# Effects of the Nysted Offshore Wind Farm on harbour porpoises.

## - Annual status report for the T-POD monitoring program

Technical Report to Energi E2 A/S

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# Summary

This report describes data collected in 2004 on the harbour porpoise monitoring program in connection to Nysted Offshore Wind farm and compares with results from previous years of monitoring. The year 2004 was the first year of operation of the wind farm and as the monitoring continues throughout 2005, conclusions must be considered preliminary. Conclusions on animal abundance and behaviour during 2004 were nevertheless clear. No significant increase in abundance of porpoises in the wind farm area was seen in 2004 relative to the construction period and levels are still about a factor 5 lower than during baseline monitoring. In parallel with this was a decline observed in the reference area, about 10 km east of the wind farm, but this decline in abundance in the reference area was significantly smaller than in the wind farm itself.

Porpoises were not absent from the wind farm however, and when present their acoustic behaviour was not significantly different from baseline behaviour. The reason why fewer porpoises frequented the wind farm during its first year of operation is unknown and it is too early to establish whether the effect is permanent or recovery to baseline levels is slower than originally anticipated.

# Dansk Resumé

Denne rapport beskriver data indsamlet i 2004 under marsvineovervågningen i forbindelse med Nysted Havvindmøllepark og sammenligner disse med data fra tidligere år. 2004 var det første år mølleparken var i fuld drift og da overvågningen fortsætter i 2005 skal alle konklusioner i rapporten betragtes som foreløbige. Resultaterne vedrørende tilstedeværelse af marsvin i mølleområdet og deres adfærd er imidlertid temmeligt klare. Der er ikke observeret en stigning i forekomsten af marsvin i 2004, set i forhold til konstruktionsperioden og forekomsten er således stadig omkring 20% af hvad den var i referenceperioden før mølleparken blev bygget. Der er ligeledes en nedgang i forekomsten af marsvin i referenceområdet ca. 10 km øst for mølleparken, set i forhold til før mølleparken blev bygget, men denne nedgang er signifikant mindre end for selve mølleparken.

Marsvinene er imidlertid stadig tilstede i mølleparken og når de er der, er deres akustiske adfærd ikke anderledes end den var før mølleparken blev bygget. Årsagen til at der er færre marsvin i mølleparken og til dels i referenceområdet er ukendt og det er for tidligt at afgøre hvorvidt der er tale om en permanent effekt af mølleparken eller om marsvinene blot vender tilbage til området langsommere end oprindeligt forventet.

# 1 Introduction

This report describes the current status of the harbour porpoise monitoring program at Nysted Offshore Windfarm. Results obtained in 2004, the first year of operation of the wind farm, are discussed and compared to results from baseline and construction periods. Detailed descriptions of baseline data and data collected during the construction period can be found in previous reports (Henriksen et al. 2003, Henriksen et al. 2004, Teilmann et al. 2001).

