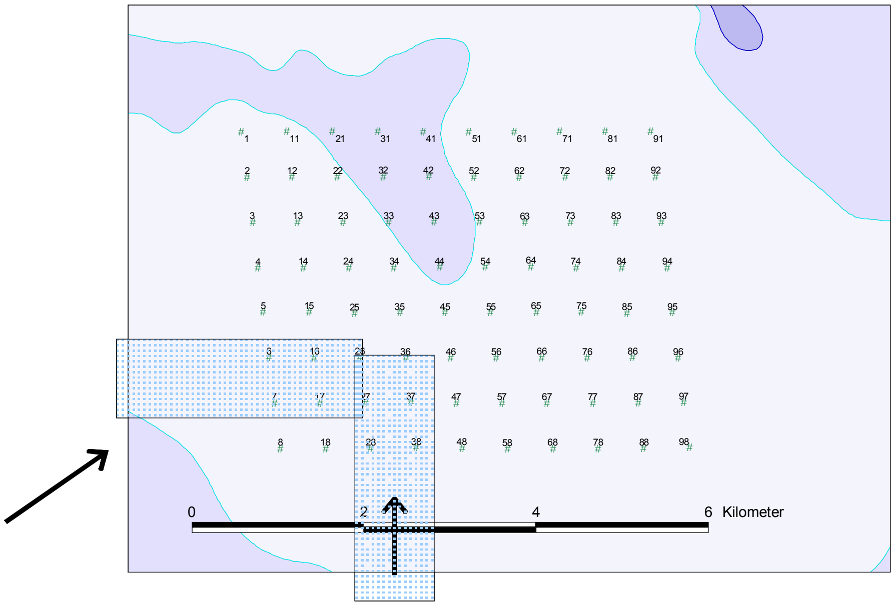


Fig. 4.1: Horns Rev spring - area covered by vertical radar and visual observations (rectangles) and expected direction of migration (arrows)

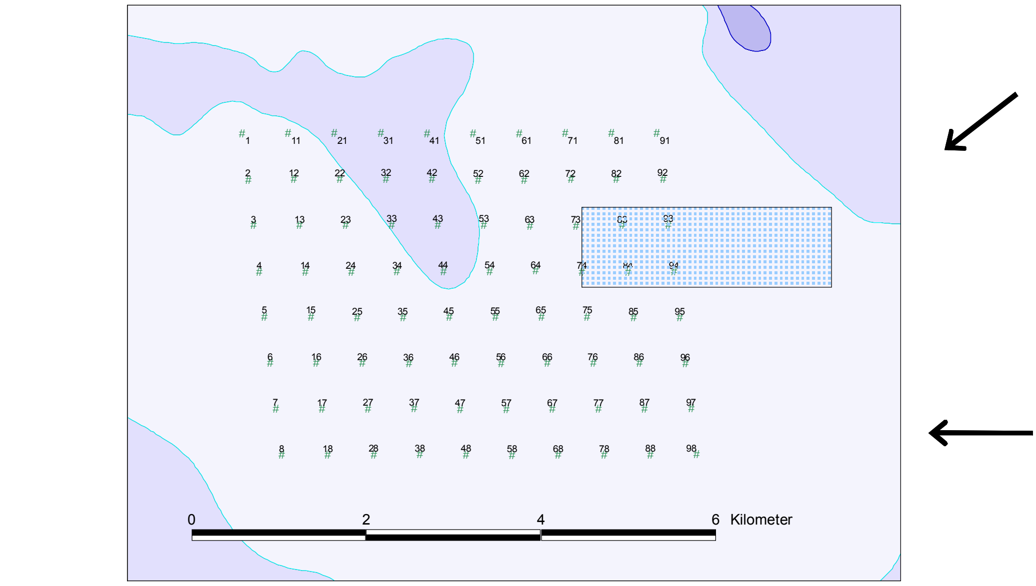


Fig. 4.2: Horns Rev autumn - area covered by vertical radar and visual observations (rectangles) and expected direction of migration (arrows)

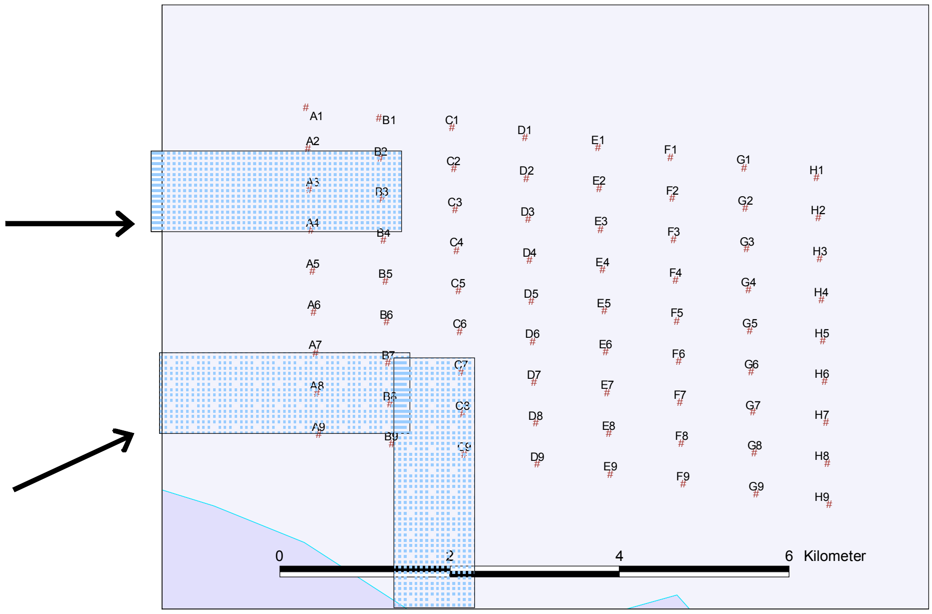


Fig. 4.3: Nysted spring - area covered by vertical radar and visual observations (rectangles) and expected direction of migration (arrows)

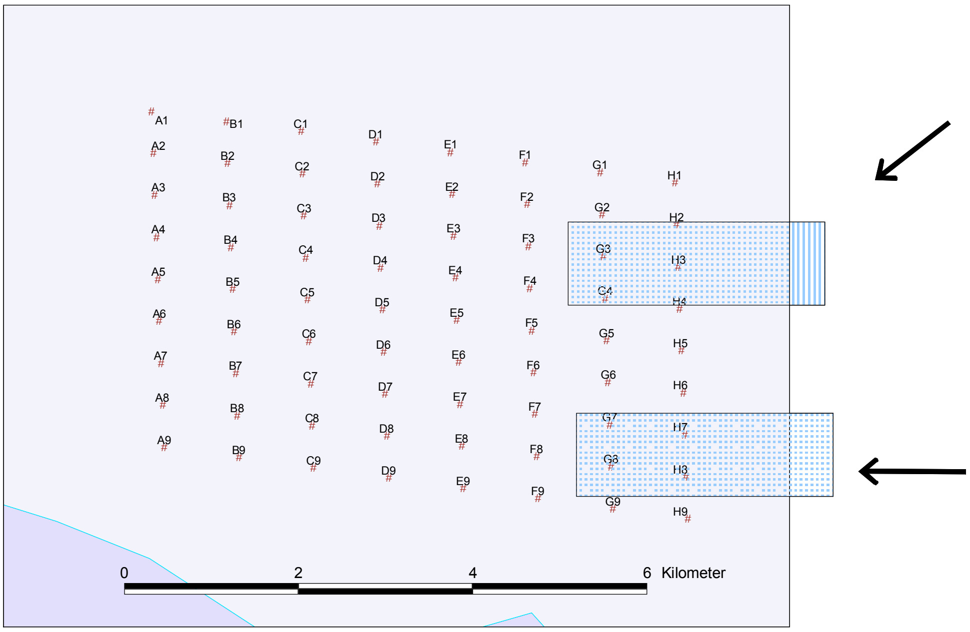


Fig. 4.4: Nysted autumn - area covered by vertical radar and visual observations (rectangles) and expected direction of migration (arrows)

4.1.2. Effort

To conduct studies, especially radar studies, from a ship, weather conditions have to be favourable; a sea state higher than 4 (waves > 1.5 – 2 m) will produce considerable disturbance on the radar screen and will largely influence analyses of lower altitudes. Rain will clutter radar screens. Good conditions are more frequent in the Baltic Sea than in the North Sea.

In 2005, 25 trips with 83 effort days were carried out. The two study periods aimed to focus on migrating birds and hence to cover the main migration periods; thus investigations were carried out between March 30th and May 24th and between September 5th and November 19th. Details of trips and effort are listed in Tab. 4.1.

Tab. 4.1: Effort / ship days in the two windfarm areas in spring and autumn 2005

Horns Rev		**Nysted**	
Spring		**Spring**	
observation period	**effort days**	**observation period**	**effort 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		**Autumn**	
observation period	**effort days**	**observation period**	**effort 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

4.1.3. 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 M/V Søløven both radars were mounted on one common mast, the one on top being the horizontal radar and the other one on half-mast position being the vertical radar. On MV 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.

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 M/V Christoffer could be run in vertical mode, too. For technical specifications of the radar devices see Tab. 4.1.

Tab. 4.1: Specifications of radar devices

brand	Decca Litton Marine Systems	Raytheon
type	BridgeMaster E-series	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

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

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 1500 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 1500 m). Further settings during vertical operation see Tab. 4.2.

The horizontal radar, aimed to show flight directions of birds was projected in North-up mode in order to show true flight directions. The range was set to 1,5 nautical miles (~2780 m). A prerequisite for the use of horizontal radar is a calm sea state (wind speeds less than 2 m/s). Otherwise the signals will be concealed by sea clutter, caused by the reflection of the radar waves by a rough water surface. A filter to suppress the sea clutter was used to a certain extent if necessary. Otherwise the settings were identical with those of the vertical radar.

Tab. 4.2: Settings of radar devices

parameter	Decca BridgeMaster E-series		Raytheon Pathfinder	
range	~500 m	~1500 m	~930 m	~2780 m
pulse length/prf	„Short“ (0,05 µs) / 1800 Hz		0,09 µs / 3000 Hz	0,35 µs / 2000 Hz
target trails	„Long“ (30 s)	„Long“ (45 s)		

Radar images of the vertical radar were captured from the screen signal via video splitter by a framegrabber card on a mobile PC using a custom-made software by HaSoTec GmbH, Rostock. One screenshot was stored every 150 seconds.
To analyse the data obtained by vertical radar the HaSoTec-software was used, too. 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. The program then calculated the altitude, the direct distance from radar and the lateral distance from 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. All data were stored into a text file; from there data were transferred to databases and tables fur further analyses.

Screenshots

A screenshot was considered a snapshot of the current situation; tracks visible on the screen (light blue) but without an actual signal (yellow) were not considered for analyses.
The number of signals per screenshot is the main unit to describe bird densities. It has been calculated for certain time periods of interest. When presenting data obtained with different radar ranges, each range was considered separately. The corresponding results cannot be compared directly because the radar sensitivity differs for different ranges.

Signals traced

In addition to producing screenshots as digital data stored directly, radar signals were captured using transparencies fixed on the radar screen. Each newly appearing signal was copied with a permanent marker to the transparency and its way was followed as long as it was visible on the screen; periods of 150 s were covered.
This method allows to analyses 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.

Also, this method proved to be the most sensitive method to identify radar detected bird signals, because moving signals were much easier and securely to identify as birds than signals on a screenshot which sometimes may be hard to distinguish from disturbances and artefacts.

Corrections of raw data

Correction factor area:

To analyse altitude distributions, a correction of the actual results was necessary. Since the radar screen was a full circle, of which only the upper half circle applied when the radar was used in vertical position. However, altitude classes should represent rectangular squares of equal area. Naturally, the representation of altitude classes captured by the circular radar screen decreased with increasing altitude. The sum of signals from each altitude class was corrected for this bias. Proportional signal distributions per altitude class are presented for data gathered during the whole observation period.

Correction for distance-dependent detection probability:

A further correction may be applied to data whose distribution is influenced by different detection probabilities depending on the distance from the observer or the recording device; this applies e.g. for data collected during transect counts as well as for radar data. A function describing detection probability in dependence of distance following BUCKLAND et al. (2001), can be used to correct the data distribution. This correction has been applied to radar data in several studies (e.g. STAHL & NEHLS 2004, HÜPPOP et al. 2004). So far, a distance-dependent correction factor has not yet been applied to the data presented here because it is still unknown to which degree considerable disturbing echoes produced by windmills allow to conduct these calculations.

Correction factor for disturbance / noise:

Tall and vertical structures as well as sea clutter produce “noise” on the radar screen.
Direct noise: On the areas covered by this noise no signals can be detected.
Indirect noise: It is assumed that the direct noise will have a shadow additionally hiding signals.
To correct for this noise, the area covered directly by the noise and the area potentially covered by the noise shadow should be subtracted from the area considered for analysis. Since areas covered by noise are different for each picture, this would require a time-intensive measuring of the “disturbed” area, still leaving the question of the noise shadow unanswered.
In this study, windmills did cause noise and in general, the windfarm side was more disturbed than the opposed side; however, exceptions apply e.g. in cases when signals appeared as half circles or “mirrored” windmills on the non-windfarm side (Figures Fig. 4.1 and Fig. 4.2).

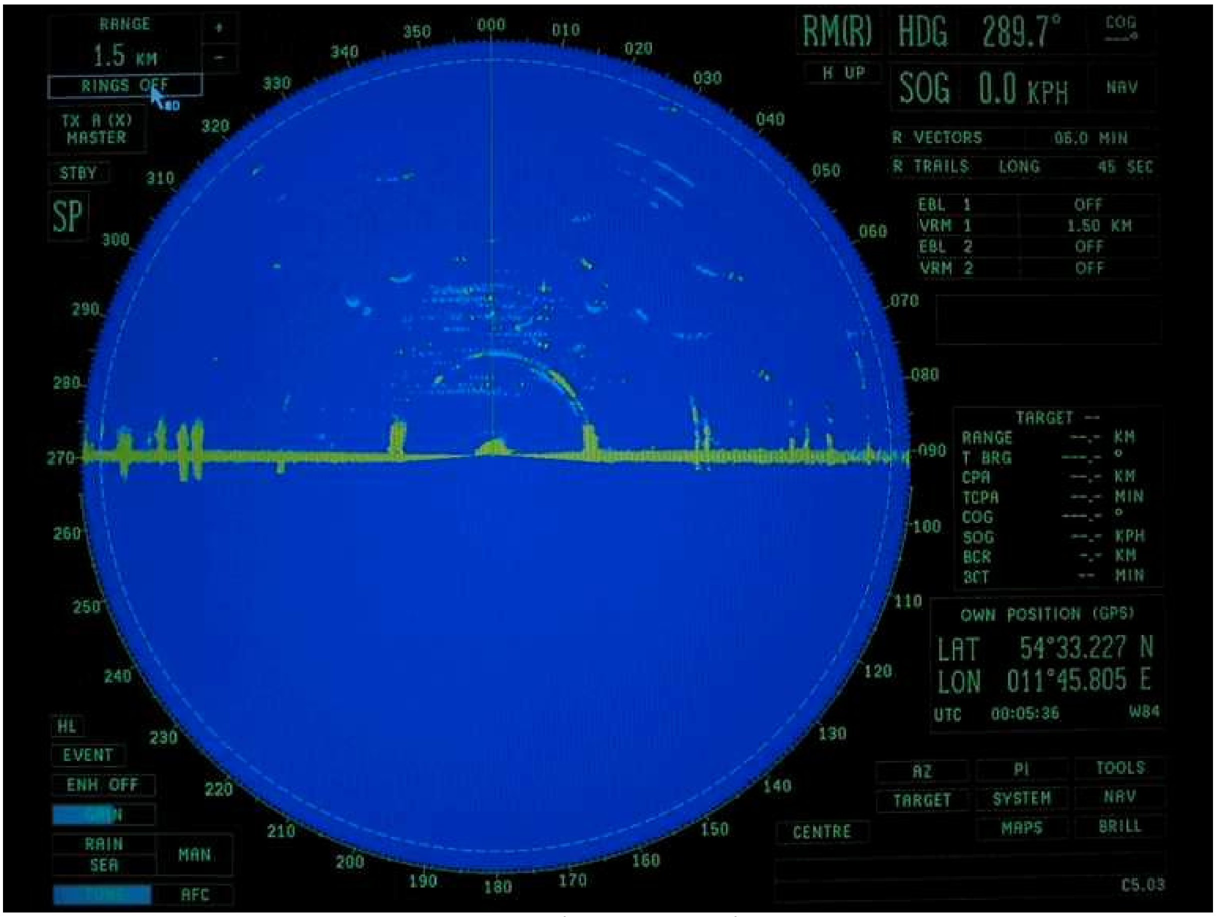


Fig. 4.1: Nysted – exemplary radar screenshot (digital camera) 1.5 km - showing little noise due to sea clutter near the sea surface, disturbances due to windmills on the left side, disturbances by mirrored windmills on the right side, a weak yellow disturbance carried over from left to right from the windmill nearest to the ship.

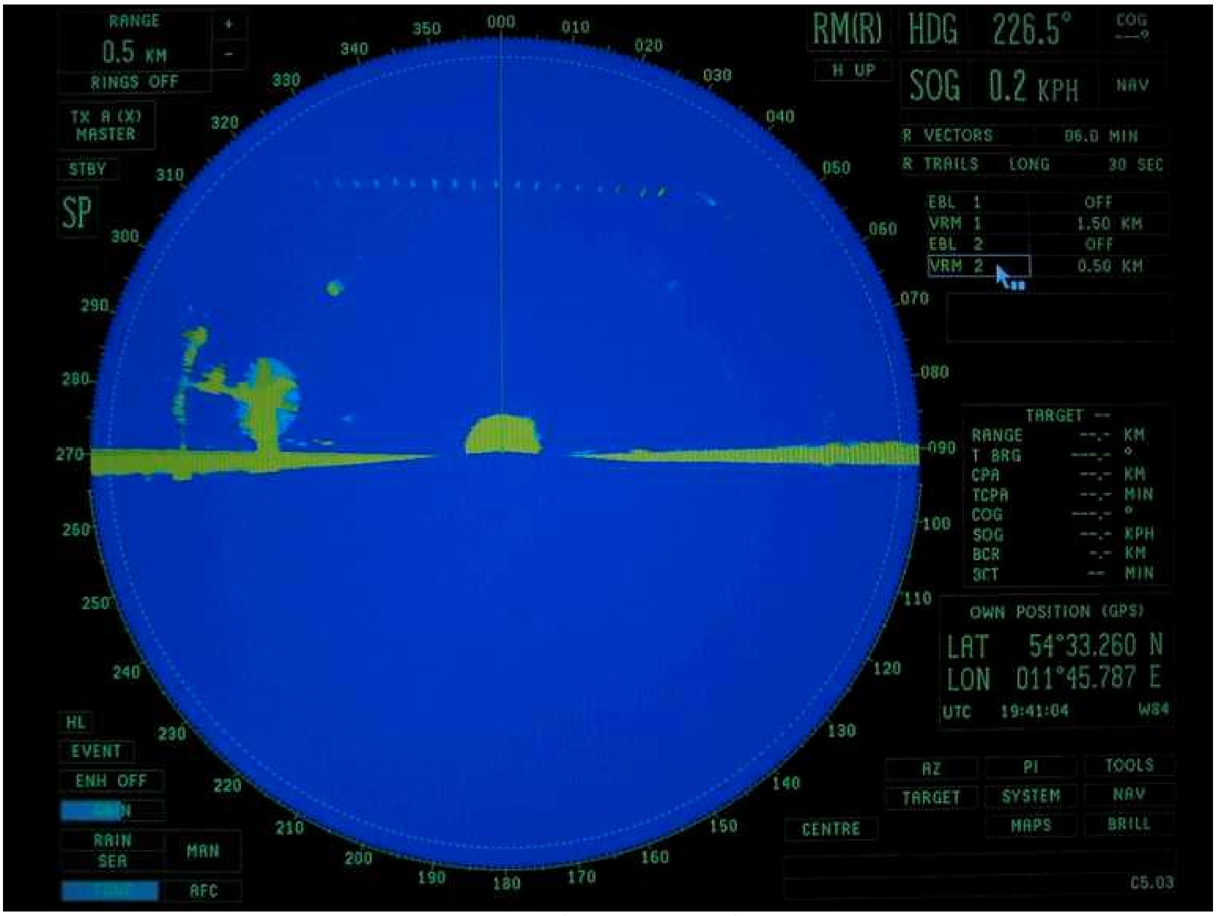
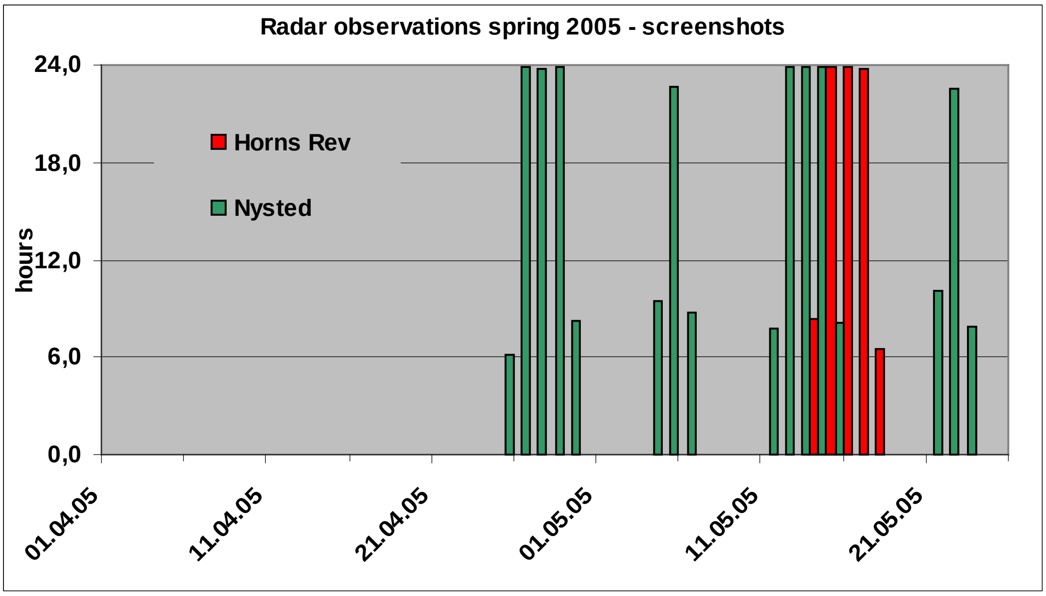


Fig. 4.2: Nysted – exemplary radar screenshot (digital camera) 0.5 km - showing little noise due to sea clutter near the sea surface, disturbances due to windmills on the left side plus a so-called “streak” produced by the windmill, a weak yellow disturbance carried over from left to right as well as a point shaped disturbance on the left side probably also produced by a windmill.

All radar recordings (screenshot, tracing of signals) were analysed separately for the wind farm side (wf) and the opposite side (non wind farm – non-wf). Although the position of the ship was always in a distance of 180 - > 300 m outside the wind farm, data on the side of the wind farm are per definition “inside”.

Tab. 4.1: Hours of radar observations and number of screenshots

Horns Rev – North Sea			
Season	time of day	hours of radar observation	number of screenshots / signals
Spring 2005	day	61	2.472 / 359
	night	25	953 / 164
Autumn 2005	day	261	5.662 / 9.431
	night	292	6.756 / 25.784
Nysted – Baltic Sea			
Season	time of day	hours of radar observation	number of screenshots / signals
Spring 2005	day	177	6.237 / 2.539
	night	78	3.001 / 8.858
Autumn 2005	day	246	5.622 / 10.416
	night	284	6.697 / 24.258



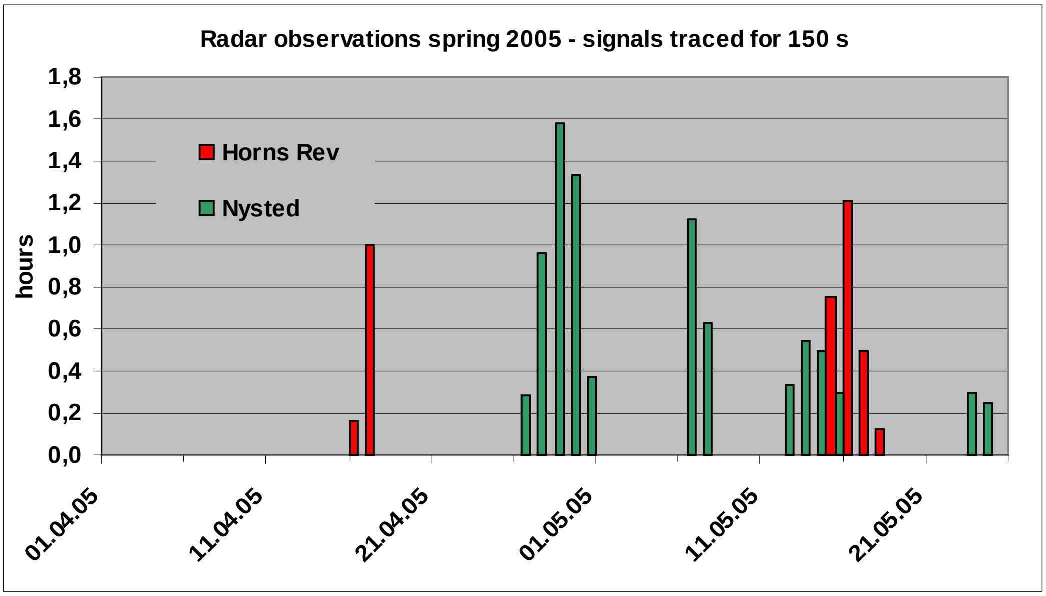


Fig. 4.3: Radar observations in spring – only periods are shown from which data have been recorded and transferred to databases.