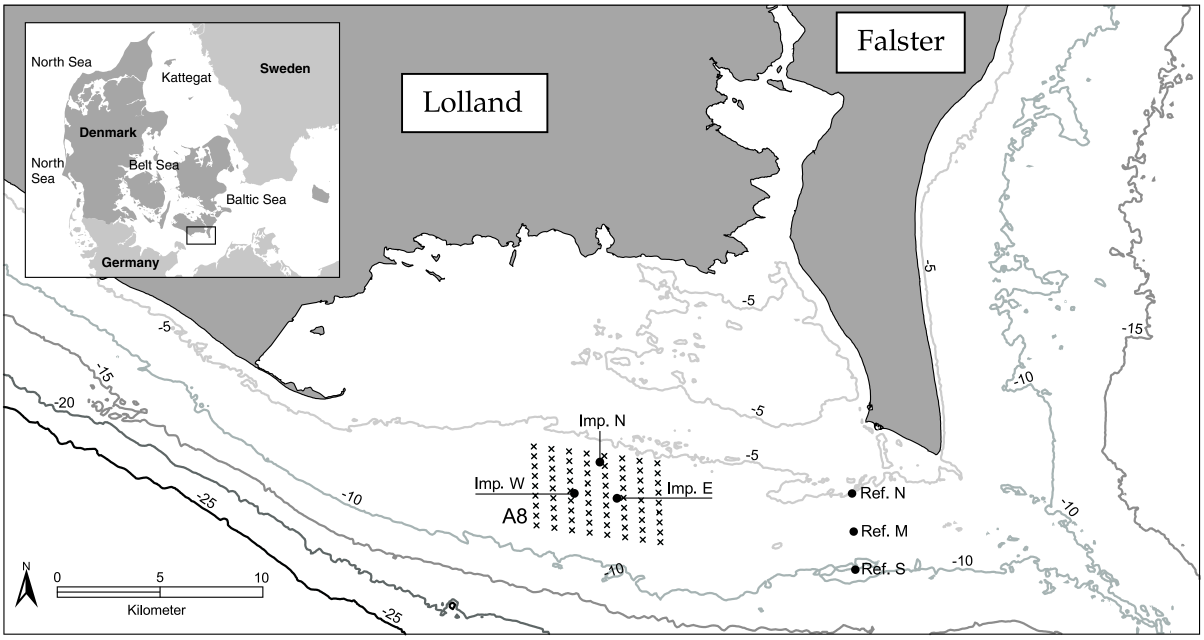


Figure 1: Study area. Wind turbines are indicated with x and T-POD monitoring stations with solid circles. Three stations (Imp. W, N and E) are located inside the wind farm and three stations (Ref., N, M and S) are located in a reference area east of the wind farm.

## 1.1 The Rødsand/Nysted area

The Nysted Offshore Wind Farm is situated about 10 km southwest of Gedser in the Femer Belt (Figure 1) and about 4 km south of the sandbarrier Rødsand. This narrow barrier runs about 25 km from Hyllekrog to Gedser and is partly exposed at normal water levels. The sand reef borders a shallow lagoon area (depths 0.5-7 m), which is an important area for fish, birds, seals and recreational coastal fishery.
Water depth in the wind farm varies between 6 m and 9.5 m and the sea floor consists primarily of glacial depositions (Hansson 2000). The largest part of the area is covered by sand/silt bottom with larger and smaller ridges and with aggregations of pebbles, gravel and shells scattered throughout the area. No reef-like aggregations are found in the area.

The water is brackish and varies with the freshwater surface flow from the Baltic Sea and the more saline water from Kattegat. The tide is weak in the area (less than 0.5 m) and variations in water level is primarily determined by wind.

*Figure 2* Nysted Offshore Wind Farm. Photo: Energy E2.

## 1.2 Nysted Offshore Wind Farm

The wind farm was build in 2002/2003 as part of a Danish national demonstration project, aimed at assessing and developing the possibilities in large-scale offshore wind farms. An integral part of the demonstration project has been assessment of environmental impact of construction and operation of the wind farms. This assessment consists of monitoring programs for invertebrates, fish, birds and marine mammals conducted before construction (baseline period), and during the construction phase and the initial years of operation.

The start of the construction period was mid-June 2002 where excavations for the foundations started. The last wind turbine was mounted July 27th 2003 and the last 33 kV cables were covered up in December 2003. The wind farm officially started in normal operation December 1st 2003, which is adopted in this report as the cut-off date between construction phase and operational phase.

## 1.3 Harbour porpoises in the Nysted/Rødsand area

The harbour porpoise (*Phocoena phocoena*) is the only cetacean regularly found in inner Danish Waters and the western Baltic. It is very common in Danish waters, with a total population in Kattegat, Belt seas and western Baltic estimated around 40.000 animals (Hammond et al. 1995). Porpoises are found in most of the western Baltic, but with a sharp gradient in densities in the waters west of Bornholm. With the exception of small populations off the coast of Poland and perhaps other small and local populations, porpoises are virtually absent from the Baltic proper. The area south east of the islands Lolland and Falster (see Figure 1) is thus the easternmost areas where porpoises are found on a regular basis and thus at the south-eastern limit of the main distribution range of porpoises.

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 fouraging very close to shore, even in the surf zone.

Baseline observations showed that harbour porpoises regularly exploit the Nysted Offshore Wind Farm area. Very limited knowledge exists on porpoise habitat use in general and it is not known how they used the area prior to construction of the windfarm, i.e. whether they were foraging, used the area as a breeding ground or merely as a transit area. Studies during the first part of the construction period (fall 2002) showed a pronounced effect of construction activities on echolocation activity of harbour porpoises (Henriksen et al 2003). Largest effects were observed in connection with the vibration and pile driving of steel sheet piles around foundation A8. Harbour porpoises left the construction area when the activity began but returned again after the end of each vibration/pile driving operation. Mitigation procedures in the form of acoustic pingers and seal scarers were deployed prior to each vibration event. The impact from the vibration/pile driving activity was not restricted to the wind farm area, as a significant effect was also found in the control area. The average "waiting time" between harbour porpoise encounters in the wind farm area rose from a few hours in general to more than 24 hours after each pile driving activity. Once the porpoises returned to the area, the activity was back to levels normal for the operation period as a whole. These general levels were considerably lower than baseline levels, most likely caused by the general disturbance of the various construction activities, of which pile driving constituted only a minute part.

Disturbance of porpoises in the Nysted Offshore Wind Farm area during the construction period and displacement from the area was anticipated in the environmental impact assessment (Bach et al., 2000). The EIA also predicted that animals would return to the wind farm area in the operational period following end of construction.

## 1.4 Expected effects from a wind farm in normal operation

Offshore wind farms in normal operation can potentially affect harbour porpoises in least three different ways: changes in habitat (net effect may be positive or negative), disturbance from turbines and disturbance from service and maintenance activities.

### 1.4.1 Changes in habitat

The direct, physical loss of habitat is of little importance, as the loss of seabed due to the turbine foundations is negligible. Of importance are only secondary changes induced by the turbines, most importantly possible changes in the abundance and species composition of fish inside the park, due to the introduction of hard bottom substrates. This issue is dealt with by a separate study conducted by Bio/consult. It is important to note however, that changes in fish fauna can be potentially negative to harbour porpoises (exclusion of important prey species) or potentially positive (attraction of important prey species by the increased epifauna attached to the wind turbine foundations and scour protection).