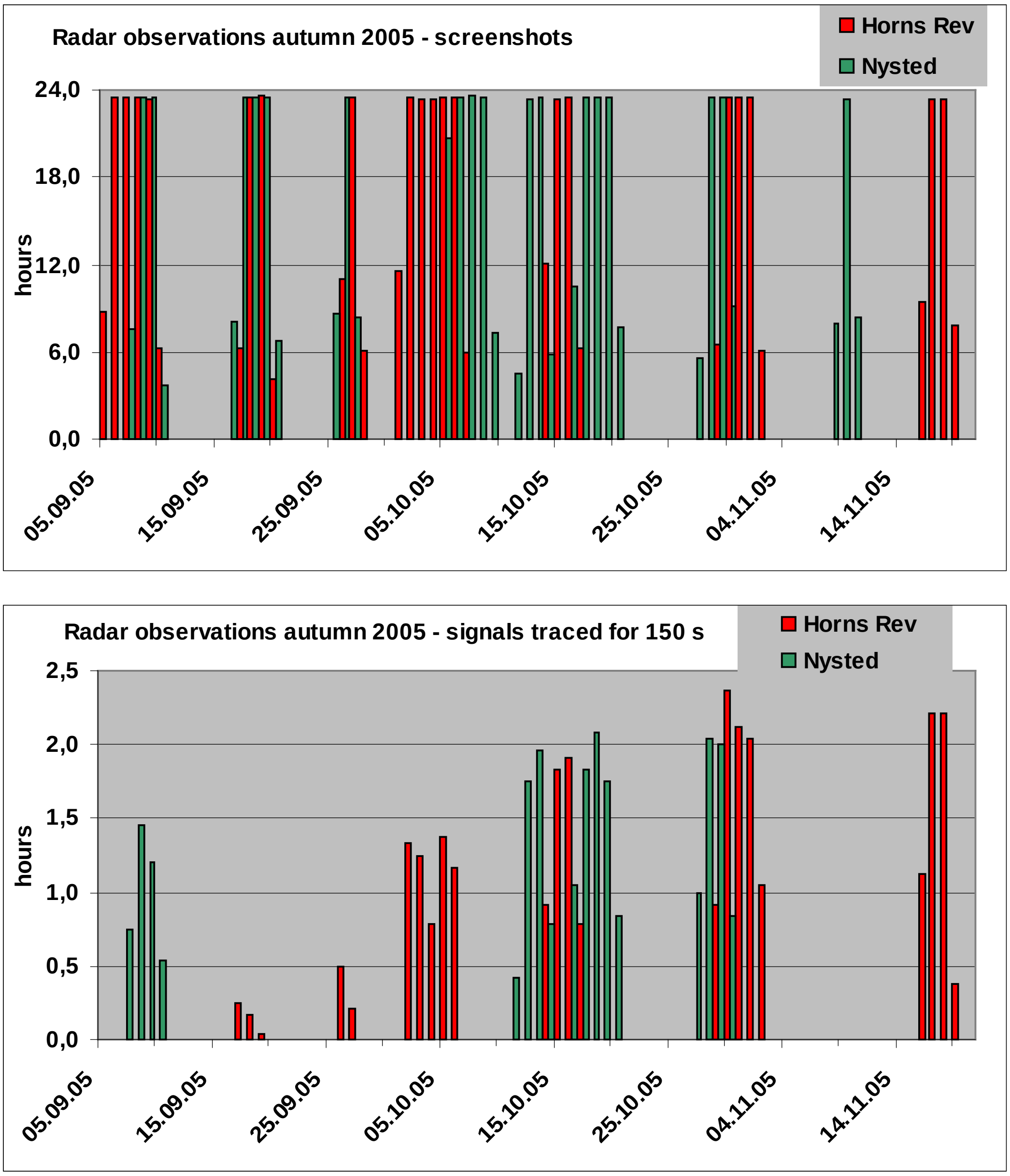


Fig. 4.4: Radar observations in autumn

In spring, the project had a late start for administrational reasons. Thus, the month of March was not covered at all. During the first trips in April, installing and testing the equipment as well as the hardware and software caused several delays and resulted partly in different methods applied and different data formats yielded. While for the Nysted wind farm data have been obtained in the desired form from middle April onwards, trips on the North Sea were additionally hampered by inclement weather, further reducing the data yielded during this season.

In fall, 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. 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.

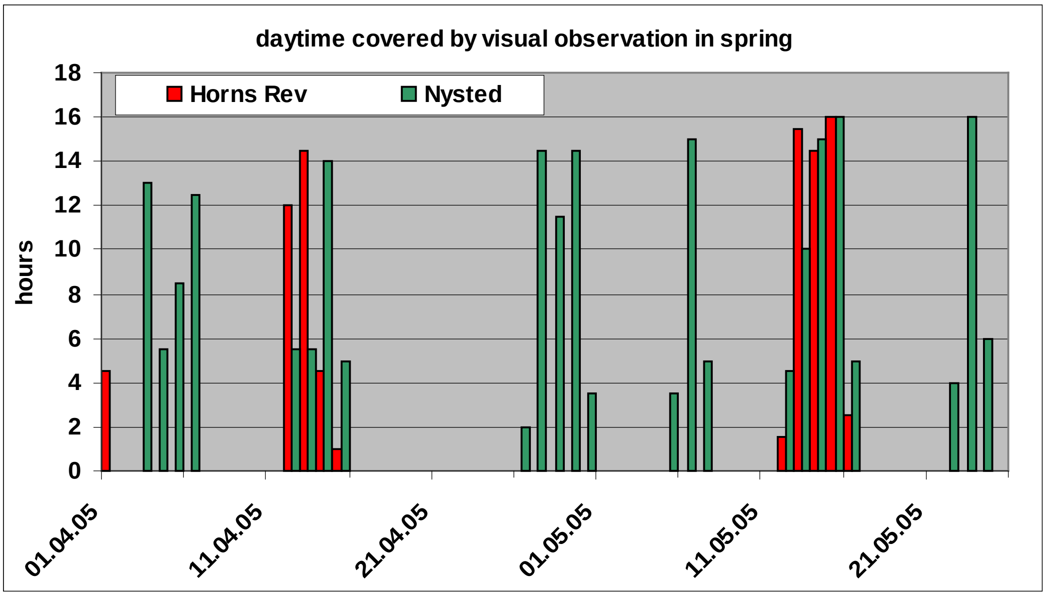
4.1.4. Visual observations

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 MV Søløven this location was the stern deck with ca. 3 m height. On MV 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 inaccessible during effort because of the microwave radiation caused by the radars.

Visual observations were carried out along a transect line; one side of the transect led from the vessel into the wind farm, the other side led from the ship into the opposite direction. The transect line was supposed 1.) to meet the wind farm area more or less perpendicularly and 2.) to be more or less identical with the radar beam direction of the vertical radar (see Fig. 4.1 and Fig. 4.2).

Both sides of the transect line (related to the vessel), the one heading into the wind farm and the opposite one, were recorded separately on different forms (wind farm side and non-wind farm side).
Visual observations of flying birds (including migration as well as movements from/to/between feeding and/or resting sites) were carried out on effort days from before sunrise until after sunset including the twilight periods of some 20-30 min before sunrise and after sunset, as long as light conditions allowed. Birds were counted during intervals of 15 minutes each (one per every half hour), with a minimum of 5 minutes between the intervals.
In every counting unit two experienced observers (one on either side) registered all flying birds and noted the species (whenever identification was possible), distance from the observer, flight direction and flight altitude.
Distance: Three distance bands were used (0 to 300 m, 300 to1000 m and >1000 m).
Flight direction: Compass directions in 1/8 were used (NW, N, NE ...) plus „no obvious or changing direction“.
Flight altitude: Flight altitudes were pooled in four classes: 0 -5 m; 5 -30 m; 30 -110 m; >110 m. The class of 30 -110 m was chosen referring to the approximate range covered by the windmill blades.
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). Special attention was paid to spatial reactions to the windmills.
Optics used by the observers were binoculars with 10x magnification.

In Horns Rev, we observed for 86.5 hours in spring and for 241.5 hours in autumn. In Nysted we observed for 215.5 hours in spring and for 236.5 hours in autumn. During some ship days, visual observations did not take place because of PODs had to be handled.



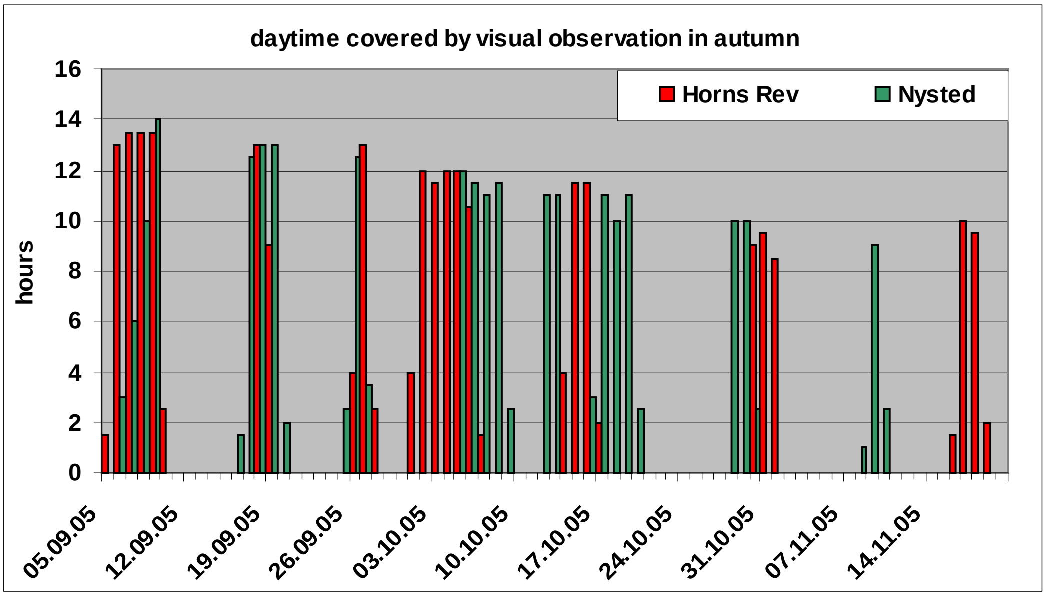


Fig. 4.1: Daytime covered by visual observations in Horns Rev and Nysted in spring and autumn 2005

Data were analysed with respect to species compositions, species groups, altitude classes and reactions assumed to be caused by the wind farms. Focus was on the comparison of birds observed inside the wind farm to those outside.

4.1.5. Acoustic observations

During darkness (from civil twilight in the evening until civil twilight in the morning) acoustic observations were carried out by experienced observers. One observer registered every bird call (except gulls) 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 were carried out during all nights on effort. In Horns Rev 67 hours acoustic observations were carried out in spring and 297.5 in autumn. In Nysted 147.5 hours acoustic observations were carried out in spring and 302 in autumn.

Acoustic observations yield species composition; naturally, only those species which 1.) call during migration and 2.) migrate during night and 3.) are close enough (distance, altitude) to be heard can be registered. The number of birds cannot be identified; however, the number of calls may give some impression of migration intensity.

4.2. Results

4.2.1. Radar observations

4.2.1.1. Migration intensity

Migration intensity was described by the number of signals per screenshot, differentiated for selected time intervals. For an impression of the phenology of migration in the selected locations, migration intensity was presented per day and night over the observation periods (Tab. 4.1; Fig. 4.1 - Fig. 4.2).
Migration intensity at night was in general higher than during daytime in both wind farms. In general, the number of signals per screenshot was higher when the radar was set to a larger range; however, exceptions applied and might have been caused by the different detection probability of the radar at different ranges. Migration intensity did vary over the season. Since birds preferred certain conditions to migrate, periods with low and periods with high migration intensity alternated in dependence of weather conditions.
Characteristics of periods with high migration intensity are in general:
tail winds, good visibility, temperature induced migration (in front of cold fronts in autumn, following warm fronts in spring), no heavy rain.
Characteristics of periods with a low migration intensity are:
head winds, bad visibility, inclement weather.

These patterns of migration become more intense in situations when birds "wait" for good conditions, that is e.g. when an extended period of bad conditions changes into good conditions; then pronounced migration peaks can occur changing back to a lower level when conditions stay the same. It is known, that during a migration period of appr. 90-100 days a large proportion of this migration may happen in a few nights (e.g. ALERSTAM 1992, BERTHOLD 2000).

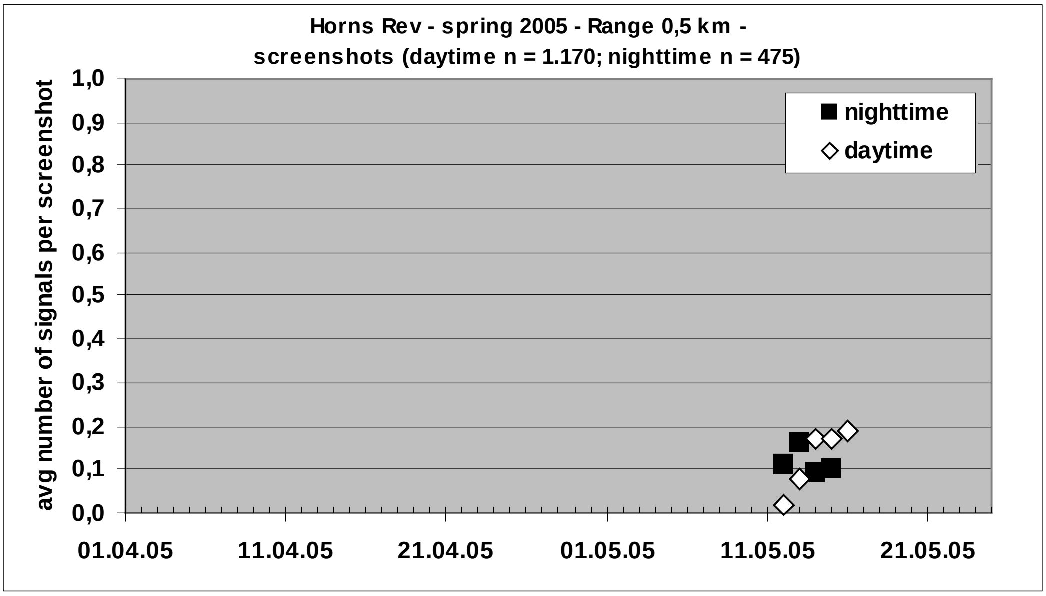
Tab. 4.1: Migration intensity during day or night per season and range

Horns Rev – North Sea		**average number of signals per screenshot**	
Season	time of day	range 0.5 km	range 1.5 km
*Spring 2005**	*day*	*0,10*	*0.13*
	night	*0.12*	*0.20*
Autumn 2005	day	1.77	1.93
	night	3.01	3.80
Nysted – Baltic Sea		**average number of signals per screenshot**	
Season	time of day	range 0.5 km	range 1.5 km
Spring 2005	day	0.57	0.36
	night	1.54	3.44
Autumn 2005	day	1.37	2.34
	night	2.62	4.71

*Available data for Horns Rev in spring are only from three days in May 2005. However, more data from spring 2005 will become available due to the use of additional analysis tools.

Horns Rev

In spring, radar data from only one trip could be analysed. During this trip, bird migration was very low (< 1 signal per screenshot) compared to other intervals. Thus, radar data screen shots were surely not representative for migration intensity during the spring season.



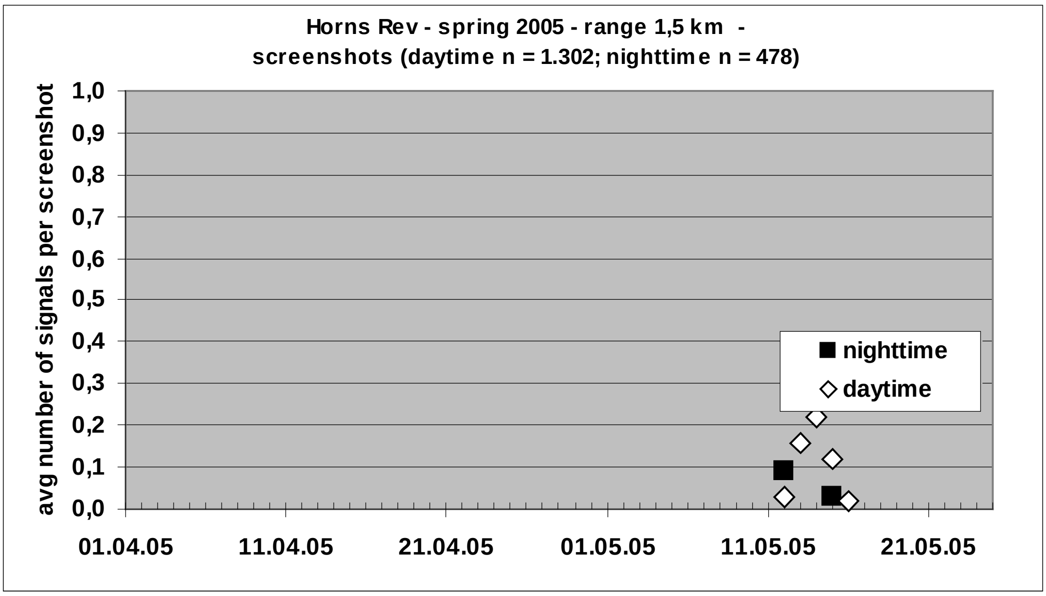
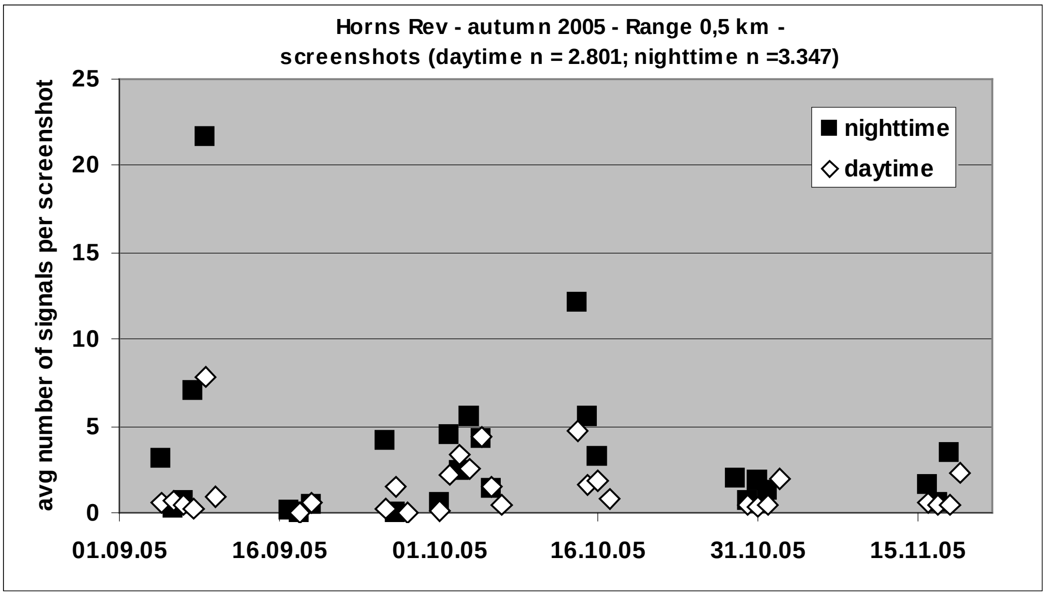


Fig. 4.1: Horns Rev - migration intensity in spring for ranges 0.5 km and 1.5 km

In autumn, migration intensity was modest to intensive during the entire period; most intensive migration occurred on September 9th, around October 4th and around October 14th.



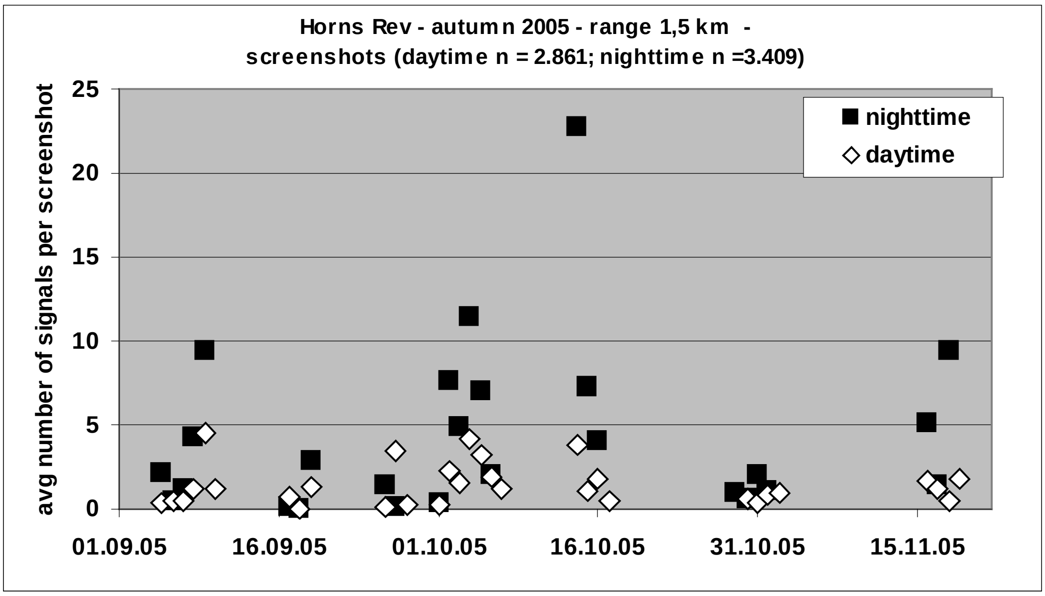
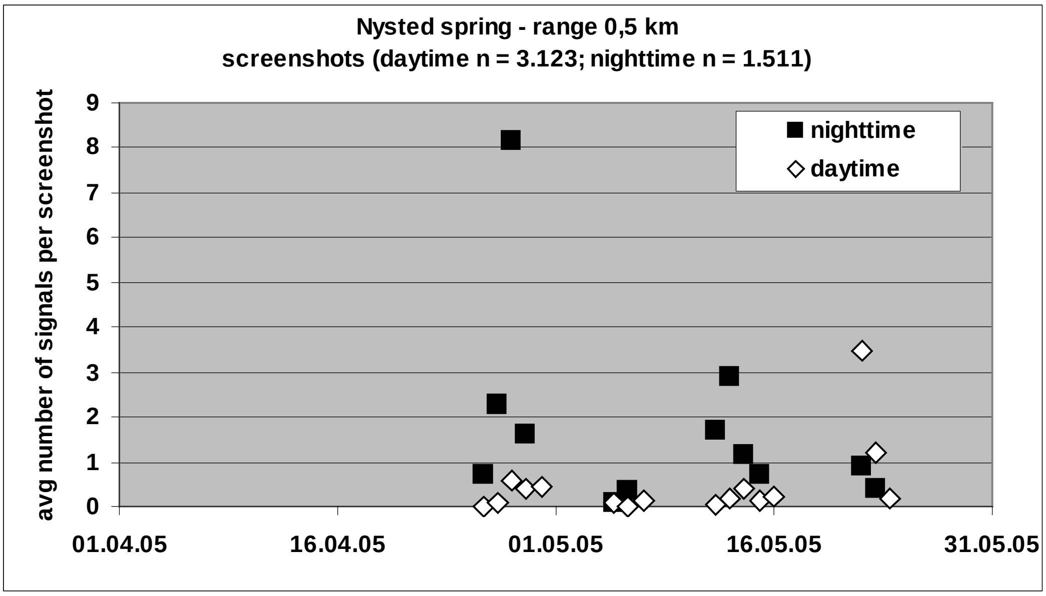


Fig. 4.2: Horns Rev - migration intensity in autumn for ranges 0.5 km and 1.5 km

Nysted

Migration during spring was moderate; intensive nighttime migration occurred on April 28th and May 12th/13th .