### 1.4.2 Noise from operating wind turbines

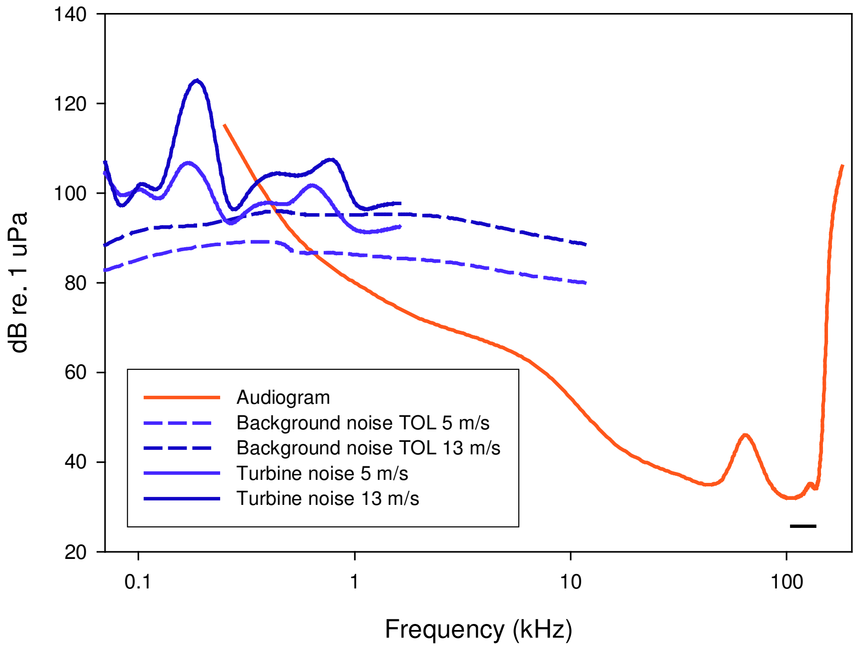


*Figure 3* Harbour porpoise audiogram (Kastelein et al. 2002), third-octave noise levels from a wind turbine at Utgrunden Wind Farm (Ingemansson, 2003), measured at a distance of 83 m, and third-octave background noise levels from the Baltic (Willie and Geyer 1984) at two different wind speeds. Horisontal black bar indicates the frequency range of harbour porpoise sonar signals. Noise with intensities above both the audiogram and background noise are audible to the porpoise. Turbine and background noise were not measured above 2 kHz and 12 kHz, respectively.

The physical presence of the turbines themselves is unlikely to keep porpoises out of the park. Noise radiated from the turbine foundations into the water could potentially have an effect. Based on measurements on other offshore wind turbines, the noise from the wind turbines is expected to be of relatively low intensity and frequency (see Wahlberg and Westerberg (2005) for review of measurements). Calculations and field experiments indicate that harbour porpoises are able to hear individual turbines at distances up to about hundred meters (Henriksen 2001). *Figure 3* shows noise from a single 1.4 MW turbine at Utgrunden Wind Farm (Ingemansson, 2003), the by far loudest turbine noise measured to date. Absolute third-octave levels measured at 83 meters distance from the turbine foundation are low, with a maximum of 126 dB re 1 μPa at 180 Hz, measured at a wind speed of 13 m/s. This level roughly coincides with the extrapolated audiogram of the porpoise, indicating that it should be just audible to a porpoise 83 m from the turbine, where the measurement was made. A second, smaller peak around 800 Hz is present in the turbine noise. This peak is considerably above threshold level for the porpoise at 800 Hz and 10-15 dB above background noise level, and should be clearly audible to the animal at 83 meters. The distance at which this peak disappears below the background noise can be calculated given knowledge of the transmission loss in the waters around the turbine. Measurements from Ingemansson (2003), recalculated by Madsen et al. (2005) indicate a transmission loss of 30 dB per 10-fold increase in distance. Using this value, the peak at 800 Hz reaches the background noise level at a distance of 260 m from the turbine.

No measurements of noise from the turbines at Nysted Offshore Wind Farm are available and it is thus not known whether the measurements from Utgrunden are representative. The measurements of Ingemansson (2003) are about 10 dB higher than levels reported from other wind farms (Westerberg 1994, Degn 2000, Fristedt et al. 2001, Henriksen, 2001) and thus represents worst case for existing wind farms.

The noise from the turbines at Nysted Offshore Wind Farm are not likely to be audible at distances beyond 1-300 m from the turbines. When it comes to reactions of the porpoises to the noise, we are left with qualified guessing. Sound pressure levels where behavioural reactions are observed are likely to be considerably higher than levels of audibility and may vary considerably from individual to individual. A high dependence on context is also likely, as animals engaged in important activities, such as feeding or mating, may be more tolerant to increased noise levels. The extent of the zone of responsiveness (*sensu* Richardson et al., 1995) is thus likely to be considerably smaller than the zone of audibility and reactions may thus be expected to occur only in the very vicinity of the turbine foundations.

Besides being a disturbing factor in itself, noise has the potential to interfere with detection of other sounds, known as masking. This may occur when there is an overlap between the frequency ranges of the noise and the sound in question. The low frequency emphasis of the turbine noise makes it very unlikely that it will mask any sounds of importance to the porpoises under any conditions. The echolocation signals of porpoises contain virtually no energy below 100 kHz and are thus completely outside the frequency range of the turbine noise. There may be other sounds, such as from potential prey, which contains significant energy at lower frequencies and thus potentially could be masked by the turbine noise. However, it is well established that the audiogram of a particular animal reflects the frequency content of the sounds of importance to the particular animal. Porpoises have poor low frequency hearing, poorer than e.g. seals and considerably poorer than low frequency hearing specialists, such as fish. Thus, by this indirect inference, it seems unlikely that they listen for sounds below 1 kHz on a regular basis and any masking by the turbine noise in this frequency range is thus unlikely to be significant to the animals.