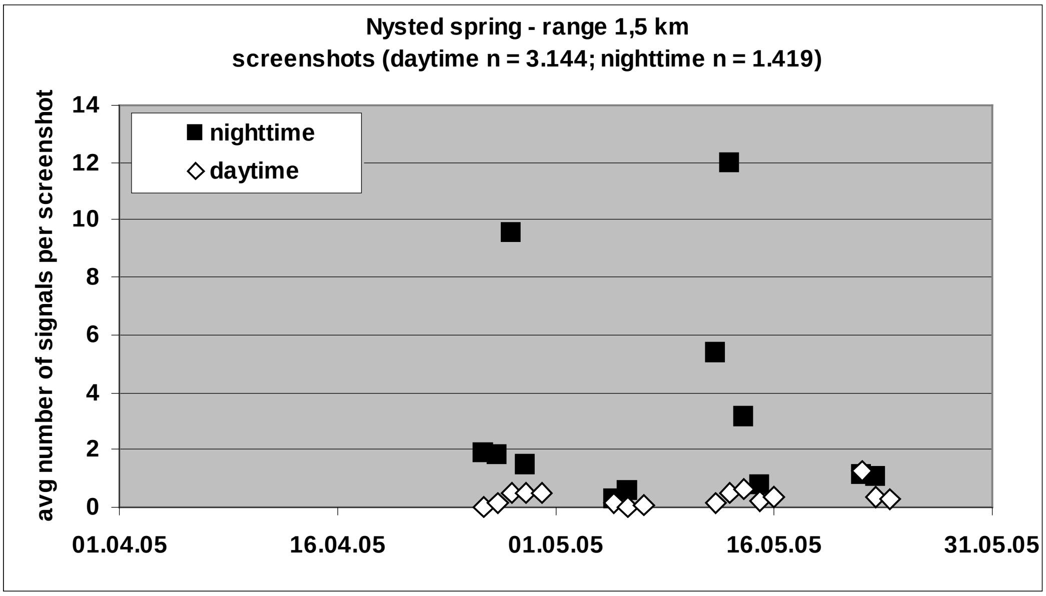
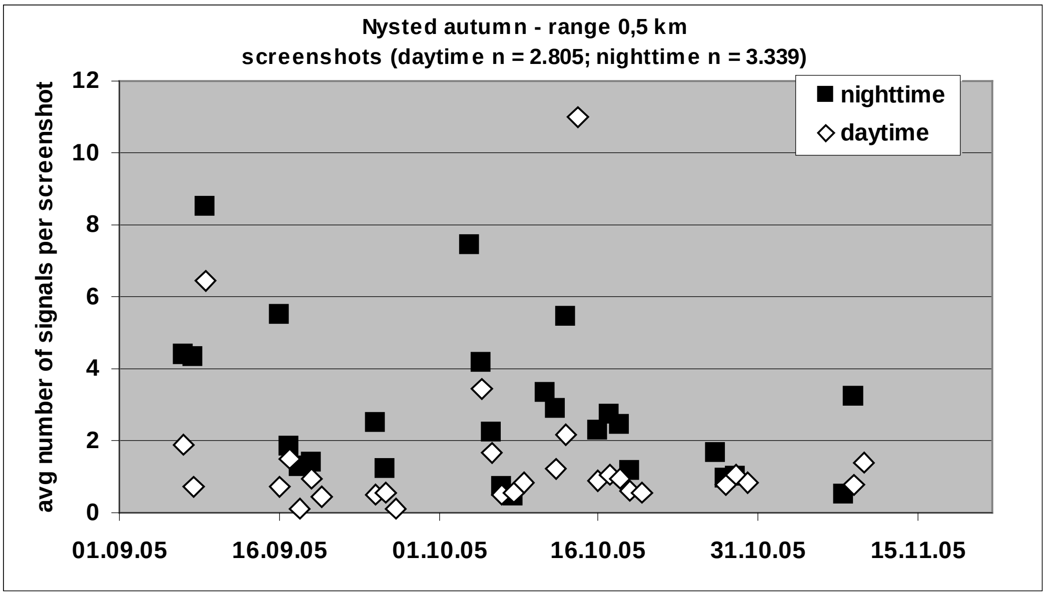


Fig. 4.1: Nysted - migration intensity in spring for ranges 0.5 km and 1.5 km

Migration during autumn was generally higher than during spring. Intensive migration was recorded on September 9th and 16th as well as on October 13th/14th and the days following.



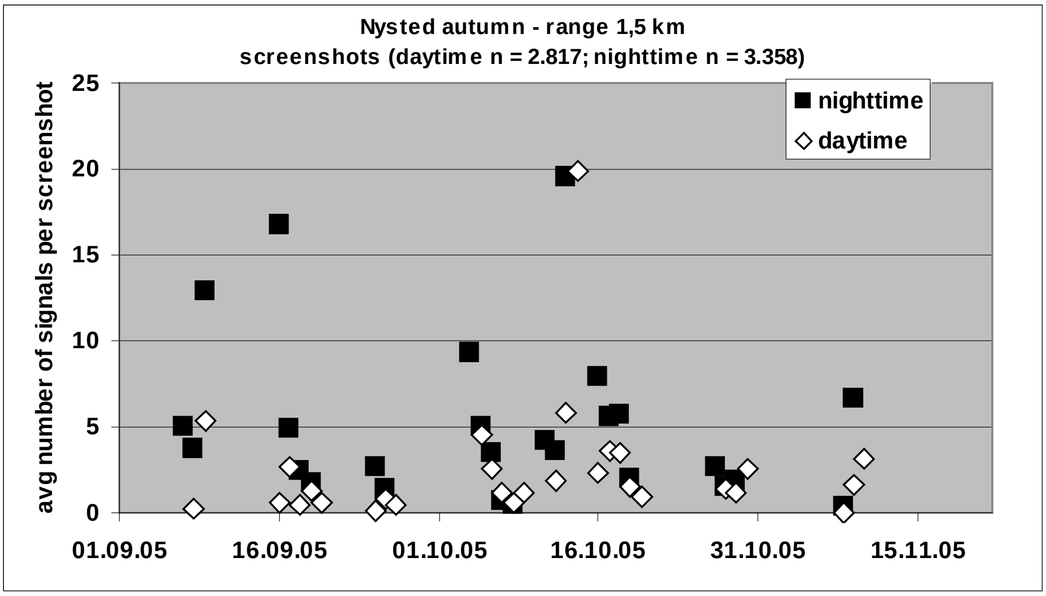
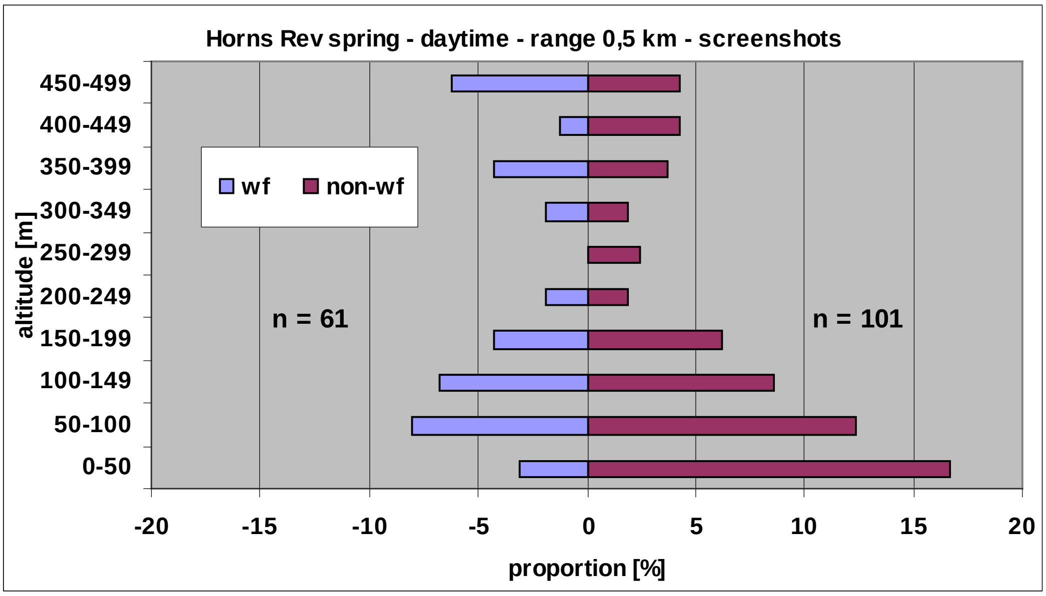


Fig. 4.2: Nysted - migration intensity in autumn for ranges 0.5 km and 1.5 km

4.2.1.2. Altitude distributions

Horns Rev[1]

In spring, only three days of radar data were available so far, so generality of the findings may be doubtful.



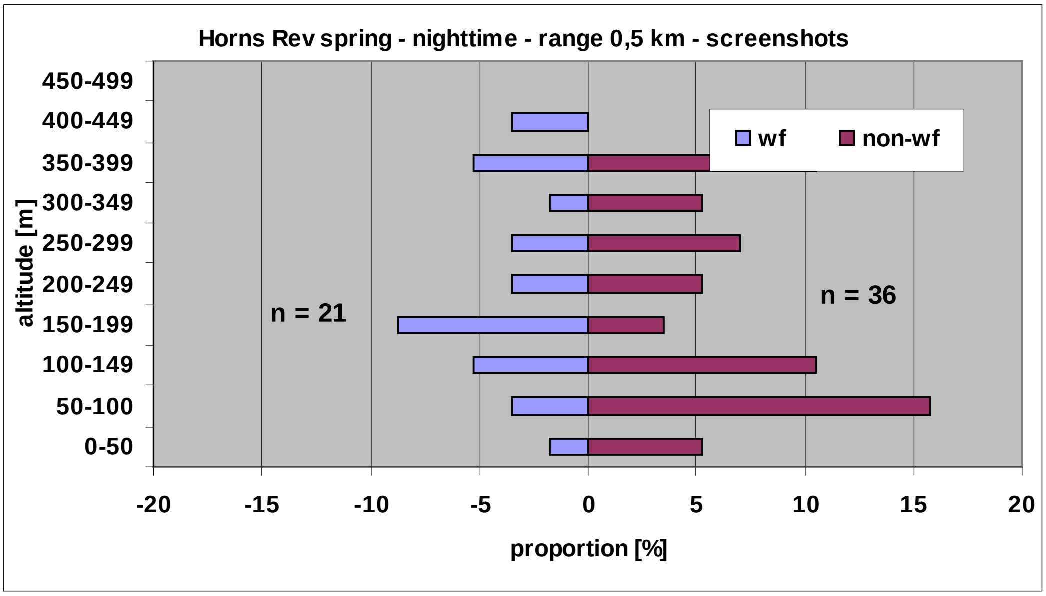


Fig. 4.1: Horns Rev – altitude distribution of signals, expressed as proportion of all signals, method screenshots. Range 500 m in 50 m classes. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

[1] Figures of screenshots and traced signals are placed symmetrically on facing pages, thus facilitating eyeballing and comparing the altitude distributions.

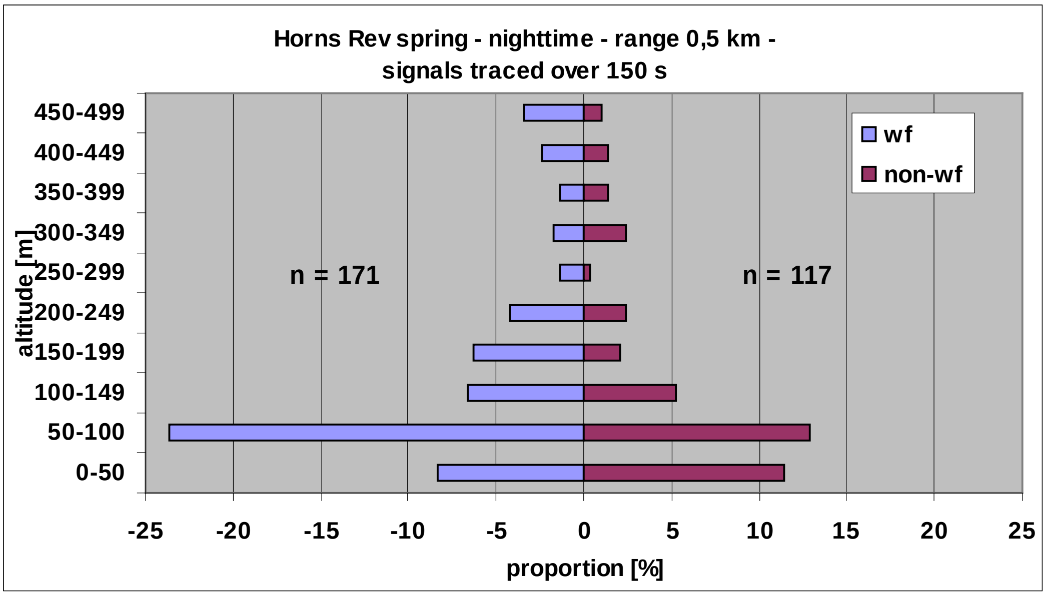
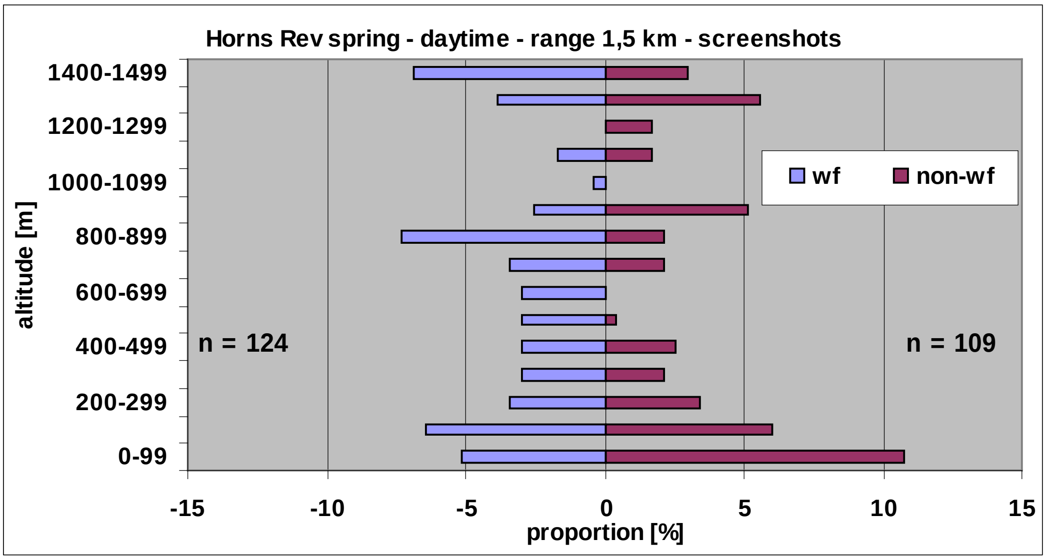


Fig. 4.2: Horns Rev – altitude distribution of signals, expressed as proportion of all signals, method traced signals. Range 500 m in 50 m classes. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

Again, only few data were available for analysis; figures might have been affected by random effects.



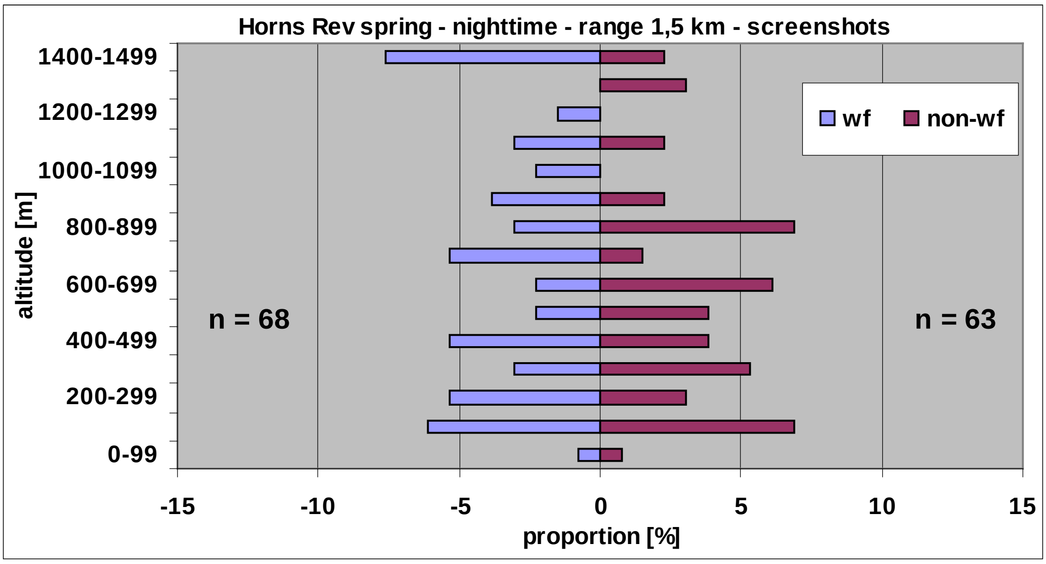


Fig. 4.3: Horns Rev – altitude distribution of signals, expressed as proportion of all signals, method screenshots. Range 1.500 m in 100 m classes. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

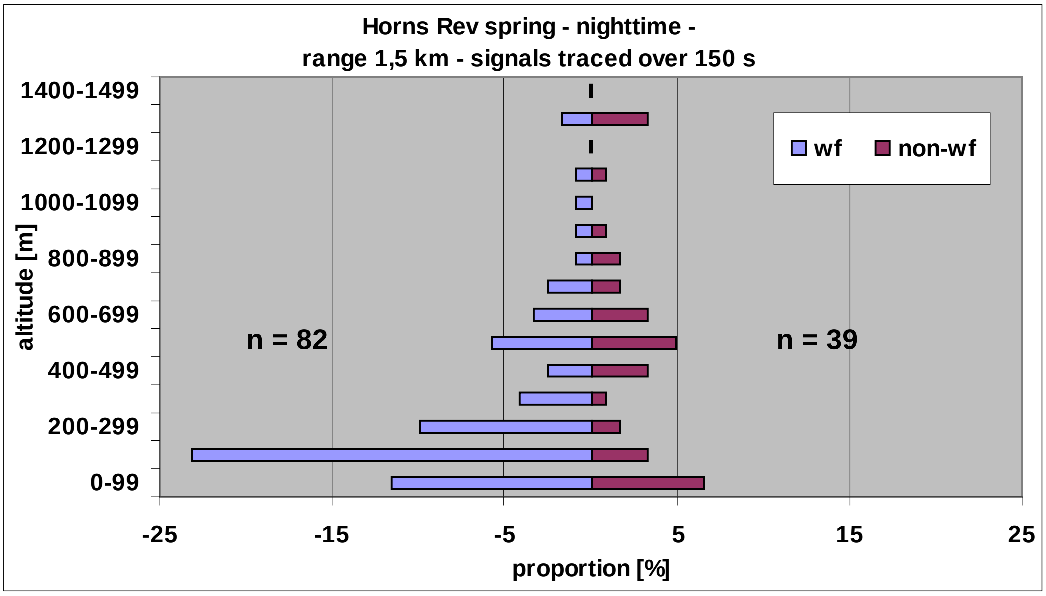


Fig. 4.4: Horns Rev – altitude distribution of signals, expressed as proportion of all signals, method traced signals. Range 1.500 m in 100 m classes. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

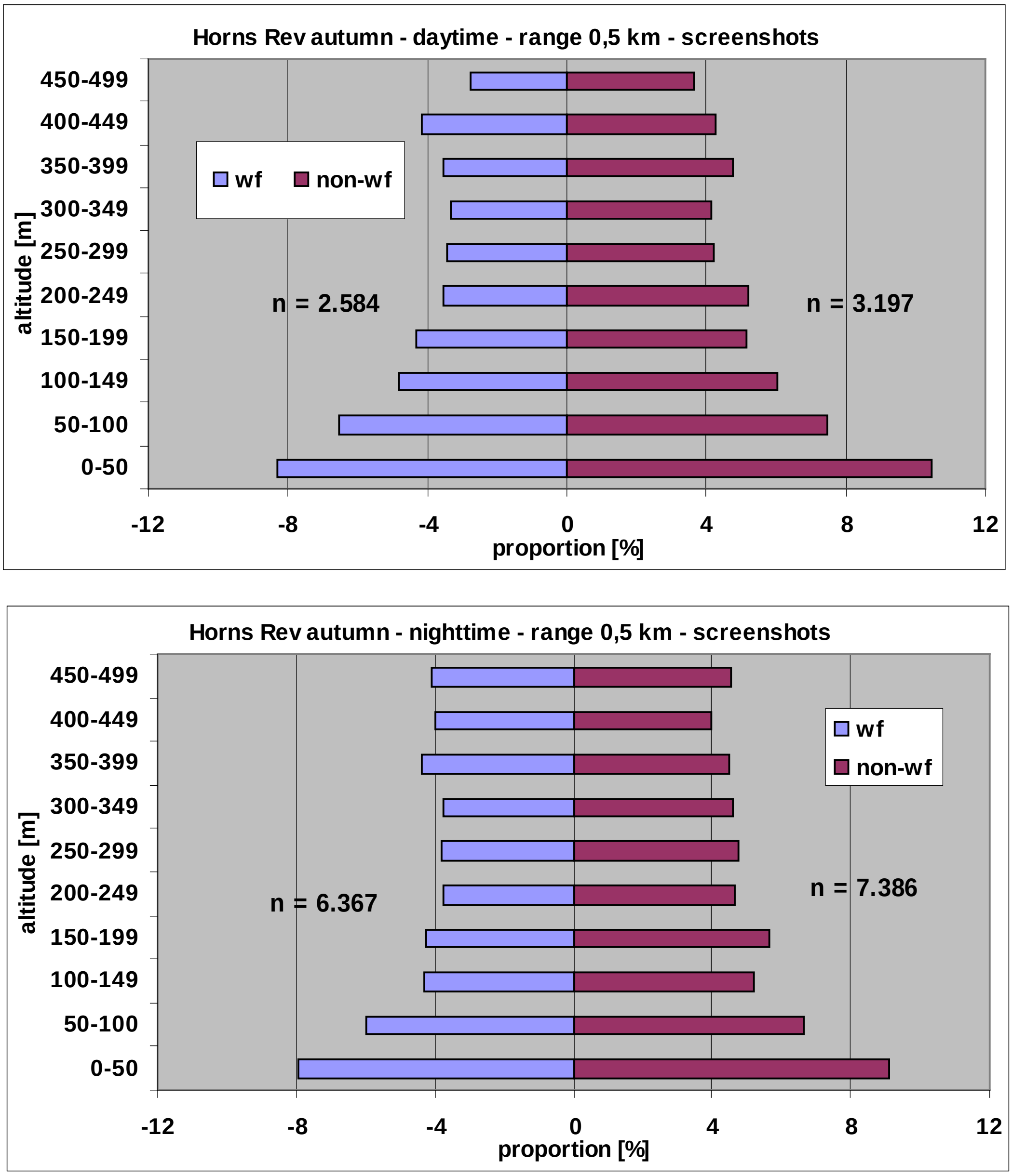
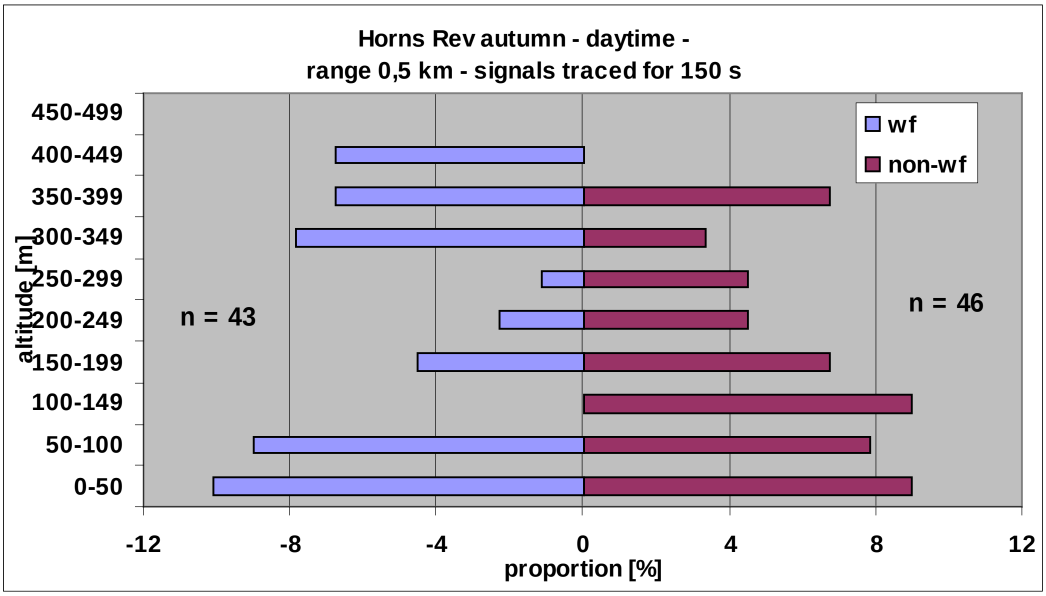


Fig. 4.5: Horns Rev – altitude distribution of signals, expressed as proportion of all signals, method screenshots. Range 500 m in 50 m classes. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

Altitude distribution in the 500 m range during day or night seemed to be rather regular with some more signals represented below 100 m and thus within the altitude of the windmills; since the radar method underestimates birds in this altitude segment, even more birds should be assumed below 100 m.