### 1.4.3 Noise from service and maintenance activities

The third potentially disturbing factor is service operations on the turbines, where small, fast boats commute between land and the wind farm, as well as between the wind turbines. Such boats are known to be very noisy especially at cruising speeds above 15 knots (Richardson et al., 1995, Erbe 2002) and the pure presence of these boats are likely to have a deterring effect on harbour porpoises. In contrast to the noise from the turbines, the boat noise is of intermittent nature and overall disturbance will depend on the duration of each visit and intervals between visits. The wind farm area was previously used mostly for recreational traffic to and from Nysted harbour (Figure 1). A regular presence of service vessels in the area will be a marked increase in boating activity, especially outside the summer season where the leisure traffic to Nysted is negligible.

The effects of boat traffic on presence of harbour porpoises are poorly documented and while there is a general agreement that porpoises will evade individual fast motor vessels, there is no basis for concluding that high boat traffic levels in general correlate with low abundance of porpoises. Some of the highest densities of porpoises in inner Danish waters are in fact found in the most heavily trafficked areas, Storebælt and Lillebælt (Kinze et al. 2003, Teilmann et al. 2004).

## 1.5 Major events in monitoring period

A number of events unrelated or only indirectly related to the construction of the wind farm have occurred in the monitoring period. These events are of a nature that could potentially interfere with conclusions, either by affecting the abundance of porpoises or by interference with the T-POD acoustic detection system. These events are described briefly below and the most significant, pile drivings in Gedser harbour is discussed in the results and discussion sections.

**Pile driving in Gedser Harbour in 2002**

Pile driving operations were undertaken at Gedser harbour in the period 5th to 12th of September 2002 (i.e. concurrent with pile drivings at foundation A8 in the wind farm). Fifty-one sheetpiles along the outer side of a breakwater were driven 6 meters into the seabed. No mitigation procedures towards reducing impact on marine mammals were employed.

**Other activities**

In July 2003 a new lighthouse was established at Gedser Rev, about 30 km from the wind farm. The lighthouse was mounted on top of a steel monopile foundation, which was hydraulically driven into the seabed on the 28th of July. No mitigations towards protecting marine mammals were employed.

Dredging activities in the deepwater channel into Gedser harbour has been ongoing daily from May 2nd 2003 and onwards, except on days with bad weather.

Multibeam sonar was used in the wind farm area during construction in connection with dredging and cable burrowing operations. In the period from April to November average activity was 2.6 hours per day, distributed over 73 days.

Four monopile foundations for meteological measuring towers were driven into the seabed in the area east and west of the wind farm on 26-28$^{th}$ of September 2004. Mitigations towards reducing risk to marine mammals and in the form of acoustic underwater pingers and seal scarer were used.

A horizontally mounted splitbeam sonar was used in the wind farm in the periods 16-26$^{th}$ April and 8$^{th}$ of November to 10$^{th}$ of December 2004 as part of a fish monitoring program. Additionally, vertical surveys with the same sonar were conducted on the 30-31$^{st}$ of October 2004.

# 2 Materials and Methods

Comparatively few porpoises are observed in the Nysted/Rødsand area. The sighting rate on visual surveys conducted as part of the environmental impact assessment was very low (Bach et al. 2000) and visual surveys were thus considered to be ineffective in addressing questions of impact of the wind farm on harbour porpoises. Instead a design relying on passive acoustic detection of porpoises by means of long term deployment of dataloggers was adopted.