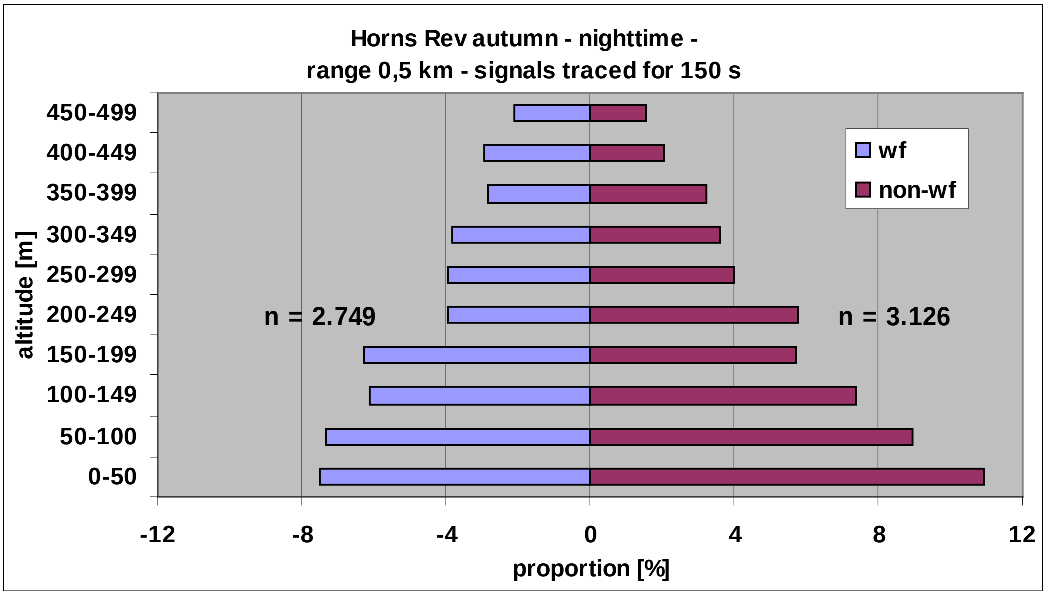
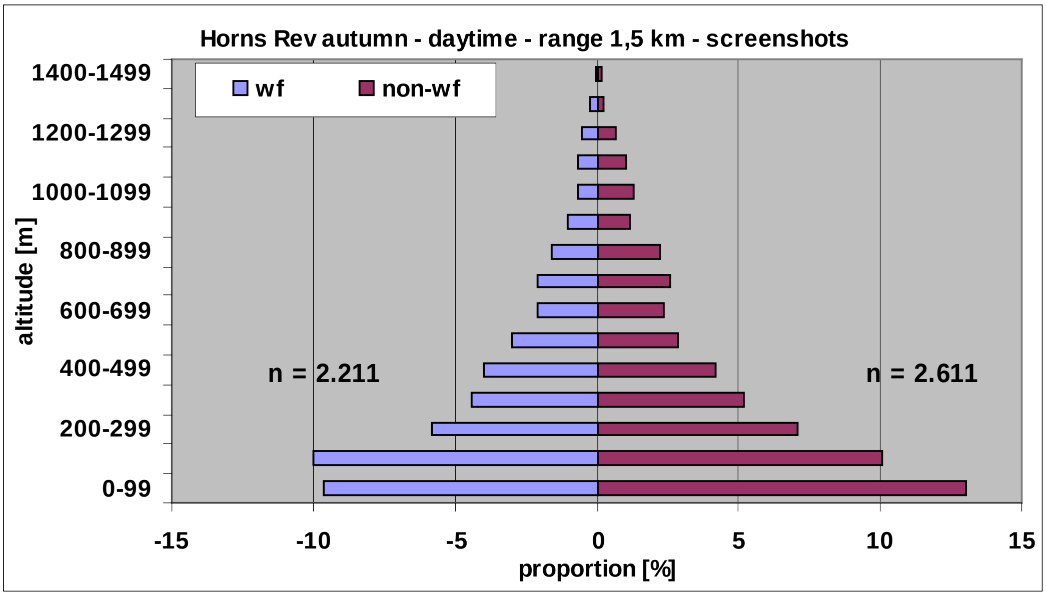


Fig. 4.6: Horns Rev – altitude distribution of signals, expressed as proportion of all signals, method traced signals. Range 500 m in 50 m classes. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

Comparing the screen shots with the traced signals no obvious differences occurred during daytime; during nighttime the traced signals seemed to predominate in the lower altitude segments.
With both methods, no obvious differences between the windfarm and the non-windfarm side were apparent.



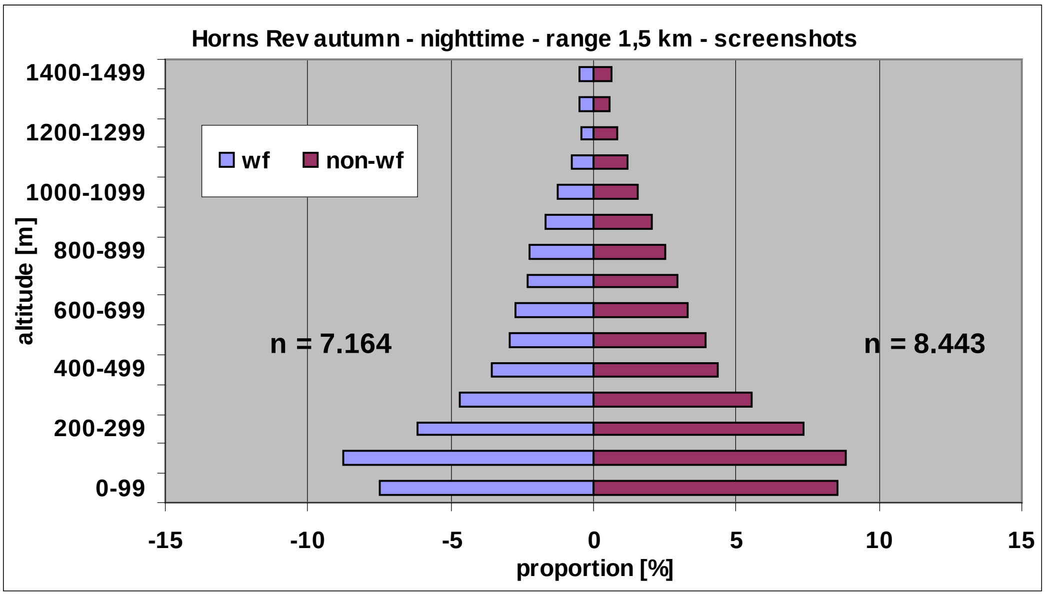


Fig. 4.7: Horns Rev – altitude distribution of signals, expressed as proportion of all signals, method screenshots. Range 1.500 m in 100 m classes. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

Altitude distribution in the 1.5 km was obviously skewed towards the lower altitudes. The lowest altitude band was underestimated, because radar sensitivity in combination with disturbance by sea clutter underestimates low altitudes. The unevenness was more pronounced during daytime, suggesting that non migrating birds (gulls, terns etc.) influenced the altitude distributions. During night higher proportions of birds were detected above 500 m, however, these proportions were lower than found in some other studies conducted in the North Sea (e.g. STAHL & NEHLS 2004), but comparable to others (e.g. OREJAS et al. 2005).

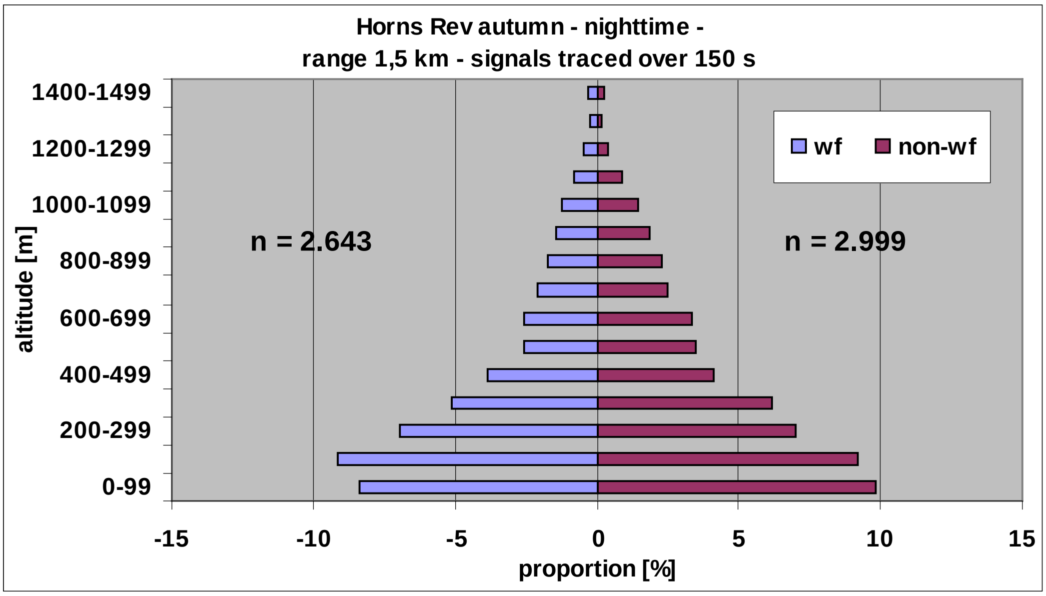
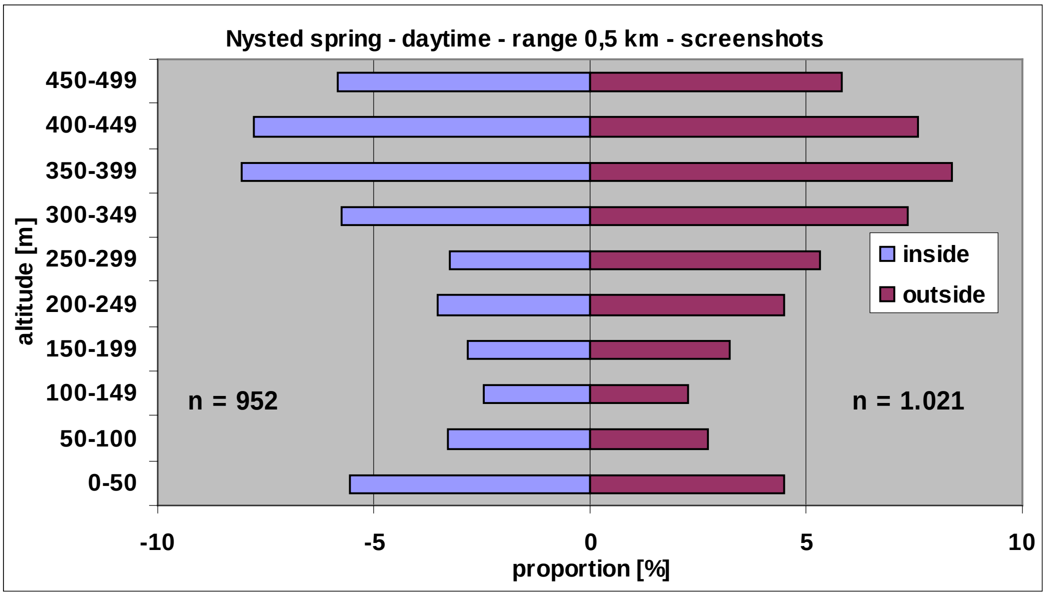


Fig. 4.8: Horns Rev – altitude distribution of signals, expressed as proportion of all signals, method traced signals. Range 1.500 m in 100 m classes. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

Comparing the screen shots with the traced signals provided almost identical figures with some fewer signals traced in the highest altitude classes.
Also in this range, no obvious differences between the windfarm and the non-windfarm side were apparent.

Nysted



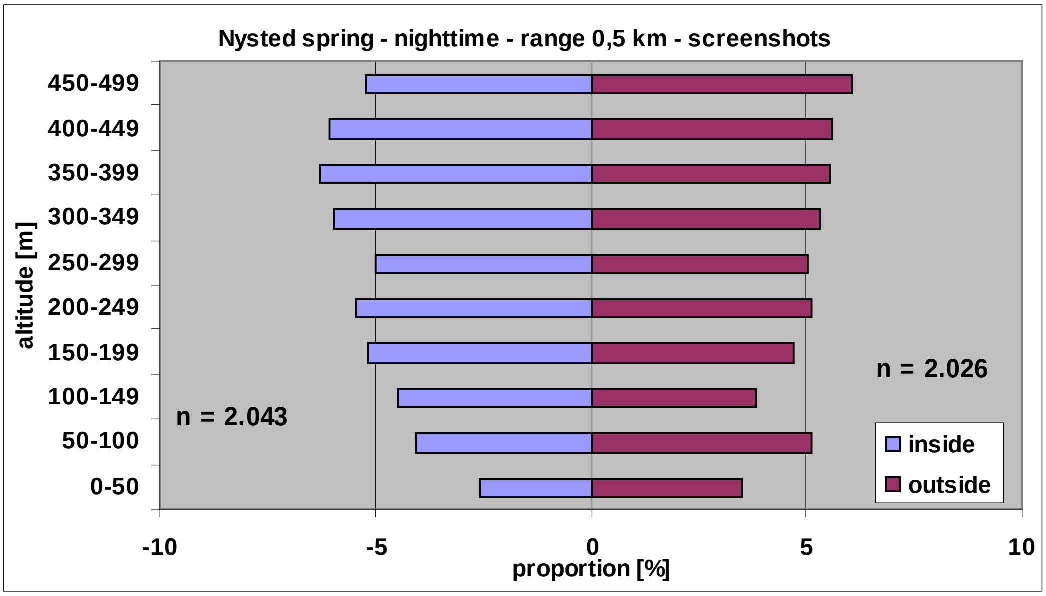
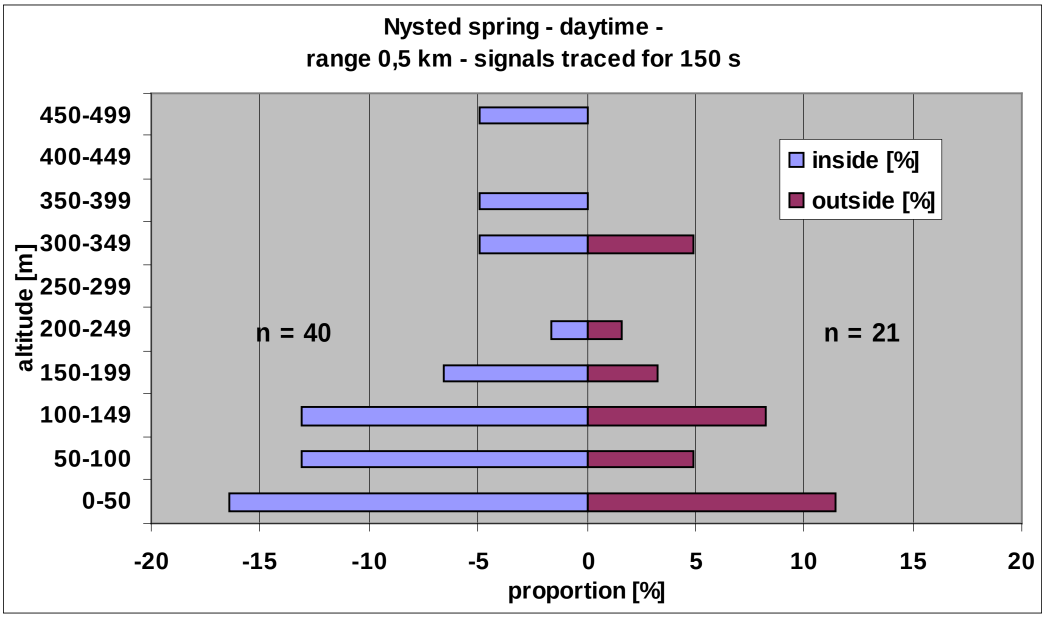


Fig. 4.1: Nysted – altitude distribution of signals, expressed as proportion of all signals, method screenshots. Range 500 m in 50 m classes. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

Altitude distribution in the 500 m range during day or night seem to be rather regular. During daytime an obvious predominance of the altitudes between 300 and 500 m existed, representing birds flying well above the reach of windmills.



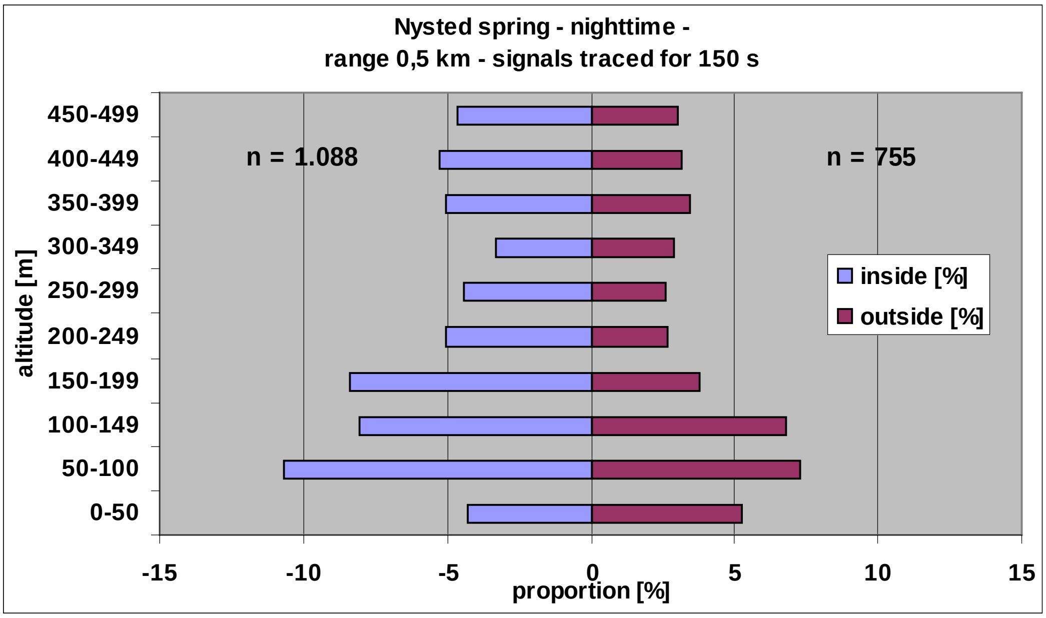
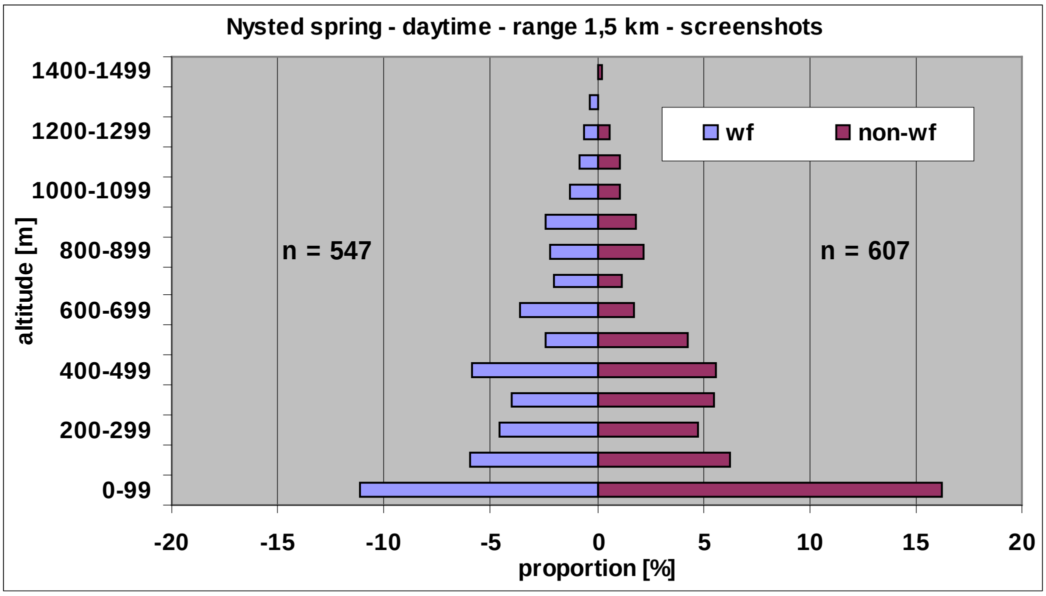


Fig. 4.2: Nysted– altitude distribution of signals, expressed as proportion of all signals, method traced signals. Range 500 m in 50 m classes. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

Comparing the screen shots with the traced signals for daytime would have been difficult, since only few traced signal data for daytime existed. During night the traced signals seemed to be more frequent at the windfarm side and compared to the screenshots more concentrated on the lower altitude bands.



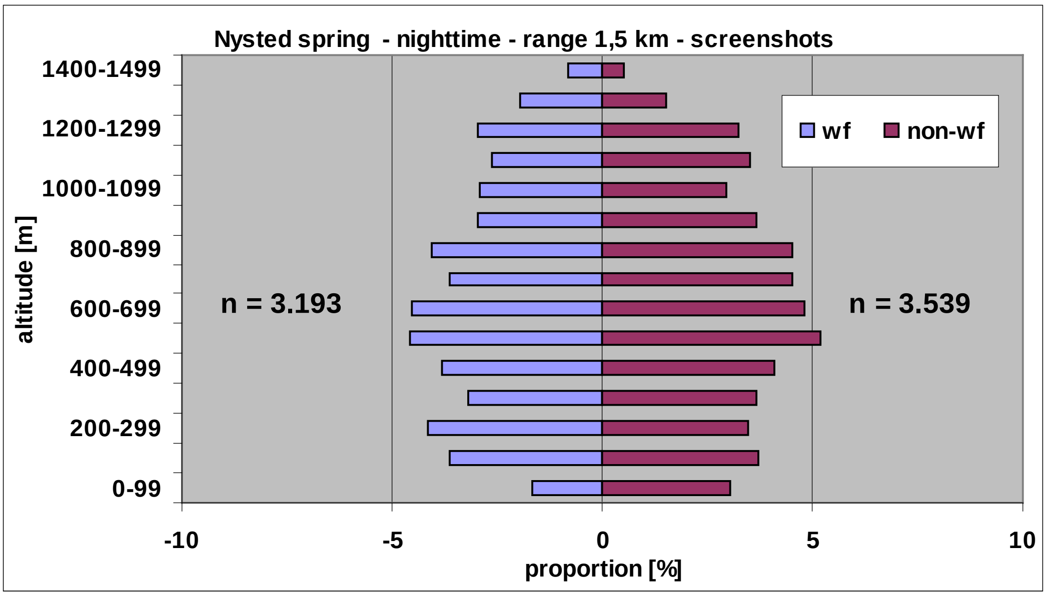
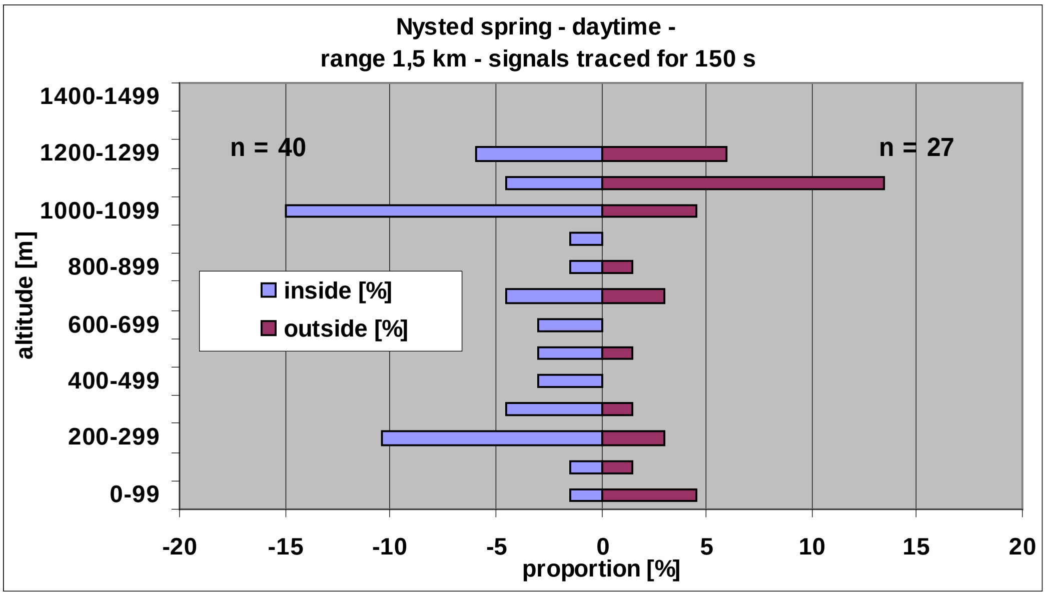


Fig. 4.3: Nysted – altitude distribution of signals, expressed as proportion of all signals, method screenshots. Range 1.500 m in 100 m classes. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

Altitude distribution in the 1.500 m range during day and night were considerably different. During day, signals in the lower altitudes were more frequent; however, although radar coverage during day and night was comparable, considerably fewer signals were recorded during daytime, assumingly presenting non-migratory birds (see visual observations). During night the altitude distribution was relatively regular; it seemed, that a slightly lower number of signals was recorded on the windfarm side.



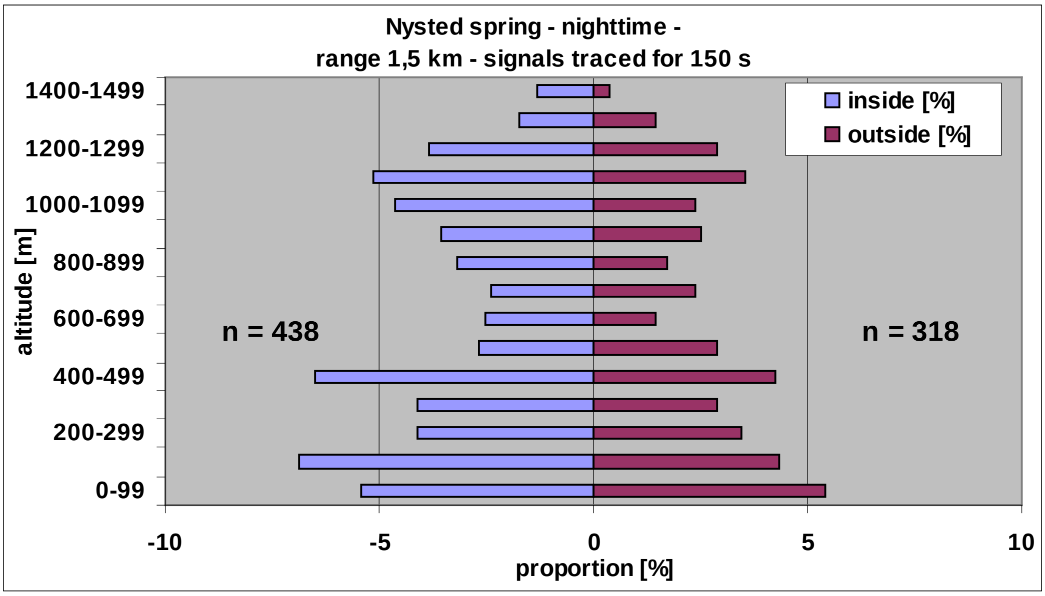
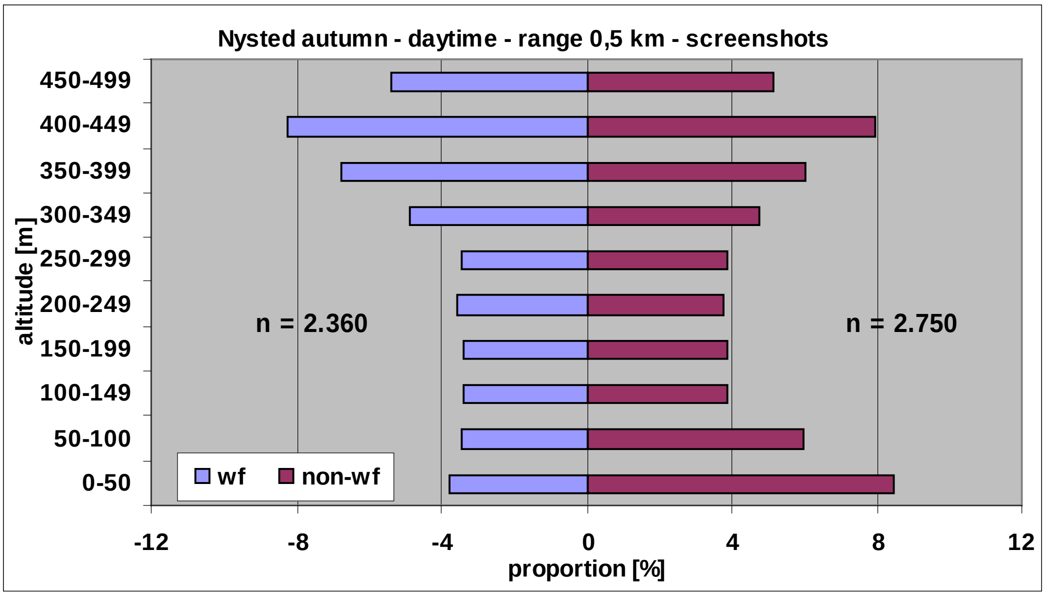


Fig. 4.4: Nysted– altitude distribution of signals, expressed as proportion of all signals, method traced signals. Range 1.500 m in 100 m classes. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

Comparing the screen shots with the traced signals for daytime would have been be critical, since only few recordings existed. But also for the nighttime periods, a comparison could be complicated by different temporal coverage of the two methods, since no traced signals were recorded during mid-May.