## 2.1 The T-POD

The T-POD or POrpoise Detector is a small self-contained data-logger that logs echolocation clicks from harbour porpoises and other cetaceans. It is developed by Nick Tregenza (Chelonia, UK). It is programmable and can be set to specifically detect and record the echolocation signals from harbour porpoises. Detailed descriptions and discussions of the methodology of using T-PODs in monitoring effects of wind farms can be found in previous reports (Henriksen et al. 2003, Teilmann et al. 2001).

### 2.1.1 Technical description of the T-POD

The T-POD consists of a hydrophone, an amplifier, a number of band-pass filters and a data-logger that logs echolocation click-activity. It processes the recorded signals in real-time and only logs time and duration of sounds fulfilling a number of acoustic criteria set by the user. These criteria relate to click-length (duration), frequency spectrum and intensity, and are set to match the specific characteristics of echolocation-clicks.

The T-POD relies on the highly stereotypical nature of porpoise sonar signals. These are unique in being very short (50-150 microseconds) and containing virtually no energy below 100 kHz (*Figure 4*). Main part of the energy is in a narrow band 120-150 kHz, which makes the signals ideal for automatic detection. Most other sounds in the sea, with the important exception of echosounders and boat sonars, are characterised by being either more broadband (energy distributed over a wider frequency range), longer in duration, with peak energy at lower frequencies or combinations of the three.

The actual detection of porpoise signals is performed by comparing signal energy in a narrow filter centred at 130 kHz with another narrow filter centred at 90 kHz. Any signal, which has substantial more energy in the high filter relative to the low and is below 200 microseconds in duration is highly likely to be either a porpoise or a man-made sound (echosounder or boat sonar).

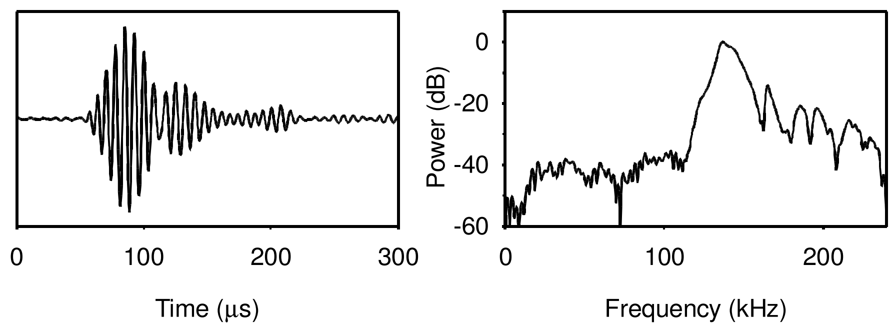


*Figure 4* Porpoise click time signal (left) and power spectrum (right). There is virtually no energy present below 100 kHz (the curve below 100 kHz represents backrgound noise of the recording).

Some spurious clicks of undetermined origin (e.g. background noise and cavitation sounds from high-speed propellers) may also be recorded. These, as well as boat sonars and echosounders are filtered out off-line in software, by analysing intervals between clicks. Porpoise click trains are recognisable by a gradual change of click intervals throughout a click sequence, whereas boat sonars and echosounders have highly regular repetition rates (almost constant click intervals). Clicks of other origin tend to occur at random, thus with highly irregular intervals.

No other cetacean regularly found in the Baltic has sonar signals that can be confused with porpoise signals. Dolphins (with the exception of the genus *Cephalorhynchus*, which does not occur in European waters) use broadband sonar clicks, i.e. energy distributed over a wide frequency range, from below 20 kHz to above 150 kHz (Au 1993). It is thus unlikely that they will trigger the T-POD, when settings are adjusted to detect porpoises.

The T-POD operates with six separate and individually programmable channels. This allows for e.g. one channel to log low frequency boat activity while the remaining channels log porpoise echolocation activity. All channels had identical settings in this study, however (Table 1).

Table 1: T-POD filter settings used during deployments.

| | |
|---|---|
| A filter frequency | 130 kHz |
| B filter frequency | 90 kHz |
| Ratio A/B | 5 |
| A filter sharpness (arbitrary unit) | 5 |
| B filter sharpness (arbitrary unit) | 18 |
| Minimum intensity (arbitrary unit) | 0 |

Each of the six channels records sequentially for 9 seconds, with 6 seconds per minute assigned for change between channels. This gives an overall duty cycle of 90% (54 seconds per minute), 15% for individual channels (9 seconds per minute). In order to minimise data storage requirements only the onset time of clicks and their duration are logged. This is done with a resolution of 10 µs. The absolute accuracy of the timing (time since deployment) is much less, due to drift in the T-PODs clock during deployment (a few minutes per month). This drift however, is only of concern when comparing records from two T-PODs deployed simultaneously. Clicks shorter than 10 µs and sounds longer than 2550 µs were discarded.

The hydrophone of the T-POD has a resonance frequency of 120 kHz and is cylindrical and thus in principle omnidirectional (equally sensitive at all angles of incidence) in the horizontal plane. T-PODs are insensitive to temperature changes within the normal operating range between 3ºC and 25ºC, except from a reduction in battery life at lower temperatures. Battery-voltage does not influence sensitivity as the electronics in the T-POD receive a stable voltage until the battery is drained below 5.1 V, where the electronics turn off.

The T-PODs used (version 1) are equipped with 8 MB RAM and powered with 49.5Ah, 7.2V lithium batteries (six 3.6V D-cells), which gives a maximum logging period of about 60 days. The memory will normally fill in 2-4 month depending on echolocation activity, background noise and software settings.

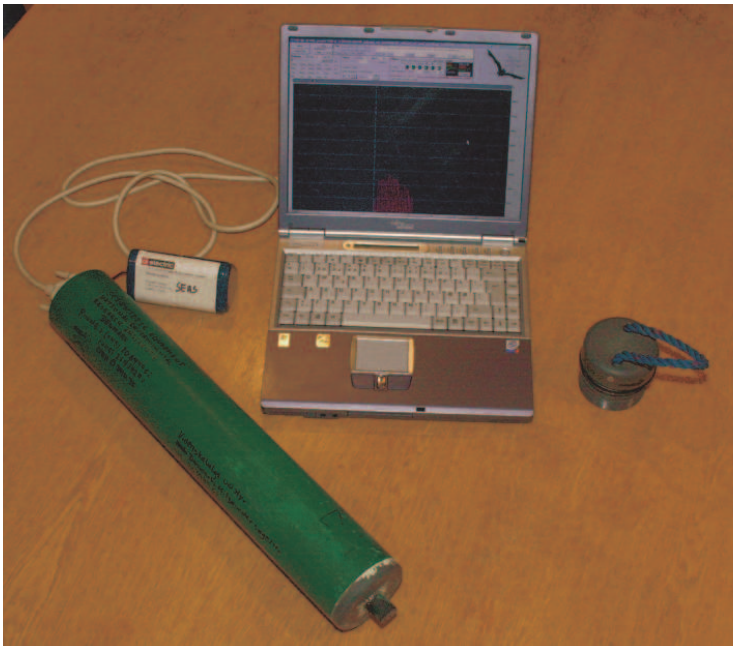

Figure 5: An open T-POD connected to a computer. The hydrophone can be seen as a small attachment in the lower end of the T-POD. A prefabricated 6xD-cell LiIon battery pack is seen behind the T-POD.

Data from the T-POD can be downloaded in the field with a parallel cable for storage on a PC (Figure 5). Data was downloaded with the T-POD.exe program designed for communication with the T-POD and subsequent analysis of data. Figure 6 shows an example of downloaded data. Harbour porpoise echolocation clicks were extracted from the background noise using a filtering algorithm that filters out non-porpoise clicks such as cavitation noise from boat propellers, echo sounder signals and similar high frequency noise. This filter has several classes of confidence of which the second highest class ("cetaceans all") was used. Data were exported in ASCII format for statistical analysis after filtering.