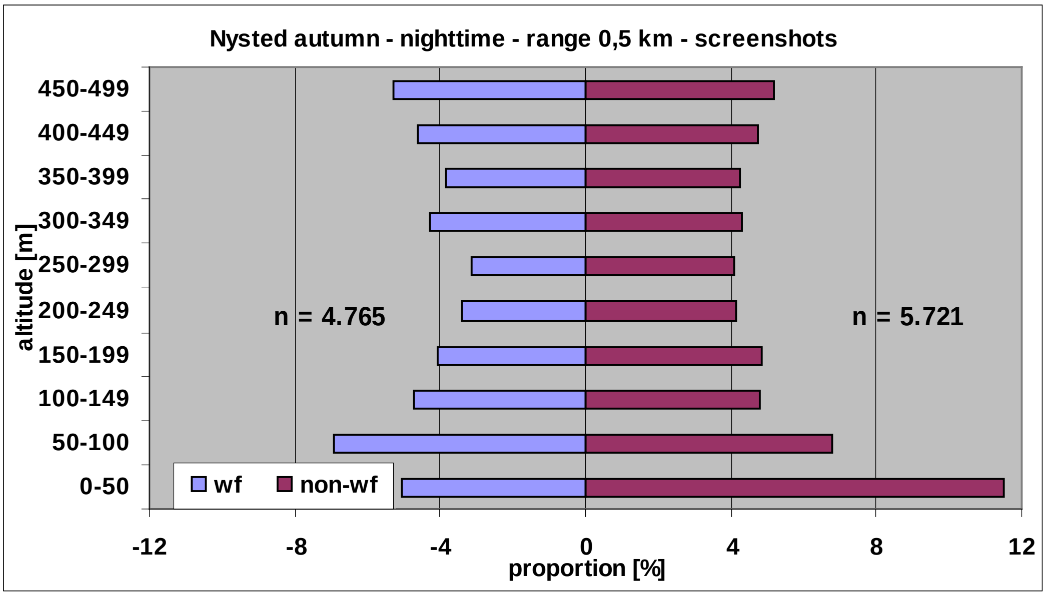


Fig. 4.5: Nysted – altitude distribution of signals, expressed as proportion of all signals, method screenshots. Range 500 m in 50 m classes. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

Altitude distribution in the 500 m range during day or night seemed to be rather regular in autumn. During daytime it seemed obvious that in the lower altitudes the number of signals on the windfarm side were lower than on the non-windfarm side; apparently, these differences did not exist in altitudes above 300 m. During nighttime differences were only recognizable in the lowest altitude range; however, this range produced irregular results due to disturbances and most likely underestimated the number of signals, so no conclusions could be drawn. However, above 50 m no differences between windfarm and non-windfarm sides were obvious.

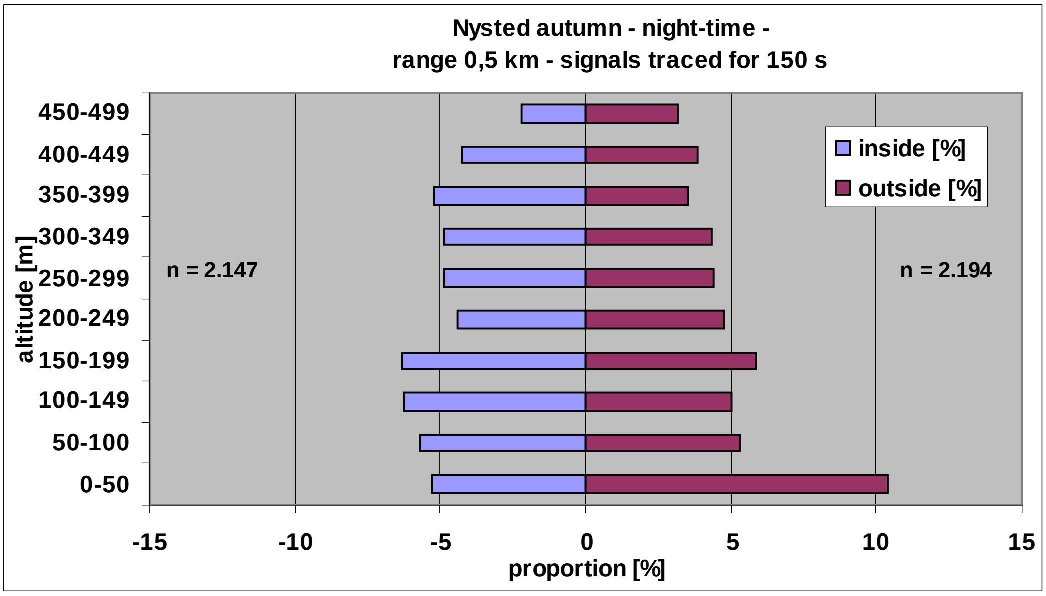
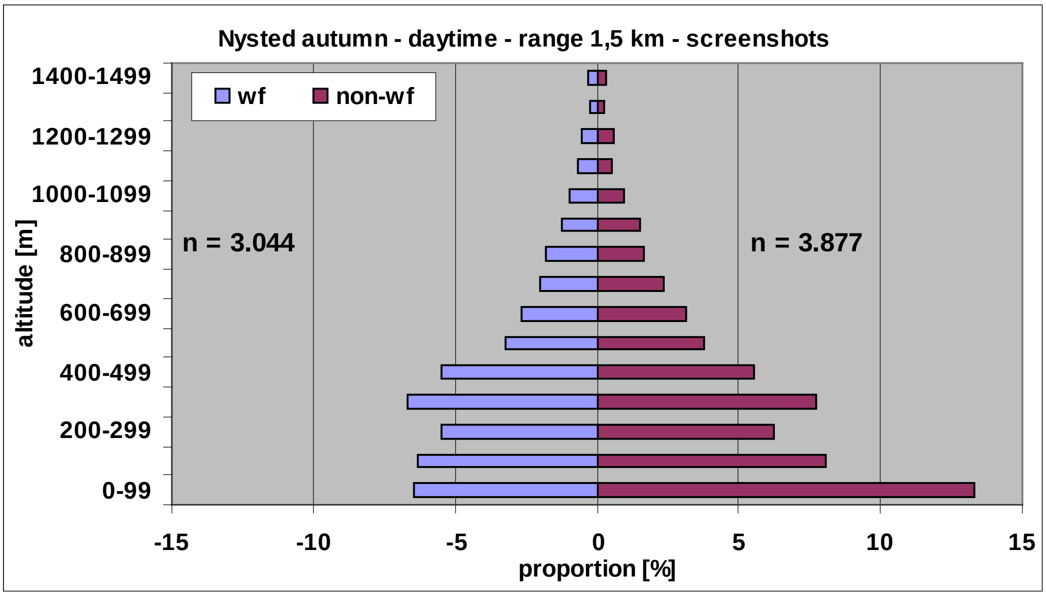


Fig. 4.6: Nysted– altitude distribution of signals, expressed as proportion of all signals, method traced signals. Range 500 m in 50 m classes. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

Comparing the screen shots with the traced signals for daytime was not possible. However, comparisons during night pointed to the same imbalance between windfarm and non-windfarm area below 50 m. Above 50 m pictures, a lower proportion of signals was registered with the traced signals method.



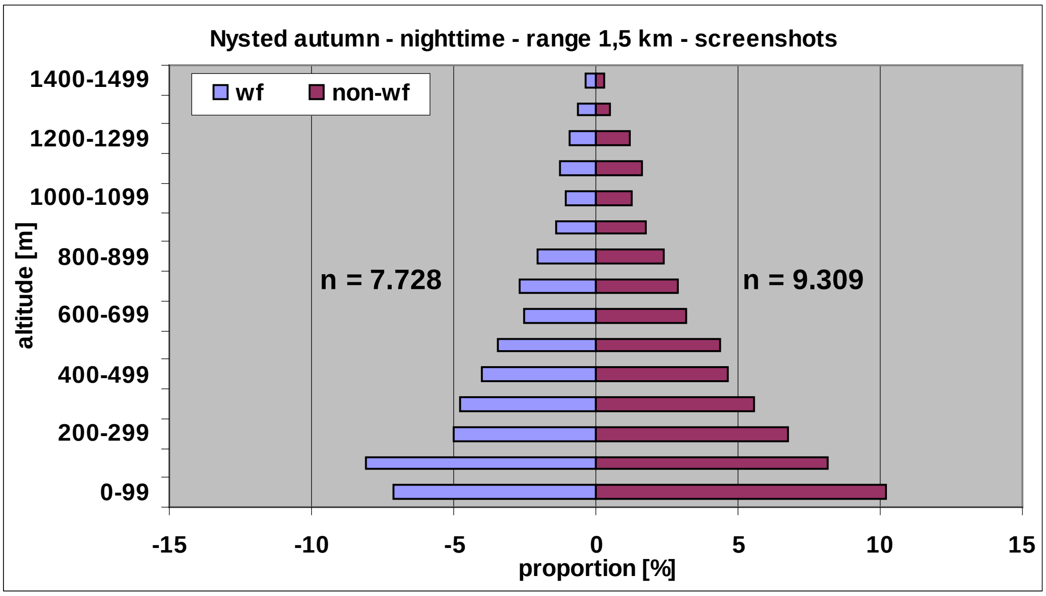
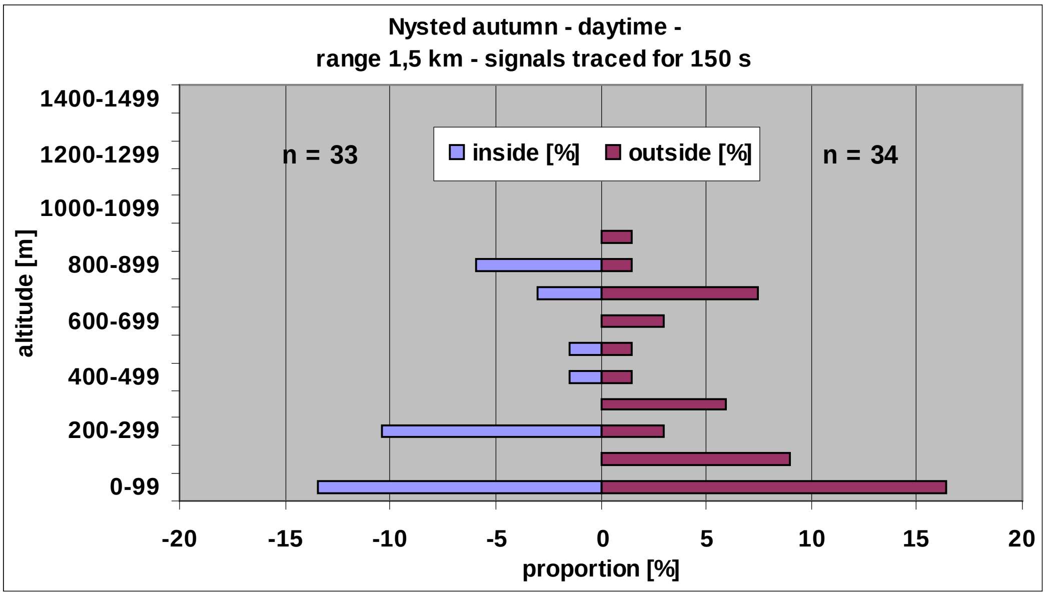


Fig. 4.7: Nysted – altitude distribution of signals, expressed as proportion of all signals, method screenshots. Range 1,500 m in 100 m classes. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

Altitude distribution in the 1.500 m range during day or night seemed to resemble the shapes known from the spring period. However, as in the 500 m range, more signals were registered below 50 m on the non-windfarm side. During night, the number of signals on the non-windfarm side was somewhat higher, while the altitude distribution – except from the 50 m range - did not differ.



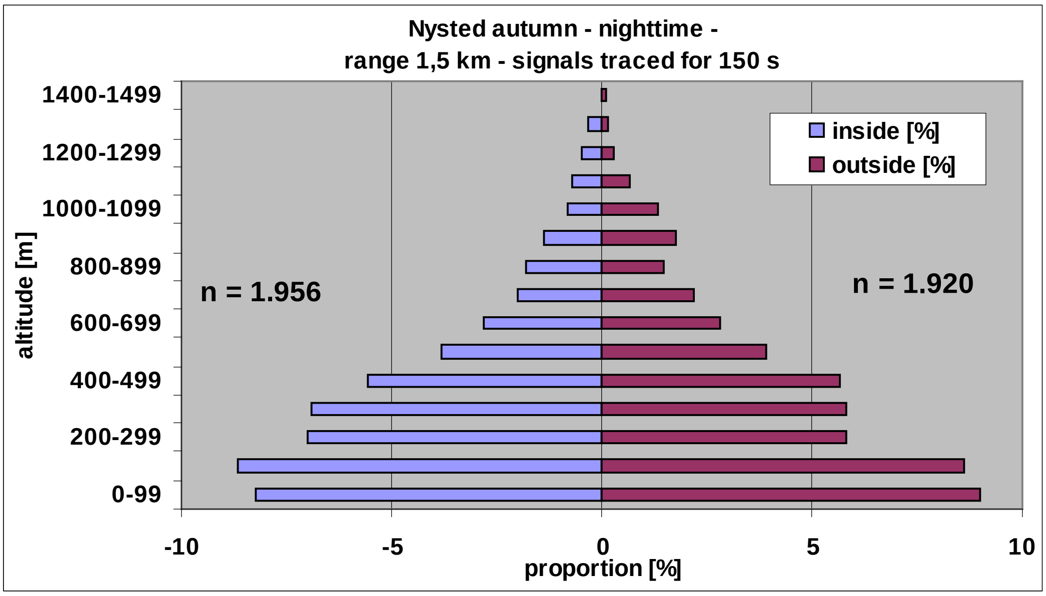


Fig. 4.8: Nysted– altitude distribution of signals, expressed as proportion of all signals, method traced signals. Range 1.500 m in 100 m classes. Lowest altitude class underestimated due to reduced sensitivity of radar / disturbance (sea clutter).

Comparing the screen shots with the traced signals for daytime would have been critical, since only few recordings existed. For the nighttime periods, the comparison yielded some similarities with the lower altitudes predominating in both methods, however, this was more pronounced on the records with traced signals. Also, while differences between windfarm and non-windfarm sides were registered with screenshots, traced signals did not support this. This might point to an assumption, that the screenshot method might have underestimated signals on the windfarm side due to disturbances (see above) while the method of tracing a signal directly on the screen might have enhanced the ability to detect bird signals.

4.2.2. Visual observations

All results of visual observations are shown separately for each survey area as well as for spring and autumn if data for both seasons were available. The presentation always compares the side of the transect leading from the ship into the windfarm (wf side) with the opposite side (non-wf side). Note that some 300 m of the wf side of transect are not really inside the windfarm (the range between the vessel and the first windmill(s); s. methods for details).

4.2.2.1. Species composition

The species composition for both Horns Rev and Nysted windfarm area is listed in Tab. 4.1 - Tab. 4.1 for each season separately. In some cases birds could not be identified to species level. These birds were identified to the highest possible taxonomic level.

During visual observation activities in spring a minimum of 35 different bird species was observed in the Horns Rev windfarm area (Tab. 4.1). 6 species flew also inside the windfarm. The lack of several (especially Songbird) species in Horns Rev area is supposed to be due to the delayed start of the field survey and the time-limited effort in Horns Rev area.
In autumn at least 77 bird species were recorded in Horn Rev area 43 of which occurred also inside the windfarm (Tab. 4.1).
Besides typical coastal water birds such as geese, ducks or gulls several pelagic species were recorded in Horns Rev (fulmar, gannet, kittiwake) as well as a wide range of migrating songbirds. Important families among the songbirds were pipits/wagtails (Motacillidae),thrushes and related (Turdidae) and finches (Fringillidae).
While fulmar was only observed in spring in most taxa more species were recorded in autumn (e.g. geese, waders).

Tab. 4.1: Bird species/taxa observed in Horns Rev windfarm area during visual observations in spring 2005. Species/taxa in bold print occurred also inside the windfarm.

unidentified Diver	Common Gull	unidentified Pipit
Fulmar	Herring Gull	White Wagtail
Gannet	Great Black-backed Gull	Dunnock
Cormorant	**Lesser Black-backed Gull**	Song Thrush
unidentified Goose	Kittiwake	Blackbird
Greylag Goose	Arctic Tern	Fieldfare
Common Scoter	Sandwich Tern	Wheatear
unidentified Duck	unidentified Tern	Willow Warbler
Merlin	Wood Pigeon	Goldcrest
Oystercatcher	**Feral Pigeon**	**Starling**
Whimbrel	unidentified Swallow	Brambling
Arctic Skua	**Barn Swallow**	**Goldfinch**
Little Gull	Skylark	unidentified Passerine
Black-headed Gull	Meadow Pipit	

Tab. 4.1: Bird species/taxa observed in Horns Rev windfarm area during visual observations in autumn 2005. Species/taxa in bold print occurred also inside the windfarm.

Red-throated Diver	Arctic Skua	Dunnock
unidentified Diver	Long-tailed Skua	**Wren**
unidentified Grebe	unidentified Skua	Robin
Gannet	**Little Gull**	**Redwing**
Cormorant	**Black-headed Gull**	**Song Thrush**
Grey Heron	**Common Gull**	Fieldfare
Greylag Goose	**Herring Gull**	**Blackbird**
Pink-footed Goose	**Lesser Black-backed Gull**	Wheatear
White-fronted Goose	**Great Black-backed Gull**	Willow Warbler
Brent Goose	Sabine's Gull	Goldcrest
unidentified Goose	**Kittiwake**	Blue Tit
Common Eider	**Arctic Tern**	Great Tit
Common Scoter	Common Tern	**Jackdaw**
unidentified Duck	**Sandwich Tern**	**Starling**
Red Kite	**Little Tern**	**Chaffinch**
Sparrowhawk	Guillemot	**Brambling**
Peregrine Falcon	**Razorbill**	**Redpoll**
Merlin	Little Auk	**Siskin**
unidentified Raptor	**Short-eared Owl**	**Greenfinch**
Oystercatcher	**Wood Pigeon**	**Linnet**
Lapwing	Barn Swallow	unidentified Finch
Turnstone	**Skylark**	Tree Sparrow
Dunlin	**Shore Lark**	Snow Bunting
Redshank	**Meadow Pipit**	Lapland Bunting
Common Snipe	**Tree Pipit**	**Reed Bunting**
Woodcock	**Rock Pipit**	Yellowhammer
Bar-tailed Godwit	Yellow Wagtail	unidentified Passerine
Curlew	**Grey Wagtail**	
unidentified Wader	**White Wagtail**	

In Nysted windfarm area a minimum of 66 bird species was recorded during spring visual observation period. 16 of these flew also inside the windfarm (Tab. 4.1).

In autumn 74 different bird species could be identified in Nysted windfarm area 40 of which were also observed within the windfarm (Tab. 4.1).

In Nysted windfarm area a wide range of non-pelagic waterbirds and migrating songbirds occurred. Furthermore a considerable number of (migrating) species of birds of prey was registered. All geese species possible to occur were observed (6 species). 13 duck species, 10 raptor species and 39 songbird species were recorded in the area.

Tab. 4.1: Bird species/taxa observed in Nysted windfarm area during visual observations in spring 2005. Species/taxa in bold print occurred also inside the windfarm.

Red-throated Diver	Red-breasted Merganser	**Meadow Pipit**
Black-throated Diver	unidentified Duck	Tree Pipit
Crested Grebe	**Marsh Harrier**	Yellow Wagtail
Red-necked Grebe	Hen Harrier	**White Wagtail**
unidentified Grebe	Honey Buzzard	Wren
Cormorant	Sparrowhawk	Blackbird
Grey Heron	Merlin	unidentified Thrush
Mute Swan	unidentified Raptor	Chiffchaff
Whooper Swan	Crane	Goldcrest
unidentified Swan	Oystercatcher	**Blue Tit**
Greylag Goose	unidentified Skua	unidentified Tit
Bean Goose	Little Gull	Jackdaw
White-fronted Goose	Black-headed Gull	Carrion Crow
Barnacle Goose	**Common Gull**	Rook
Brent Goose	**Herring Gull**	unidentified Corvid
Mallard	**Lesser Black-backed Gull**	Starling
Wigeon	Great Black-backed Gull	House Sparrow
Tufted Duck	**Sandwich Tern**	Chaffinch
Scaup	unidentified Tern	Goldfinch
Common Eider	Feral Pigeon	Greenfinch
Common Scoter	Swift	Linnet
Velvet Scoter	**Barn Swallow**	Siskin
Long-tailed Duck	Sand Martin	unidentified Finch
Goldeneye	House Martin	Reed Bunting
Goosander	Skylark	unidentified Passerine

Tab. 4.1: Bird species/taxa observed in Nysted windfarm area during visual observations in autumn 2005. Species/taxa in bold print occurred also inside the windfarm.

Red-throated Diver	Merlin	**Song Thrush**
unidentified Diver	unidentified Raptor	**Redwing**
unidentified Diver/Grebe	Grey Plover	Blackbird
Cormorant	**Dunlin**	**Fieldfare**
Mute Swan	Curlew	Red-breasted Flycatcher
Whooper Swan	unidentified Wader	Goldcrest
unidentified Swan	Arctic Skua	Blue Tit
Greylag Goose	**Little Gull**	**Great Tit**
Pink-footed Goose	**Black-headed Gull**	Coal Tit
White-fronted Goose	**Common Gull**	Long-tailed Tit
Barnacle Goose	**Herring Gull**	**Jackdaw**
Brent Goose	**Lesser Black-backed Gull**	Carrion Crow
unidentified Goose	**Great Black-backed Gull**	Raven
Mallard	**Sandwich Tern**	**Rook**
Wigeon	unidentified Tern	**Starling**
Pintail	Wood Pigeon	Tree Sparrow
Teal	unidentified Pigeon	**Chaffinch**
Common Eider	**Barn Swallow**	**Brambling**
Common Scoter	Sand Martin	**Goldfinch**
Long-tailed Duck	House Martin	**Linnet**
Red-breasted Merganser	**Skylark**	**Twite**
unidentified Duck	Shore Lark	**Greenfinch**
Red Kite	**Meadow Pipit**	**Siskin**
Marsh Harrier	Tree Pipit	Redpoll
Common Buzzard	Grey Wagtail	unidentified Finch
Rough-legged Buzzard	**White Wagtail**	Reed Bunting
Goshawk	**Yellow Wagtail**	Unidentified Passerine
Sparrowhawk	**Wren**	
Peregrine Falcon	**Robin**	

Not surprisingly the species composition in both areas differed according to the natural environment. Strongly pelagic species (e.g. tubenoses, gannets) in general occur only occasionally in the Baltic Sea whereas they are regular inhabitants of the North Sea. Depending on the weather situation they might approach the coast line more or less and thus be seen in Horns Rev windfarm area.

In Horns Rev the number of Wader species is somewhat larger and on the other hand the number of songbird species is slightly larger in Nysted. Swans were only observed in Nysted.

The composition of species and lower taxa (genera, families) is shown in percentages of all observations.

It must be made clear that all numbers are based on observation events and not necessarily on single individuals. It is impossible to track single individuals for longer periods. Especially individuals of stationary species might have appeared several times in theory. So the number can be seen as a measure of general presence of a taxon in the area. In passing migrants the number should be identical with the number of individuals.

Concerning the demonstration by pie charts it is also important to stress that these only show percentages (not numbers at the same scale). Hence the size depends on the number of all observations. For example it might be the case that one taxon formed a proportion of 10 % at wf side and 15 % at non-wf side. That does not mean that the number of observations at non-wf side was higher. The opposite could have been the case.
When dealing with gulls concerning the visual observations, Little Gull was excluded and treated separately. While all other common gull species in both areas were stationary at least for longer periods and certain individuals were likely to be present in the area for the duration of several hours or even days, Little Gulls passed by during directional migration and hence showed a very different attendance pattern.

Likewise from the group of passerines the corvids were excluded because they are much easier to spot than other songbirds due to their larger body size especially when flying at namable distances. So the likelyhood for Corvids to be recorded at any distance might have been considerably higher than for all other Passerines.

In Horns Rev area gulls (without Little Gull) represented always a large fraction on either side of the transect. In spring, gulls formed two third of all birds on wf-side. Otherwise they made up one third. Songbirds were most likely missed in spring because of underrepresentation due to a late onset of observations (see above). In autumn they formed an important fraction among all recorded birds (more than a third on non-wf side and almost half on wf side). Another important group were ducks. In spring only Common Scoters were identified. Ducks obviously formed a smaller fraction at wf side in both seasons. Jackdaws were represented in autumn due to a single incident when 250 birds passed the windfarm. (Fig. 4.1).

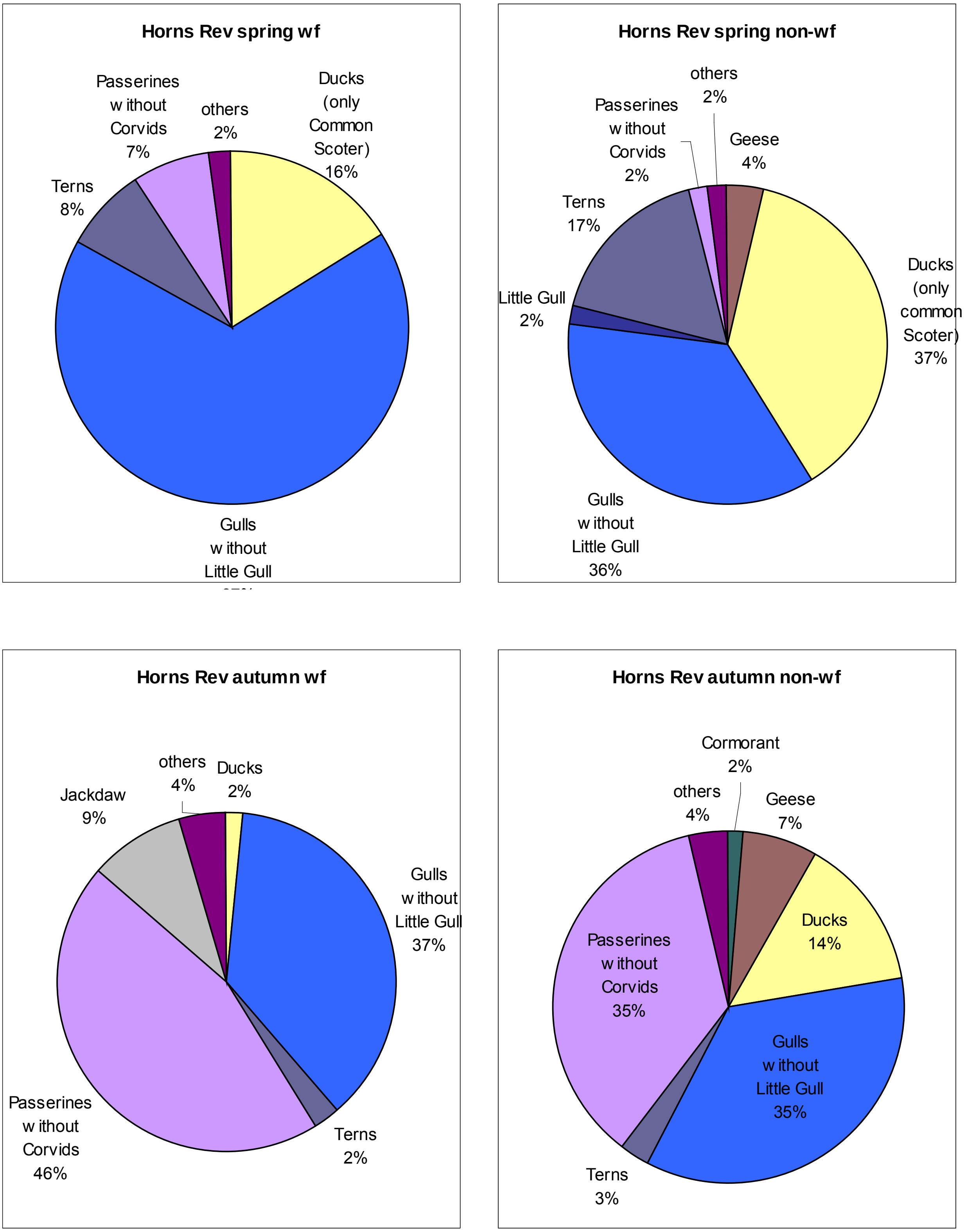


Fig. 4.1: Species composition of recorded birds in Horns Rev windfarm area in spring (top) and autumn (bottom) on windfarm side (wf, left) and non-windfarm side of transect (non-wf, right).a.) n=270, b.) n=1006, c.) n=2693, d.) n=4970.

In Nysted area, the by far most important single species was the cormorant. In both seasons it forms larger fractions on wf side of transect than on non-wf side. The large percentage of 70 in autumn on wf side is caused by one single incident when 5000 birds passed the windfarm. The species composition for autumn wf side is additionally shown excluding this incident (Fig. 4.3). Gulls (without Little Gull) were a less important group in Nysted area. In spring they represented more than a third of all recorded birds on wf side but otherwise formed always less than 15 %. Like in Horns Rev, ducks always formed a larger fraction at non-wf side than at wf side (two third in spring, one third in autumn). Songbirds were recorded in variable proportions on either side of the transect. (Fig. 4.2).

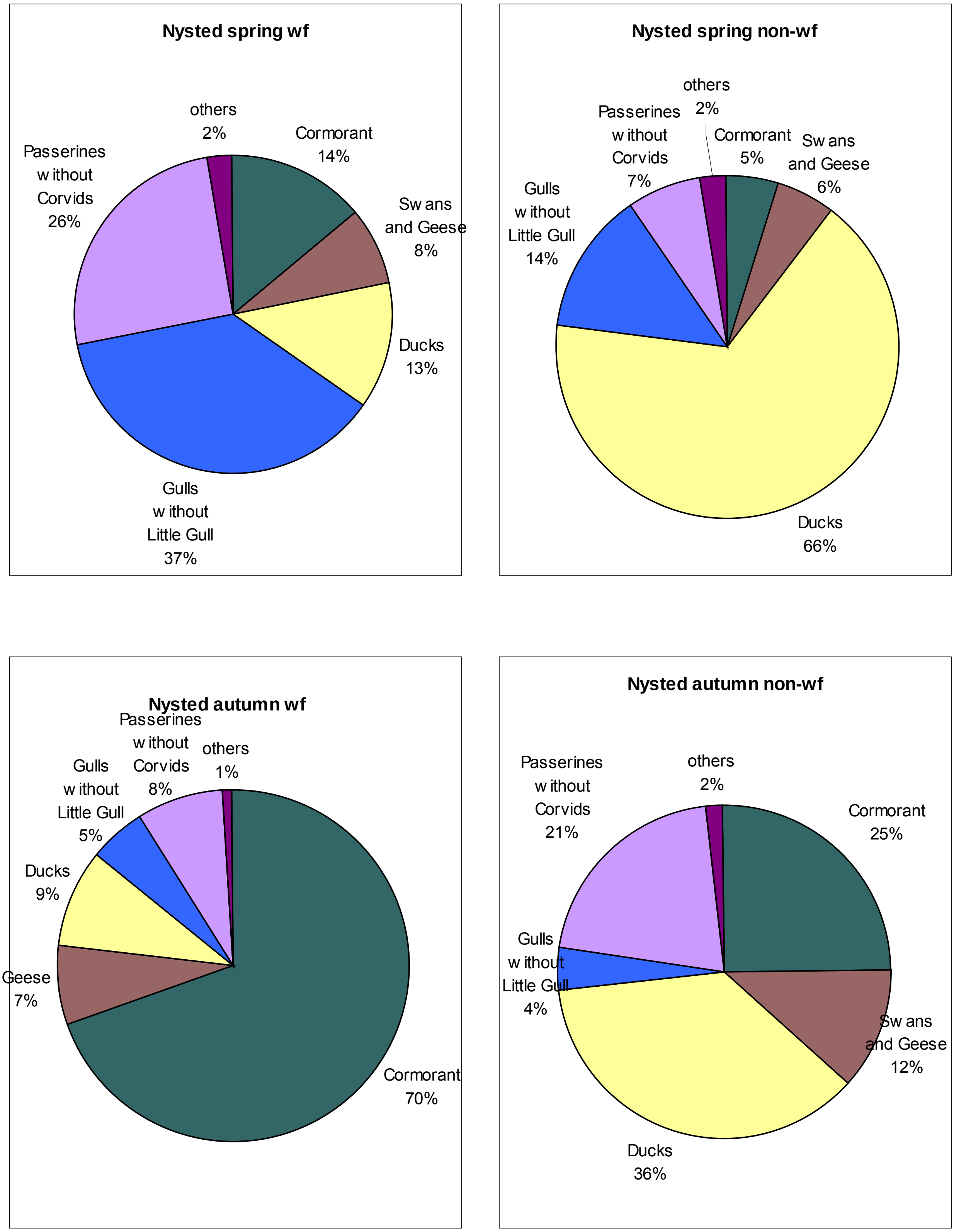


Fig. 4.2: Species composition of recorded birds in Nysted windfarm area in spring (top) and autumn (bottom) on windfarm side (wf, left) and non-windfarm side of transect (non-wf, right). a.) n=2501, b.) n=10067, c.) n=13320, d.) n=11193.

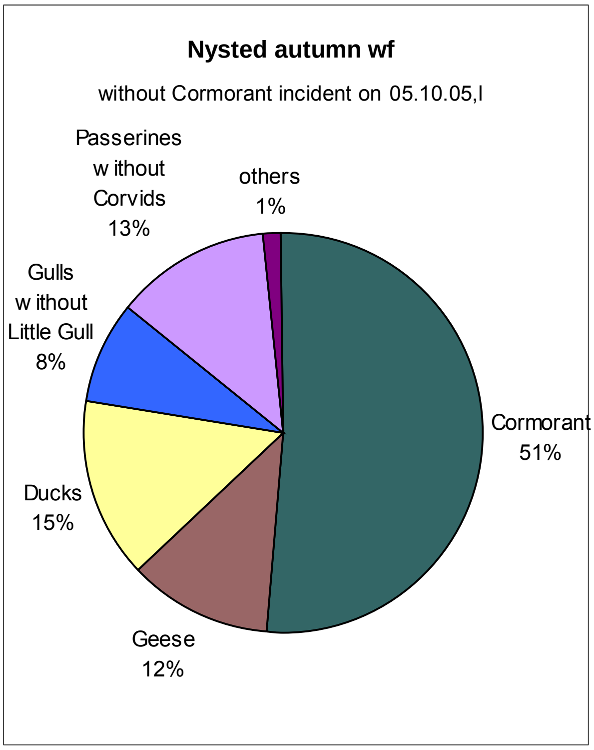


Fig. 4.3: Species composition of recorded birds in Nysted windfarm area in autumn on windfarm side of transect, excluded one single incident when 5000 Cormorants passed the windfarm. n=8320.

4.2.2.2. Altitude distribution

Altitude distribution diagrams are shown for all taxa with sufficient data base in at least one area comparing the observations of windfarm (wf) and non-windfarm side (non-wf) of the transect.

The cormorant showed in Nysted in spring the same altitude distribution at either side of the transect, preferring low flight altitudes above the water surface. The numbers observed were slightly higher at non-wf side (Fig. 4.1). In autumn the situation was biased by a single occurrence of 5000 individuals passing the windfarm what overrepresents the species at wf side (

Fig. 4.2). In Fig. 4.3 this single incident was excluded which led to an underrepresentation of the cormorant at wf side. However, it is still clearly visible that the lowest altitude class of 0 – 5 m was the one most frequented by Cormorants.

The cormorant was an example for the situation that the distribution in- and outside the windfarm could be considerably influenced by single incidents.

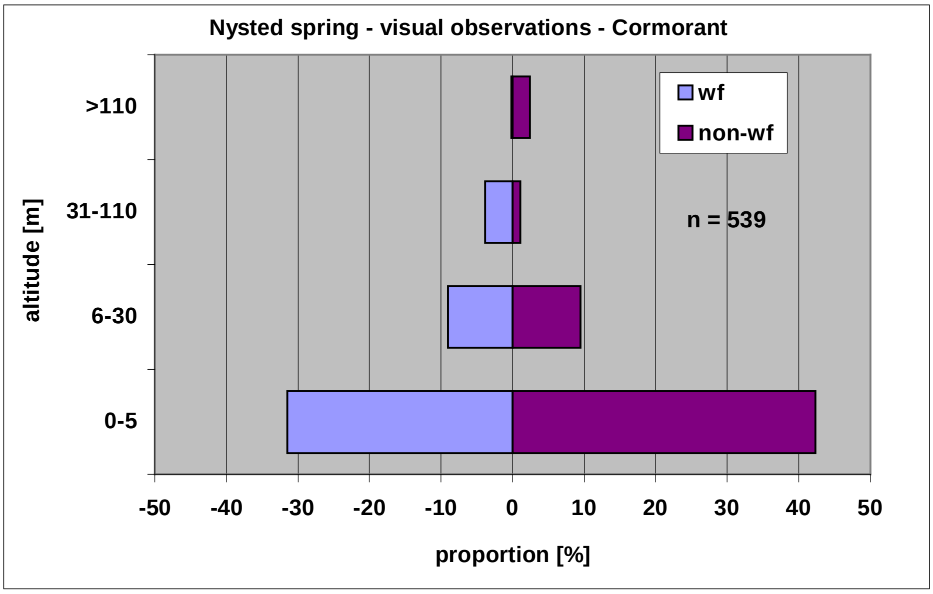


Fig. 4.1: Altitude distribution of cormorants in Nysted windfarm area in spring. Windfarm side of transect (wf) left, non-windfarm side (non-wf) right.

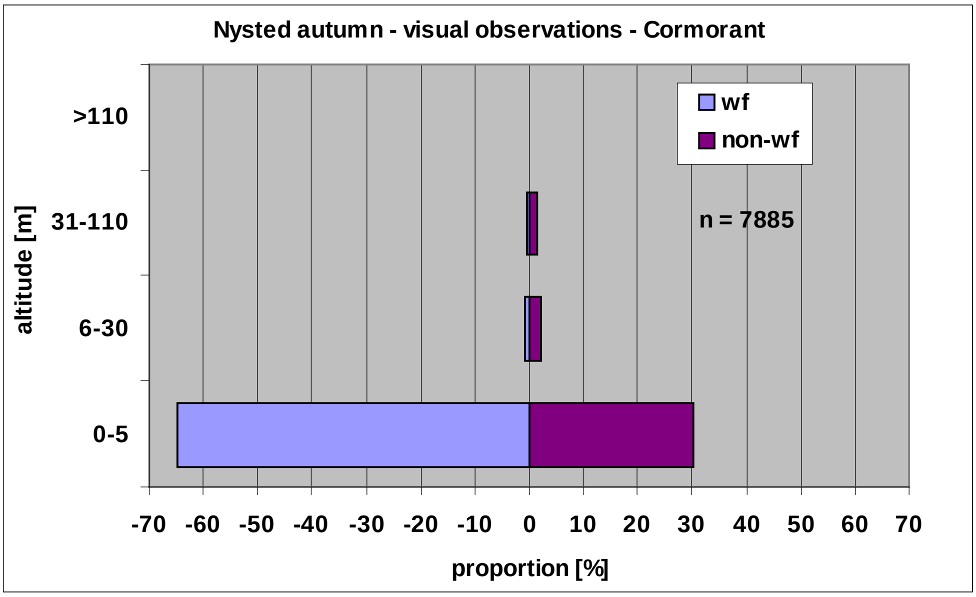


Fig. 4.2: Altitude distribution of cormorants in Nysted windfarm area in autumn. Windfarm side of transect (wf) left, non-windfarm side (non-wf) right.

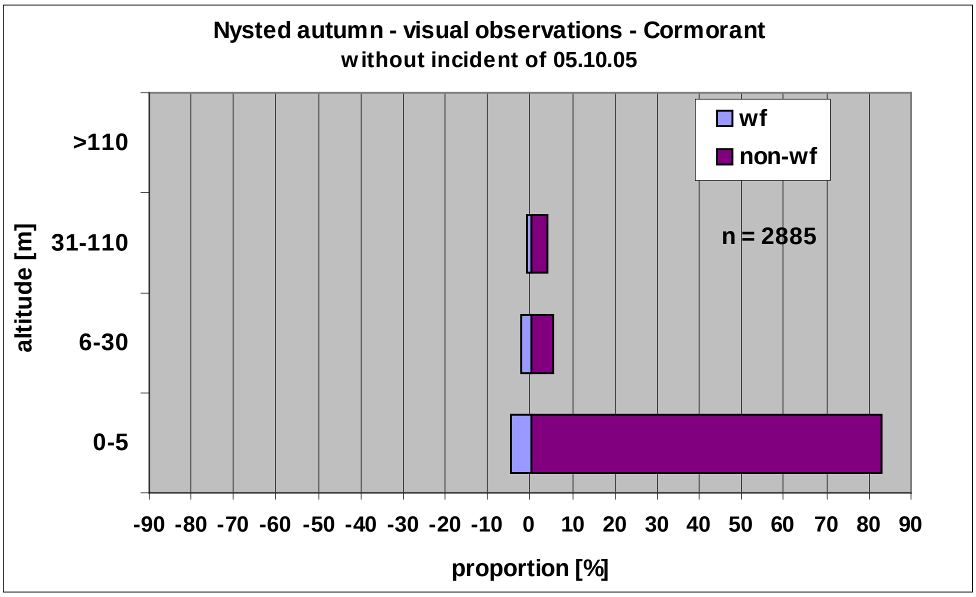


Fig. 4.3: Altitude distribution of cormorants in Nysted windfarm area in spring. Windfarm side of transect (wf) left, non-windfarm side (non-wf) right, excluded one single incident when 5000 Cormorants passed the windfarm.

Geese observed in Horns Rev in autumn did not show any clear preference for a flight altitude but seemed to avoid the wf side of transect (Fig. 4.4). The only recordings of geese on that side were from altitudes greater than windmill height.

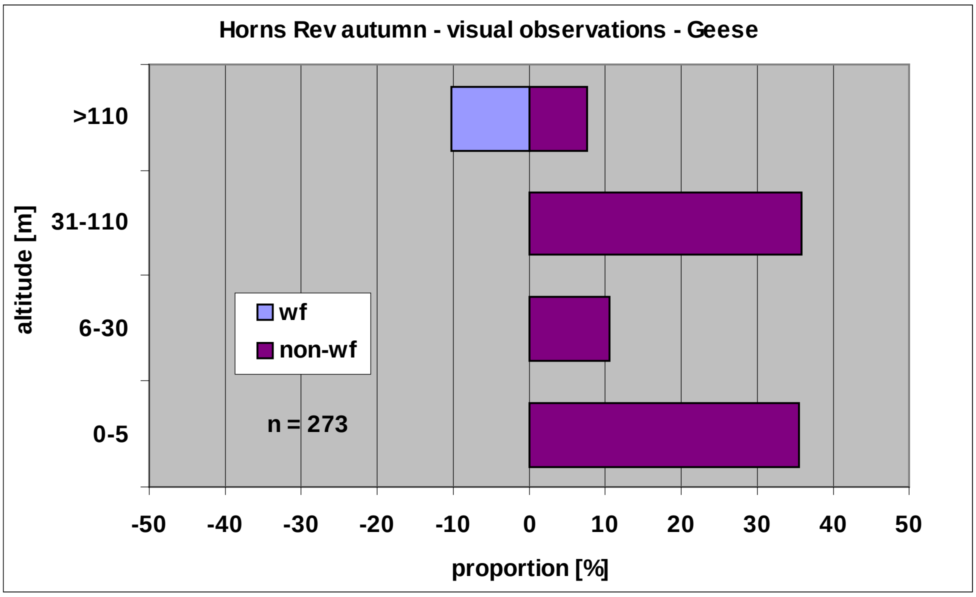


Fig. 4.4: Altitude distribution of geese in Horns Rev windfarm area in autumn. Windfarm side of transect (wf) left, non-windfarm side (non-wf) right.

As both swans and geese occurred in Nysted area, data for these two taxa with rather similar flight properties were pooled together. In Nysted swans and geese also avoided the wf side of the transect. However, a small proportion passed the wf side in spring. In opposite to geese in Horns Rev, swans and geese in Nysted showed a clear preference for the highest flight altitude class (Fig. 4.5 and Fig. 4.6).

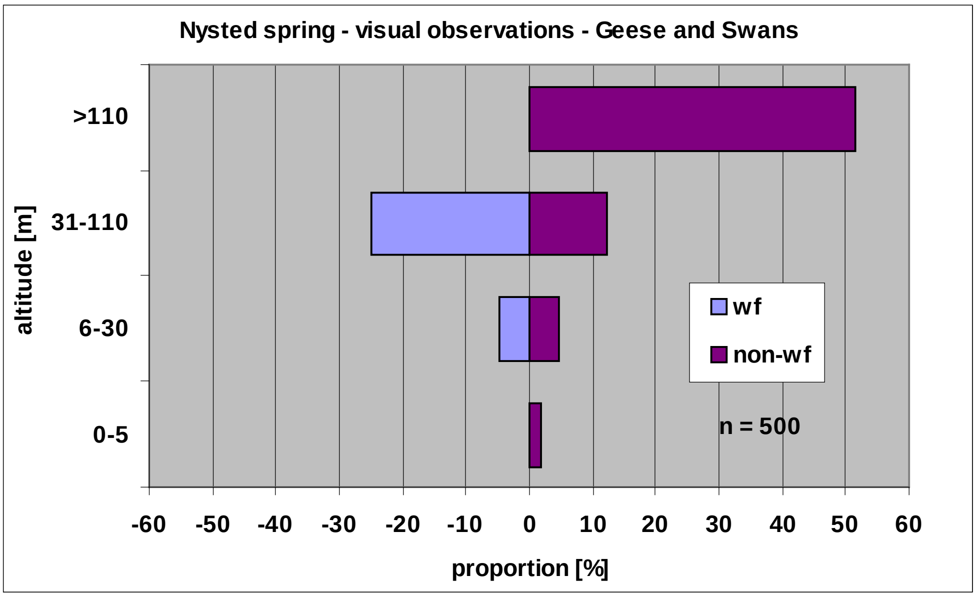


Fig. 4.5: Altitude distribution of swans and geese in Nysted windfarm area in spring. Windfarm side of transect (wf) left, non-windfarm side (non-wf) right.

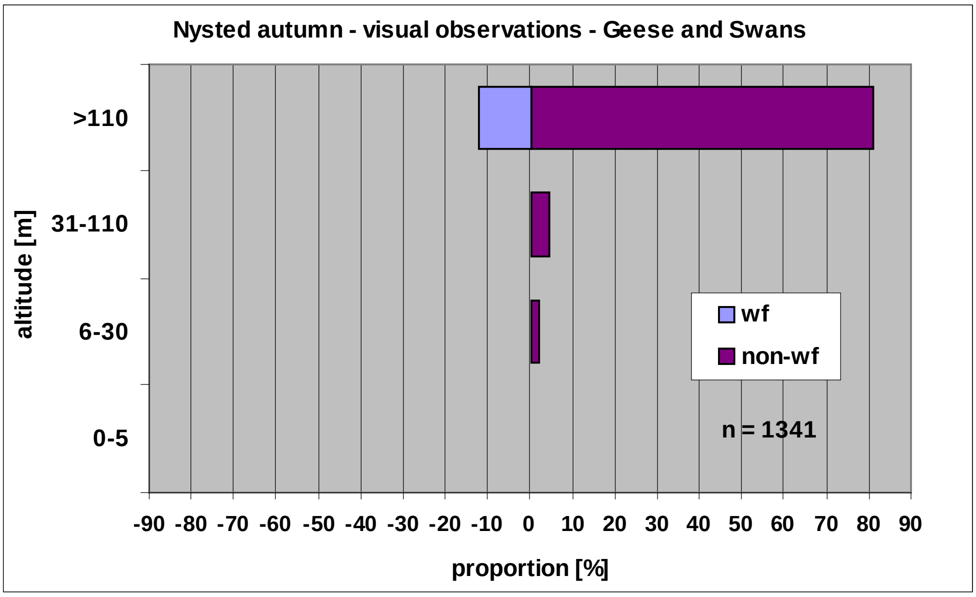


Fig. 4.6: Altitude distribution of swans and geese in Nysted windfarm area in autumn. Windfarm side of transect (wf) left, non-windfarm side (non-wf) right.

Ducks in Nysted clearly avoided the non-wf transect side in both seasons. The only considerable proportion of ducks at wf side was in autumn in the altitude class above the windmills. The altitude classes mostly frequented by ducks were the ones representing the area covered by a windmill propeller and the one underneath. (Fig. 4.7 and Fig. 4.8).

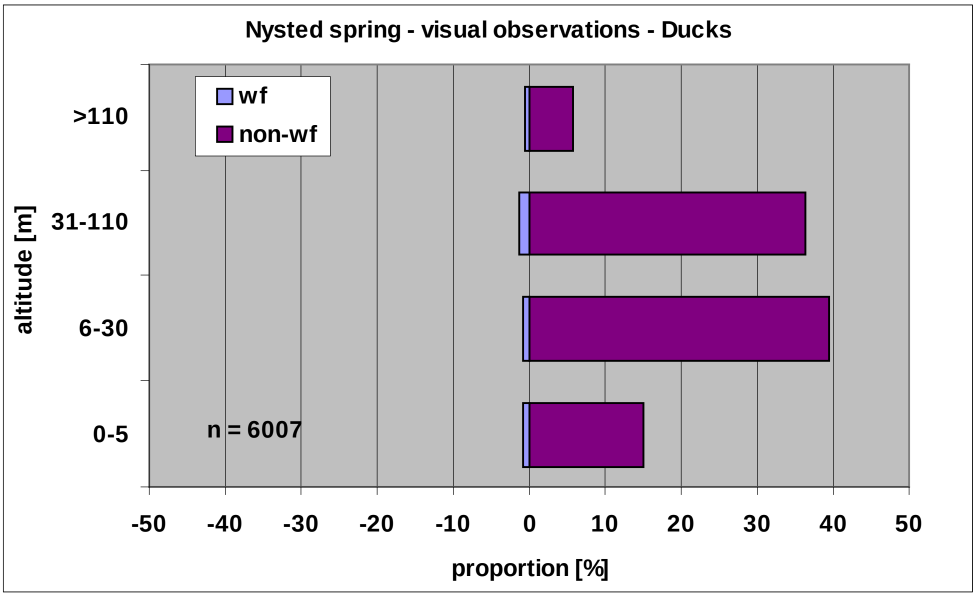


Fig. 4.7: Altitude distribution of ducks in Nysted windfarm area in spring. Windfarm side of transect (wf) left, non-windfarm side (non-wf) right.

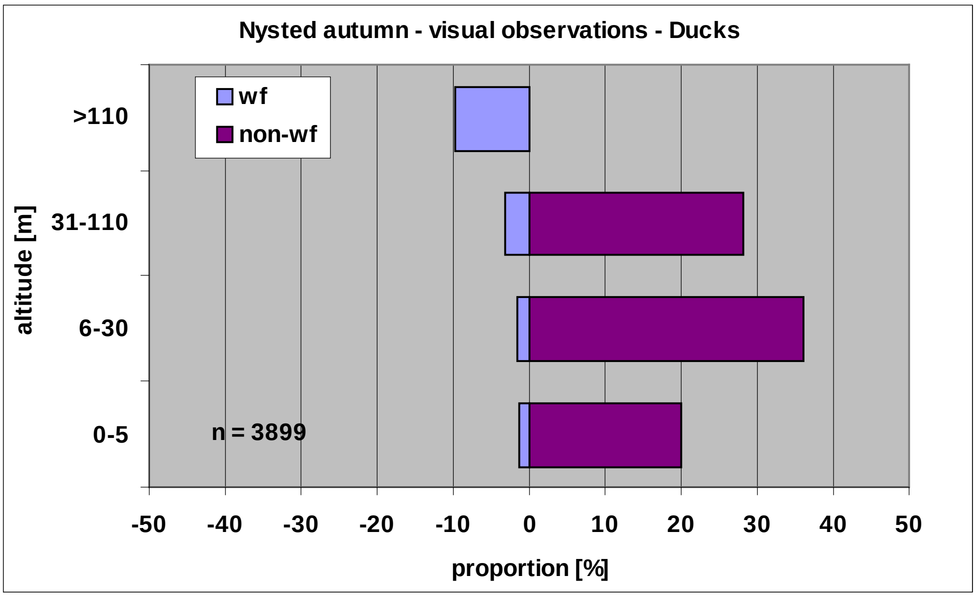


Fig. 4.8: Altitude distribution of ducks in Nysted windfarm area in autumn. Windfarm side of transect (wf) left, non-windfarm side (non-wf) right.

The only duck species recorded in Horns Rev in spring was the common scoter (Fig. 4.9). The pattern of avoidance of the wf side of transect was identical with that of ducks in Nysted. The preferred altitude classes were the two lowest ones, under the area covered by windturbines.

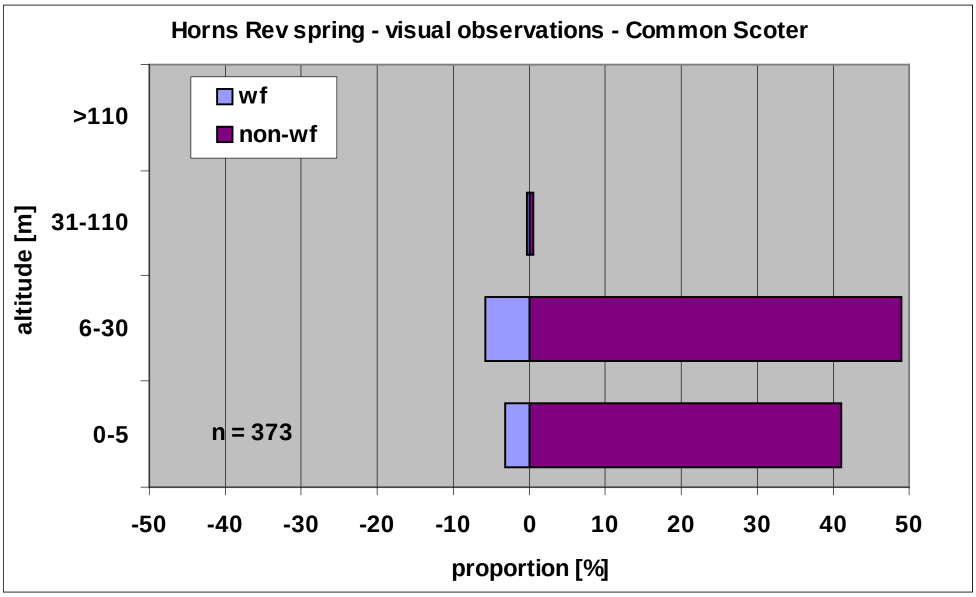


Fig. 4.9: Altitude distribution of common scoters in Horns Rev windfarm area in spring. Windfarm side of transect (wf) left, non-windfarm side (non-wf) right.

Gulls (without Little Gull) showed an almost identical altitude distribution pattern in both areas and both seasons and both sides of the transect (Fig. 4.10 - Fig. 4.13). Except for one case the proportion at non-wf side was always larger, leading to an symmetrical biased image. Obviously Gulls did not avoid the wf side of transect but were found in larger numbers at the non-wf side. The mostly frequented altitude class was that one from 6 to 30 m.

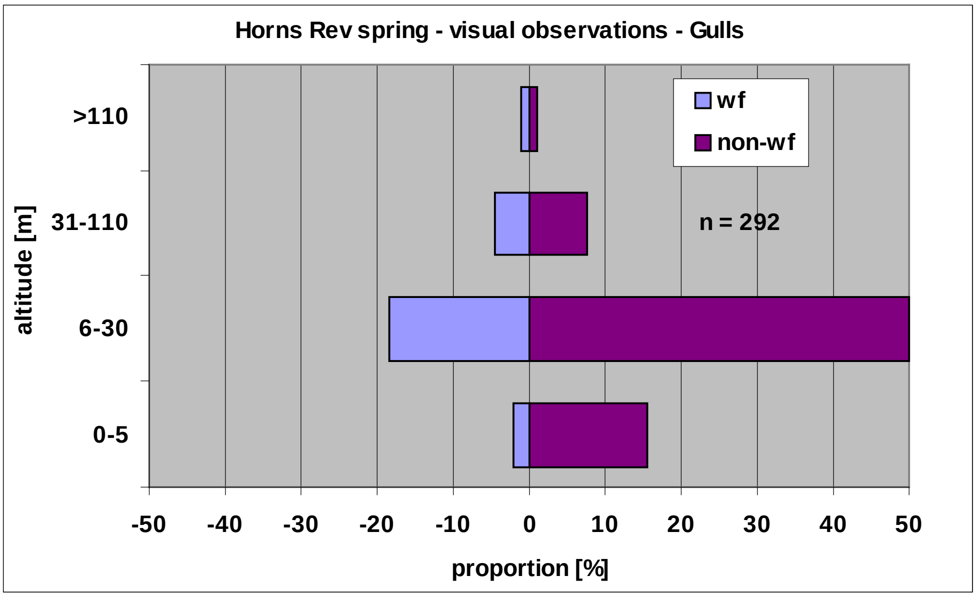


Fig. 4.10: Altitude distribution of gulls (without little gull) in Horns Rev windfarm area in spring. Windfarm side of transect (wf) left, non-windfarm side (non-wf) right.

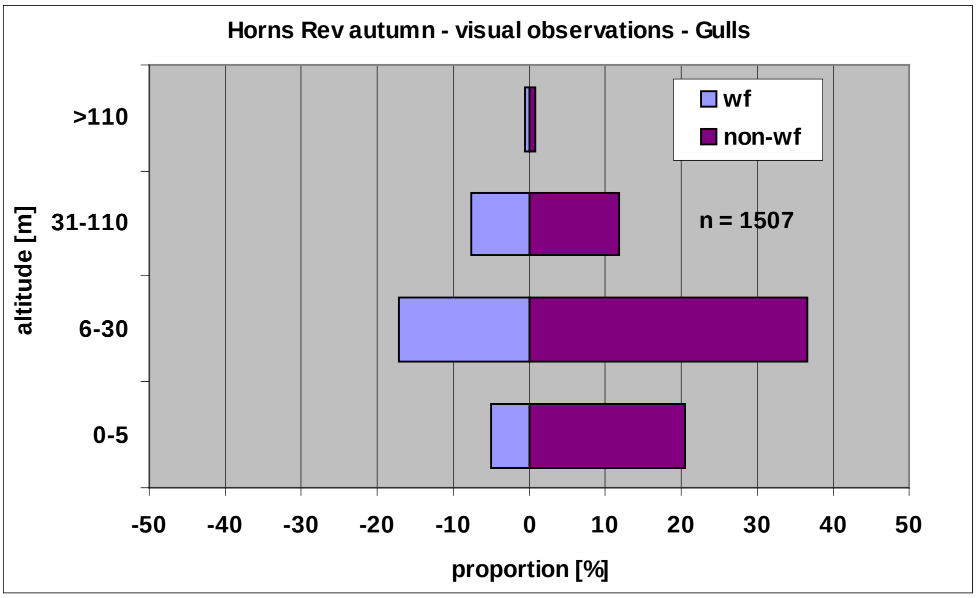


Fig. 4.11: Altitude distribution of gulls (without little gull) in Horns Rev windfarm area in autumn. Windfarm side of transect (wf) left, non-windfarm side (non-wf) right.

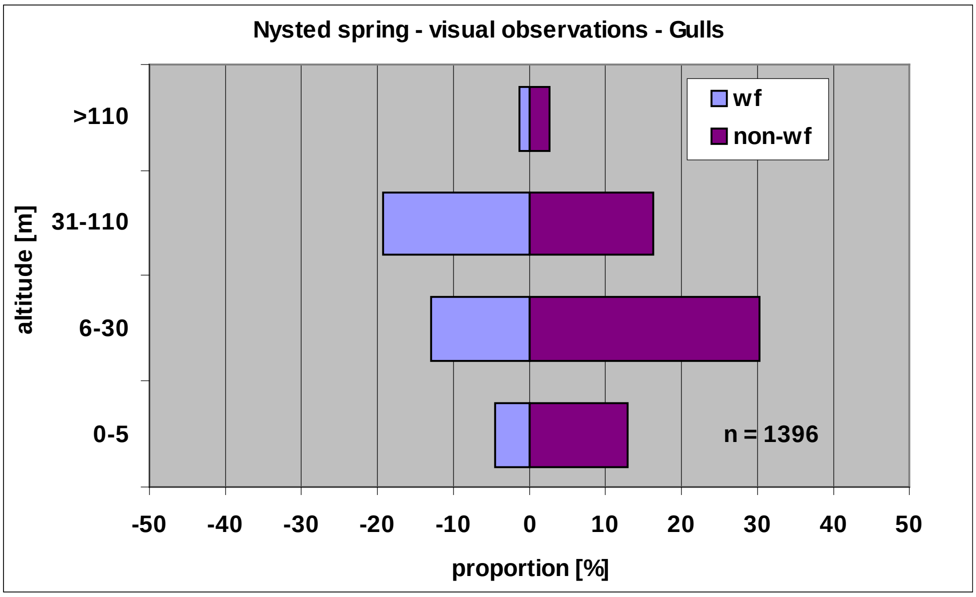


Fig. 4.12: Altitude distribution of gulls (without little gull) in Nysted windfarm area in spring. Windfarm side of transect (wf) left, non-windfarm side (non-wf) right.

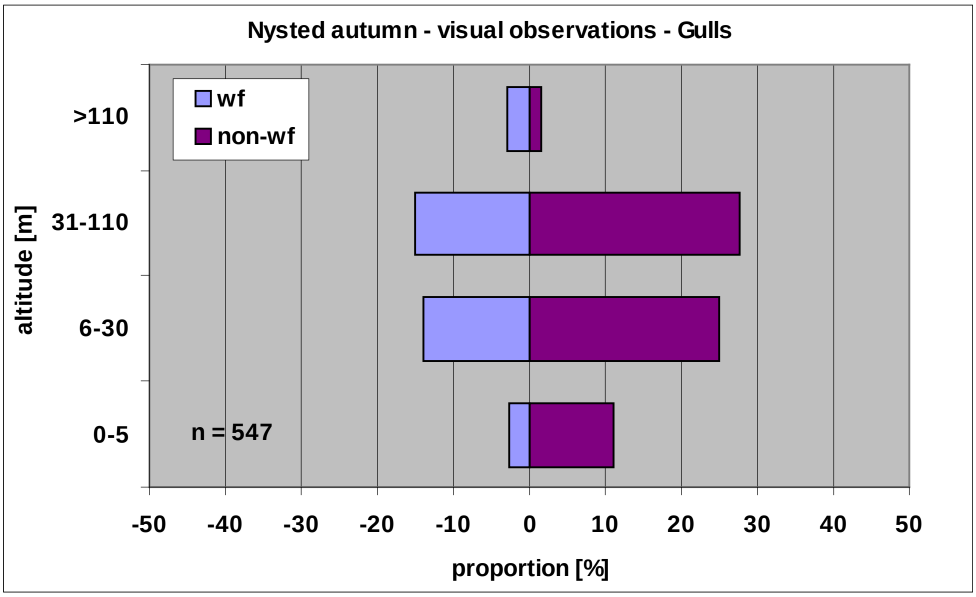


Fig. 4.13: Altitude distribution of gulls (without little gull) in Nysted windfarm area in autumn. Windfarm side of transect (wf) left, non-windfarm side (non-wf) right.

Terns in Horns Rev in spring were mainly restricted to the two lowest altitude classes at non-wf side in even proportions. Only few numbers were observed higher and at the opposite side of the transect (Fig. 4.14).

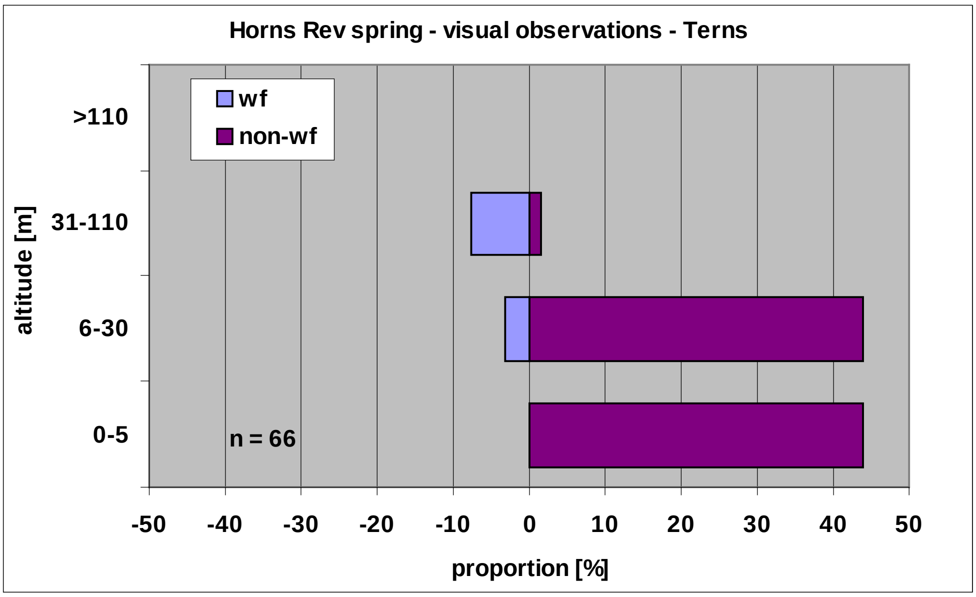


Fig. 4.14: Altitude distribution of terns in Horns Rev windfarm area in spring. Windfarm side of transect (wf) left, non-windfarm side (non-wf) right.

Passerines in Horns Rev in autumn occurred at both sides of the transect in similar proportions in all altitude classes (Fig. 4.15). In Nysted in spring the picture was similar but the altitude class above windmill level was not frequented and the one from 6 to 30 m was strongly preferred (

Fig. 4.16). In Nysted in autumn there was a conspicuous preference of the lowest altitude class (up to 5 m) and avoidance of the wf side (Fig. 4.17).

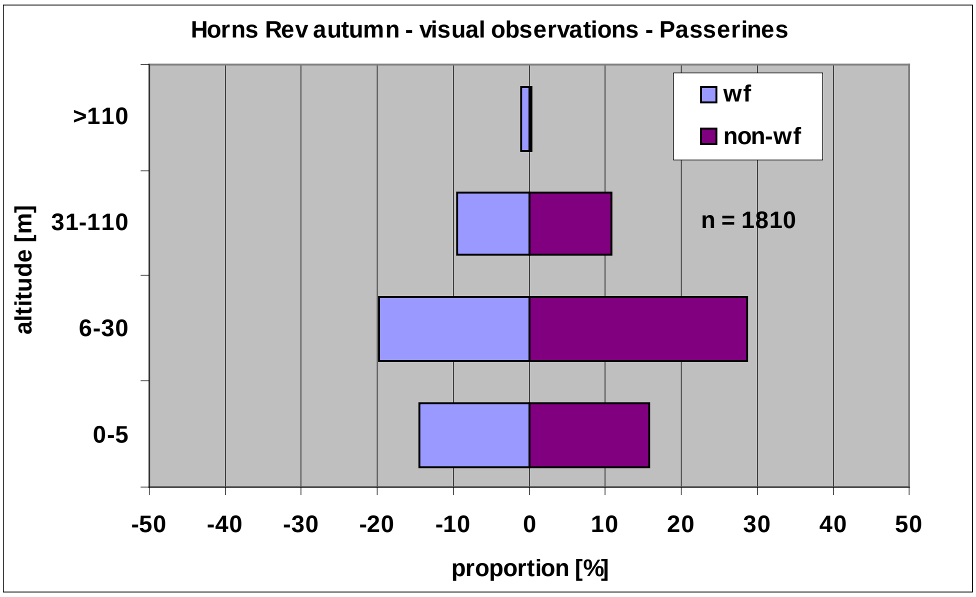


Fig. 4.15: Altitude distribution of passerines in Horns Rev windfarm area in autumn. Windfarm side of transect (wf) left, non-windfarm side (non-wf) right.

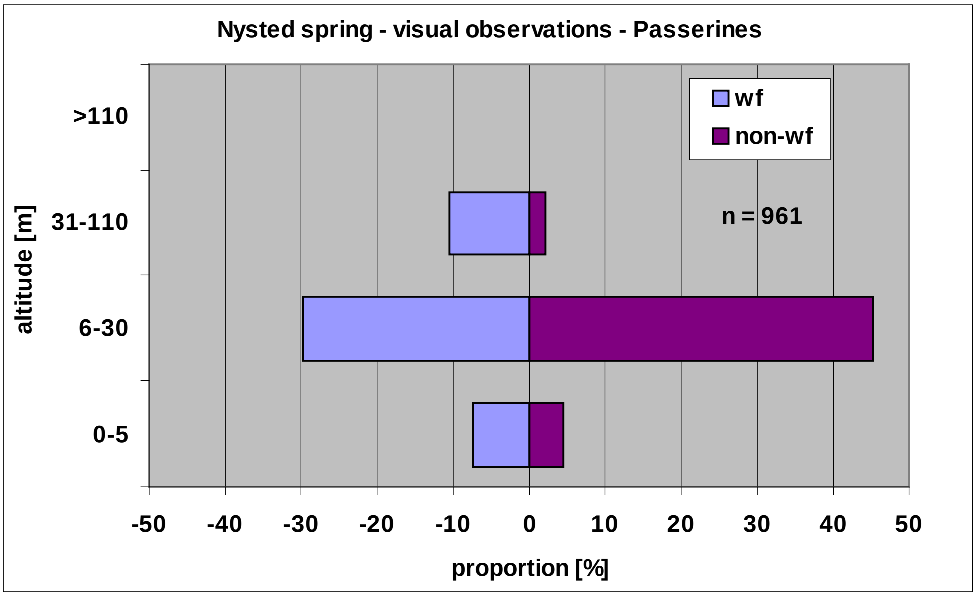


Fig. 4.16: Altitude distribution of passerines in Nysted windfarm area in spring. Windfarm side of transect (wf) left, non-windfarm side (non-wf) right.

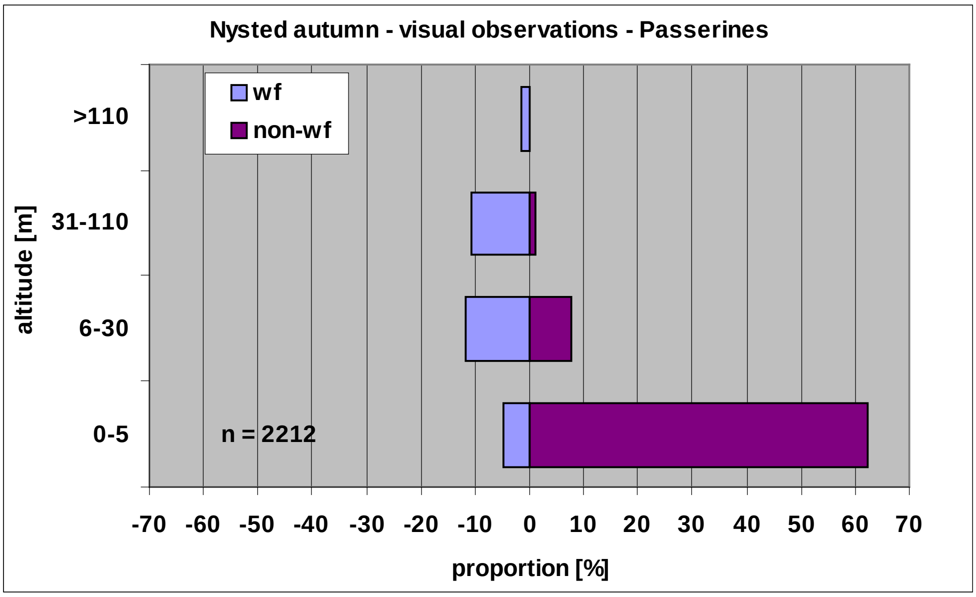
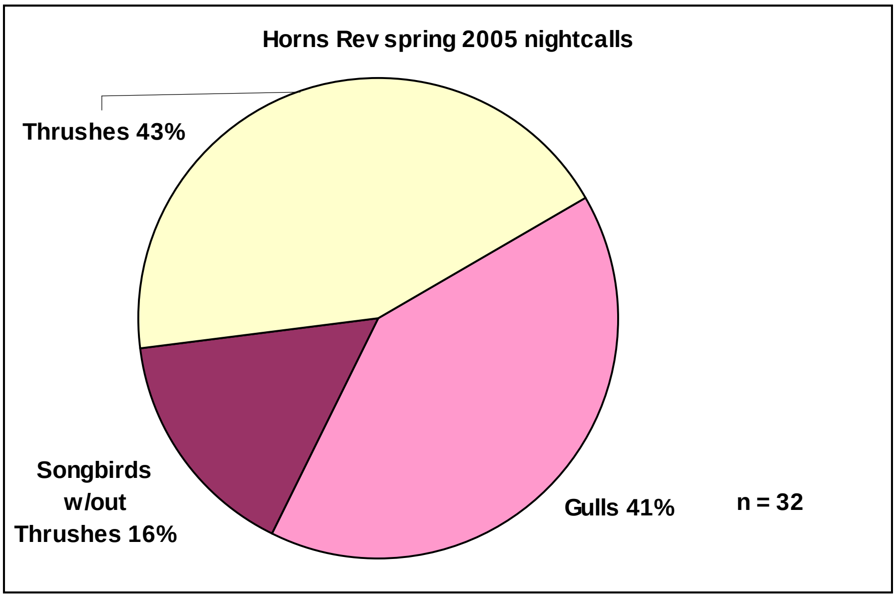


Fig. 4.17: Altitude distribution of passerines in Nysted windfarm area in autumn. Windfarm side of transect (wf) left, non-windfarm side (non-wf) right.

4.2.3. Acoustic observations

For Horns Rev in spring, only few data existed. However, despite complete coverage of nocturnal observation time during the days on effort, only very few flight calls were recorded; for some nights, noise from wind, waves and windmills did potentially conceal bird calls.
In autumn, a better data sample was achieved; the majority of species heard were thrushes (song thrush, redwing, blackbird) followed by robin; other songbird species were rather uncommon.



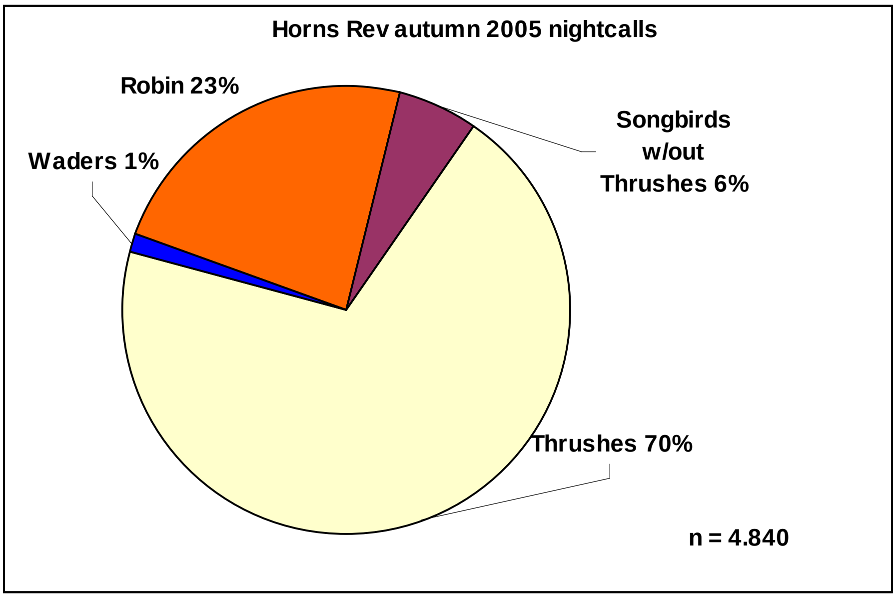
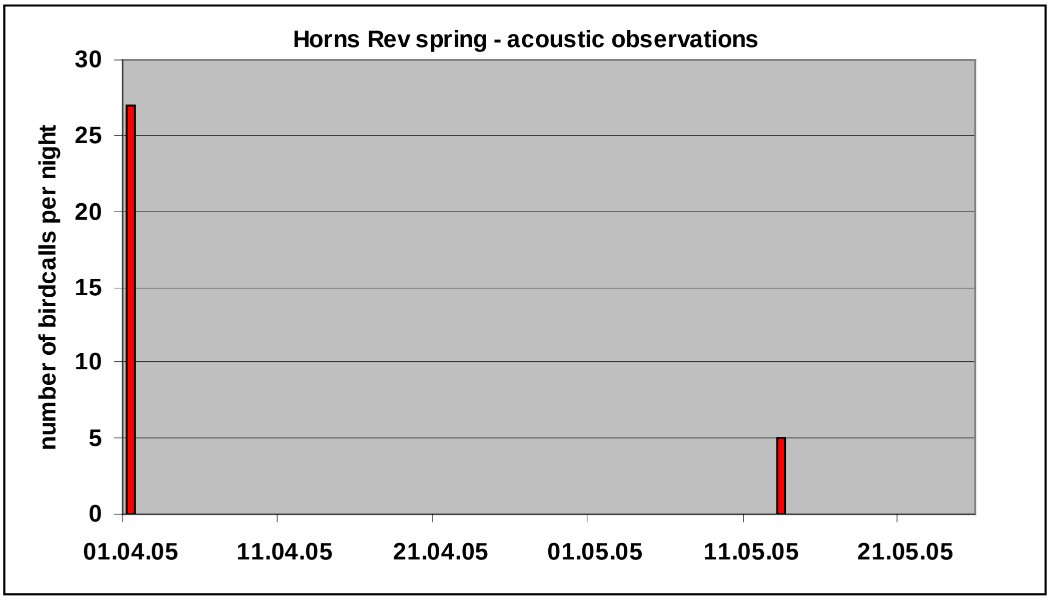


Fig. 4.1: Horns Rev – acoustic observations. Nightcalls in spring and autumn per species group. Spring – 67 hours recorded - 3 species; autumn 298 hours recorded - 21 species.

Phenology showed intense migration periods mainly during October, while a lower migration intensity was recorded in September and November.
Peaks in numbers of night calls and those of radar signals coincided only during some nights around October 4th. Radar signal peaks in September were not associated with peaks of night calls, whereas night call frequency especially around October 21st did not seem to reflect well the radar results.



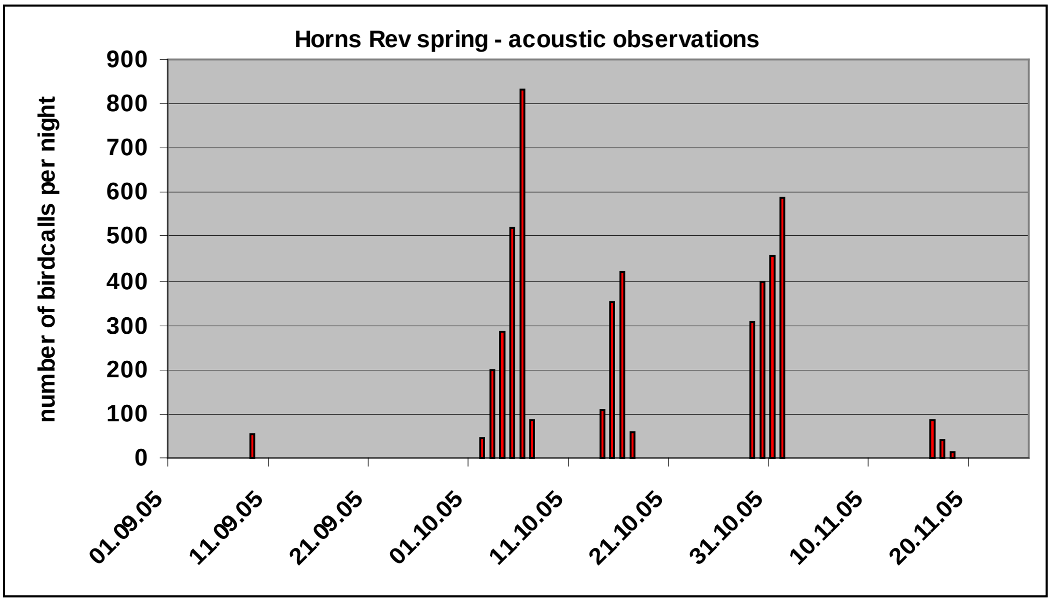
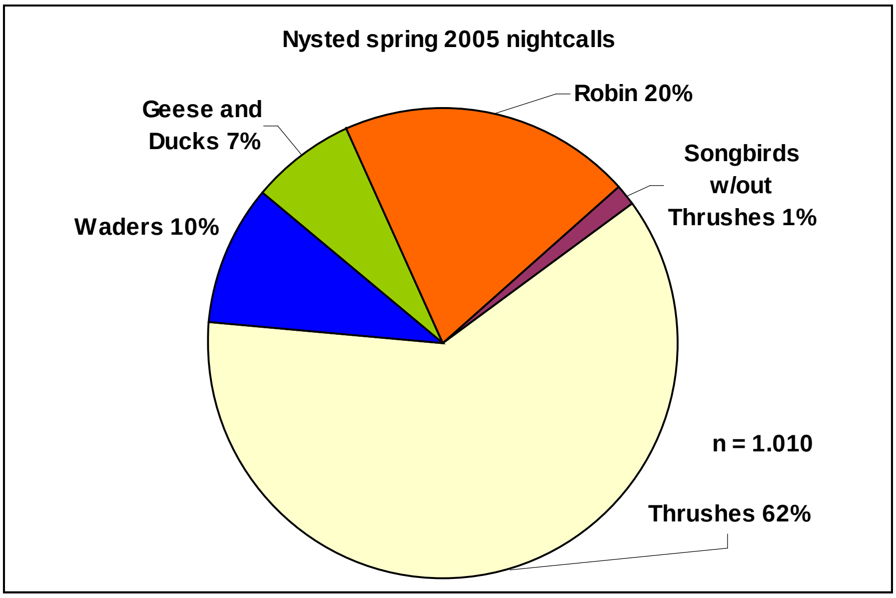


Fig. 4.2: Horns Rev – acoustic observations – phenology - in spring and autumn – all species pooled. Spring – 67 hours recorded - 3 species; autumn 298 hours recorded - 21 species.

At Nysted, acoustic observations in spring yielded much more data than in Horns Rev. Species groups were slightly more diverse. However, thrushes dominated, followed by Robin. Comparison to the radar results for May showed that migration peaks identified by radar signals were not reflected by acoustic observations.

During autumn, again, thrushes and robin dominated; some chaffinch and brambling migration was also recorded.



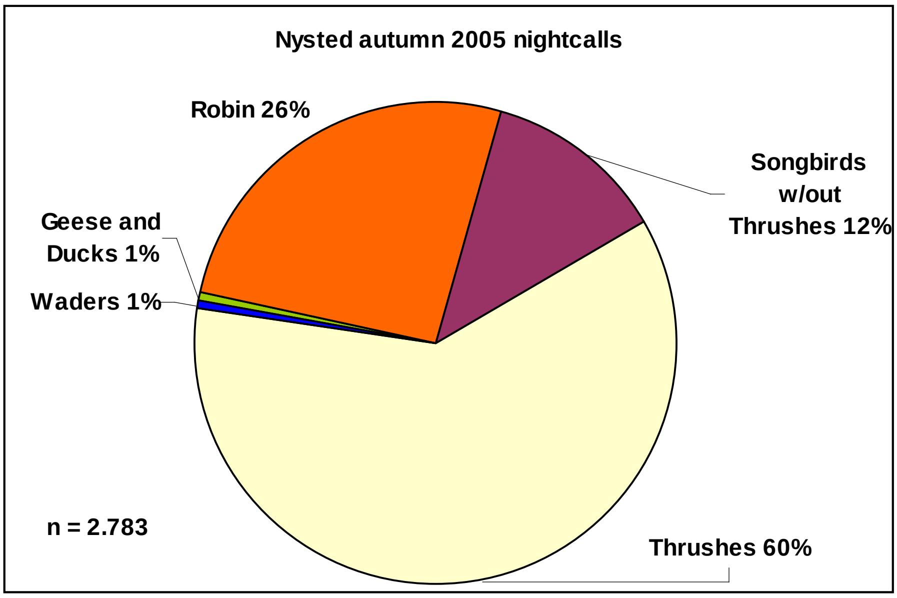
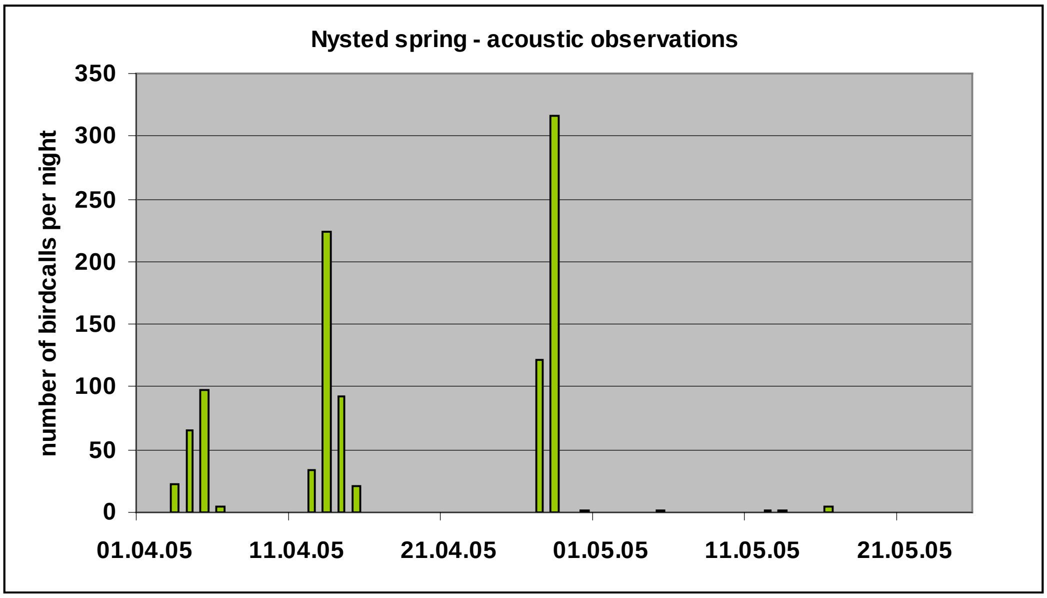


Fig. 4.3: Nysted – acoustic observations. Nightcalls in spring and autumn per species group. Spring – 148 hours recorded - 18 species; autumn – 302 hours recorded - 23 species.

Migration peaks picked up by radar around September 9th were not reflected by acoustic observations, whereas the night call peaks in October coincided better with the radar data.



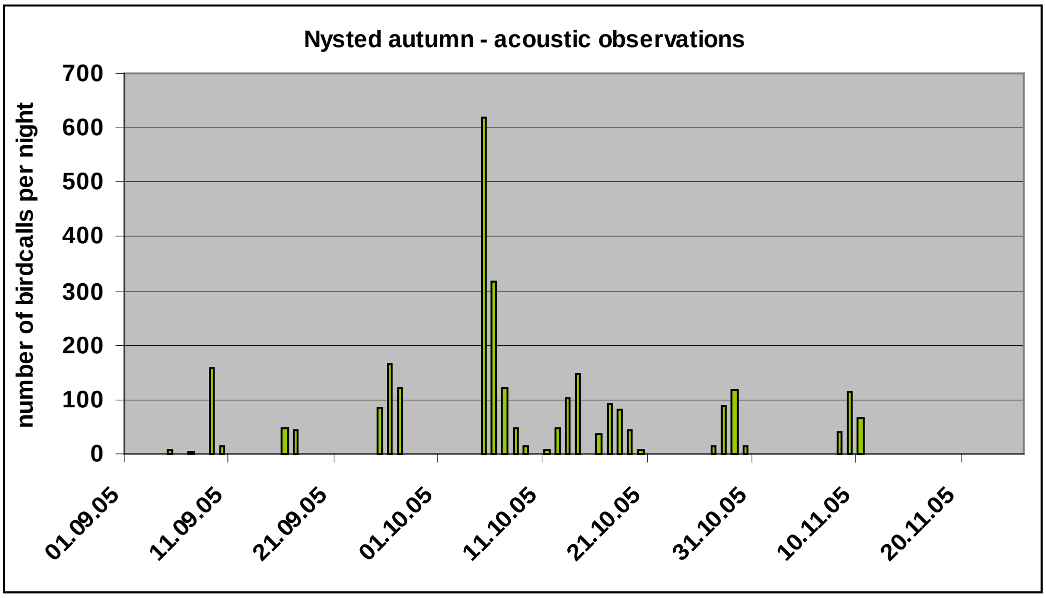


Fig. 4.4: Nysted – acoustic observations - phenology - in spring and autumn – all species pooled. Spring – 148 hours recorded - 18 species; autumn – 302 hours recorded - 23 species.

4.2.4. Reactions of birds to the windfarm

Several options exist to record reactions of flying birds when approaching a windfarm. On the vertical radar a reaction would be a measurable change of altitude of an individual signal. Therefore, on screenshots, a change of altitude would be visible if it occurred within the trail of the radar signal observed; Visibility of a potential altitude change depends on the length of a continuous trail which may reflect a period from a few up to 30 s. Naturally, the latter occasions are rather rare. Tracing signals on the screen for 150 s provides a better representation of longer observation periods and does not have to rely entirely on uninterrupted visible trails because signals produced by one bird or flock can be identified by the observer due to their actual movements and traced. An additional method of tracing signals is to have the software to overlay a series of screenshots for a defined time interval (e.g. 150 s); this option is available in principal.
So far, reactions of birds have not been analysed. However, this will be one of the main focuses in the analyses that will be performed in the coming year.

During visual observations, reactions of birds to the windfarm are an extra category in the protocol. So far, these have not been analysed in detail.

4.3. Discussion of results / Assessments

The main scope of these investigations is to provide data which allow to assess the collision risks of migrating birds with offshore wind turbines. Based on environmental impact assessments results on distributions of birds of all species groups as well as presence of birds during day and night in offshore areas have increased considerably (GRUBER et al. 2002, GRUBER & NEHLS 2003, STAHL & NEHLS 2004, HÜPPOP et al. 2004, OREJAS et al. 2005). However, most investigations have been carried out in the absence of windmills. In Denmark, two large offshore wind farms exist. For these windfarms, not only investigations before construction but also during and after construction were/are undertaken. Investigations have focussed on the distribution of birds and potential avoidance of the windfarm area. Radar and visual observations have been carried out to track birds approaching the windfarms and to document potential reactions (CHRISTENSEN et al. 2002, 2004 a/b, DESHOLM et al. 2002, KAHLERT et al. 2004 a/b). In addition, thermal animal detection systems (TADs) have been installed to record and analyse bird-windmill interactions in the direct surroundings of single windmills and blades (DESHOLM 2005). These investigations have greatly broadened and improved the existing knowledge. However, due to study design and focus some questions still need further investigations.
What are reactions of birds in the direct vicinity of the windfarms? Is songbird migration affected by existing windfarms, especially during night and inclement weather? What kind of data is needed to predict the probability of bird collisions?

Can radar observations be carried out in the direct vicinity of the windfarms?
Study design of the current investigations aims to focus on these questions. Observations have been carried out in the direct vicinity of the windfarms (200-300 m from the border), have focussed on nighttime migration, on altitude distributions analyses by vertical radar and on all bird species present during migration periods; comparisons between areas inside and outside windfarms are possible.

4.3.1. Migration intensity

Raw data on migration intensity are still hard to compare to other studies. Even though progress has been made to harmonize both methods and analyses, both hardware and software still cover a broad variety. Technical adjustments as e.g. the radar range, often depend on the focus of the study. With a large range (3-6km), you may cover large areas, but sensitivity to detect smaller birds is highly reduced. Using a smaller range with improved sensitivity, the area covered becomes smaller and chances to cover a suitable area may vary stronger. Radar devices differ in power, parameters and sensitivity; decisions made with regard to radar settings may also influence the results (WENDELN et al. unpubl., BSH 2003). Last but not least analyses of existing radar pictures depend to some degree on the user.
However, even in light of these insecurities, the scale of the results from this study seems to confirm former results. No obvious differences were detected between the two locations (Horns Rev, Nysted). Migration intensity was higher during night than during day; this was a result of effectively measuring nocturnal songbird migration with the chosen radar ranges of 0.5 and 1.5 km. Autumn migration seems to have taken place in slightly higher altitudes than spring migration; however, conclusions cannot be drawn because so far less data are available from spring than from autumn.
Migration depends highly on weather conditions (not tested here) and may concentrate in small time intervals when conditions are good; migration peaks often occur when longer periods of unfavourable conditions change into favourable conditions. Despite these weather changes are hard to predict, we have tried to be present in the study areas during such conditions to be able to collect data during migration peaks. However, only a few nights of intensive migration have been picked up; this is potentially an effect of the individual weather situation in spring and autumn 2005, when the situations of “abruptly changing conditions inducing migration peaks” have been rare; especially the autumn has been characterized by a long period of untypical warm weather probably holding birds farther north longer than expected and inducing a rather continuous flow of rather small numbers of migrating birds.

4.3.2. Altitude distributions

This is the first time, that is has been tried to measure altitude distributions in existing offshore windfarms. Due to technical constraints (sea cable), the ship had to be positioned outside the windfarm area. This results in areas of different size covered by radar investigation and visual observation respectively inside and outside the windfarm. All signals on the windfarm side have been defined as inside and all other signals as outside the windfarm. Since the distance between the rows of windmills is 450-500 m (in Nysted in north-south rows are even 850 m apart), a distance of 200 – 300 m “outside” the windfarm is not larger than the centre between rows. With these definitions, comparisons can be made for migration intensity (not analysed for this report) and altitude distributions inside and outside the windfarm area. Data help to identify birds flying within the altitude of the windmills; in future these data may be fed into collision models.

Results of altitude distributions show several patterns:

Daytime migration – more signals were found on the lower altitude bands in comparison to nighttime migration (exception: Nysted, 0.5 km range in autumn). During visual observations mainly cormorants, geese and duck species as well as gull and tern species were recorded during daytime in both locations. However, on the radar screen no species can be identified; in addition, it is in most cases impossible to attribute signals on the vertical radar to birds observed with visual methods (thus producing species specific radar data); reasons are that the exact flight path of a bird cannot be concluded from the radar screen and that even medium-sized birds flying above 100 m are hardly spotted by visual observations.

Nighttime migration – data yielded from 0.5 km range pictures frequently showed an even distribution of signals across the altitude bands. There was a slight hint, that the number of signals was lower on the windfarm side compared to the non-windfarm side. This could mean that some birds avoid flying into the windfarm area. However, these results could potentially represent artefacts. As discussed above, signals might be directly hidden by windmill echoes unavoidably covering some area on the radar screen; signals might also be indirectly hidden by these disturbance in certain ‘shadow’ areas around the direct disturbance. These potential problems are already known with regard to larger range radar investigations, when radar signals of ducks or geese “disappeared” close to the windfarm area from the radar screen (KAHLERT et al. 2004a/b). By operating at a closer distance to the windmills and by using a smaller radar range, these disturbances can possibly be reduced, but the problem that some signals are concealed will probably not be solved completely. Despite the fact disturbances existed on both sides of the windfarm, disturbances were generally more intensive on the windfarm side.

In the 1.5 km range, signals in the lower altitude ranges clearly predominated, giving the figures a certain pyramid-like shape. Again, number of signals were slightly lower on the windfarm side. While these figures suggest, that nocturnal migration also existed 200 m inside and outside the windfarm area, still the majority of signals (> 60%) was registered above 200 m. An exception was Nysted in spring 2005, when signals were distributed more evenly across the entire altitude; this may be caused by a particular species distribution; however, acoustic observations did only pick up birds close to the ship and up to an estimated altitude of 50 or sometimes 100 m; however, spring and autumn species distribution of nocturnal migrants was rather similar with thrushes and Robin representing more than 75% of the nightcalls.

Future analyses will extract and focus on altitude distributions during certain conditions (peak migration nights, weather influences such as tail or head winds, rain, nights of poor visibility). Possibly, single nights show deviating altitude distributions; then, data of these nights (migration intensity, weather data) can also be used to refine a collision model.
Visual observations (daytime) – Unlike in radar investigations in visual observations it is possible to look at altitude distributions of particular taxa. These data can be yielded only during daytime, so one will miss the majority of typically night migrating groups (e.g. Waders, Warblers). However, visual observations allow a closer look at the species concerned.
The potential overrepresentation of special conditions has to be considered adequately especially if the effort time for the observation is limited (as it was in Horns Rev in spring).

Among passerines, autumn distribution patterns in Horns Rev were to a certain degree similar to spring distribution in Nysted but they differed significantly from autumn distribution in Nysted. This might be an example for the impact of weather conditions on the results. When facing strong headwind birds seek the airspace low above the water surface to minimize air resistence. This might be explain the altitude distribution recorded. To proof such assumptions weather data will be analysed in future, too, and compared with bird-related data (both visual observation and radar data).

4.3.3. Reactions of birds

Scope of an investigation on collision risk should be to record reactions of birds to the windfarm or single windmills, respectively. Danish studies have very clearly shown, that – assumingly – low flying birds, mainly Common Eider and Common Scoter, which are flying towards the windfarm, seem to show reactions already in some 3-4 km distance from the windfarm. This becomes clear, since in a marine environment, for a low flying animal depending on sight, a windfarm with some 80 windmills covering a horizontal length of 4 to even 8 km is a structure that is well visible from this distance. During night, avoidance reactions seem to happen closer to the windfarm (~ 1 km). These reactions are well documented (KAHLERT et al. 2004a/b).
It must be assumed, that, in this study, we simply missed many birds which have reacted on the windfarms at the described distances. Clearly, ducks taking course around the windfarm would neither cross the transects used for visual observation nor would they appear on the radar. Even in a distance of 1 km, only a low proportion of individuals showing reactions will be properly recorded with our methods. The conclusion could be, that the Danish study already describes the avoidance reactions of the birds; in contrast, our study aims to describe behaviour of birds actually coming as close as < 1 km to the windfarm .
The focus of further analyses will be the description of this behaviour.
The data accumulated so far indicate a marked avoidance response of migrating birds during daylight, which was however much less clear from the radar investigations and only slightly indicated at night. It is remarkable in this respect that some species which seem to be rather familiar with the windfarms as gulls and cormorant, apparently avoid the windfarms when

passing the area. The contrasting results of visual observations during the day and radar observation during night may indicate a reduced ability of migrating birds to avoid the wind farms at night but further investigations are required before conclusions can be drawn.

4.4. Outlook / future investigations / changes of programme

The investigations will continue for a full year comprising two migration seasons. Depending on weather conditions, we will start as early in spring season as possible (March) and will be able to cover 25 ship days in each wind farm. Method descriptions and radar recordings will be refined based on the experiences made. However, it is clearly necessary to sample simply more data and to acquire data during different migration and weather conditions.
To further explain and potentially to correct for disturbance by windmills, it is intended to calibrate the vertical radar recordings. This can be achieved by holding up an object (e.g. aluminium ball, dead bird) via a helium-filled balloon at different altitudes from a small boat and to drive predetermined transects within the 0.5 and 1.5 km range; radar recordings will then show areas of good and less good detection.
As mentioned above a co-analysis of weather data and radar yielded as well as observation yielded data will be done.
To get an impression of the birds reaction to the windfarm their flight directions recorded with the horizontal radar could be taken into account, too.
To overcome the problem of how to deal with birds (observation) and signals (radar) recorded between the vessel and the windfarm (not inside the windfarm but at windfarm side of transect) an alternative experimental design might be considered. An idea is to position under favourable conditions for a few days two vessels in one windfarm area. One ship could be placed in the central part of the windfarm and the other one further outside in the direction from where the main migration activity is expected to approach. Such an experiment could help to judge the data yielded by the present method and give impulses for future projects.

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