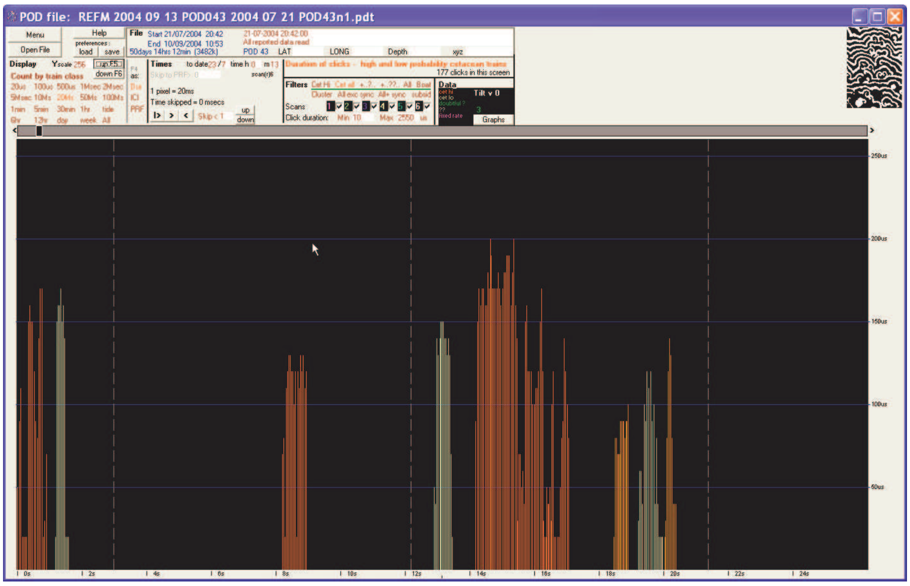

Figure 6: Screen snapshot from the T-POD.exe software. Several series of porpoise clicks can be seen as vertical bars. Time in seconds is shown on the X-axis, and the duration of each click is shown on the Y-axis.

Methods of deployment have not been altered within the last year, and are thoroughly described in the previous report (Henriksen et al. 2003). Briefly, the T-POD was suspended about 2 meters from the bottom, attached to a wire running from the anchoring block of a warning buoy and a smaller anchor 30 meters away.

### 2.1.2 T-POD calibration

T-PODs were calibrated in a laboratory test tank where the absolute sensitivity was measured. The set-up is shown in Figure 7. The small tank is a highly reverberant environment, but usable for threshold measurements, as the duration of the calibration signals are short. There is thus no time overlap and hence interference between the directly transmitted signal and echoes from tank sides and the water surface. Echoes are recorded by the T-POD however, but as the directly transmitted signal has the highest intensity threshold measurements will relate only to this signal. Echoes will always be below threshold of the T-POD and hence undetectable when the intensity of the directly transmitted signal is at threshold.

The signal used for calibration was a porpoise signal recorded about 1 m in front of a captive porpoise and digitally sampled at 12 bit, 480 samples/second. This signal was transferred to an arbitrary waveform generator (Agilent 33250) that was used as signal source. The signal from the generator was fed through a computer controlled attenuator (see below), amplified by a custom build amplifier and projected from a Brüel & Kjær 8104 hydrophone placed 25 cm from the T-POD and at the same depth as the hydrophone of the T-POD. A Reson TC4034 measuring hydrophone placed at the position of the T-PODs hydrophone (T-POD was removed) measured the sound level prior to each calibration.

Signals were presented to the T-POD at intensities ranging from well above to well below threshold. Signal levels were adjusted by the digitally controlled attenuator, which stepped down in steps of 1 dB.

Duration of each step was 9 seconds and adjusted to coincide with the six channels of the T-POD. T-POD files were inspected and the signal level where approx. 50% of the presented clicks were determined. This level is referred to as the absolute sensitivity of the T-POD. The thresholds were in all cases very sharp, with 1-3 dB between the lowest level with 100% detection and highest level with 0% detection and threshold determination thus unambigous. 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, separated with 90 degrees.

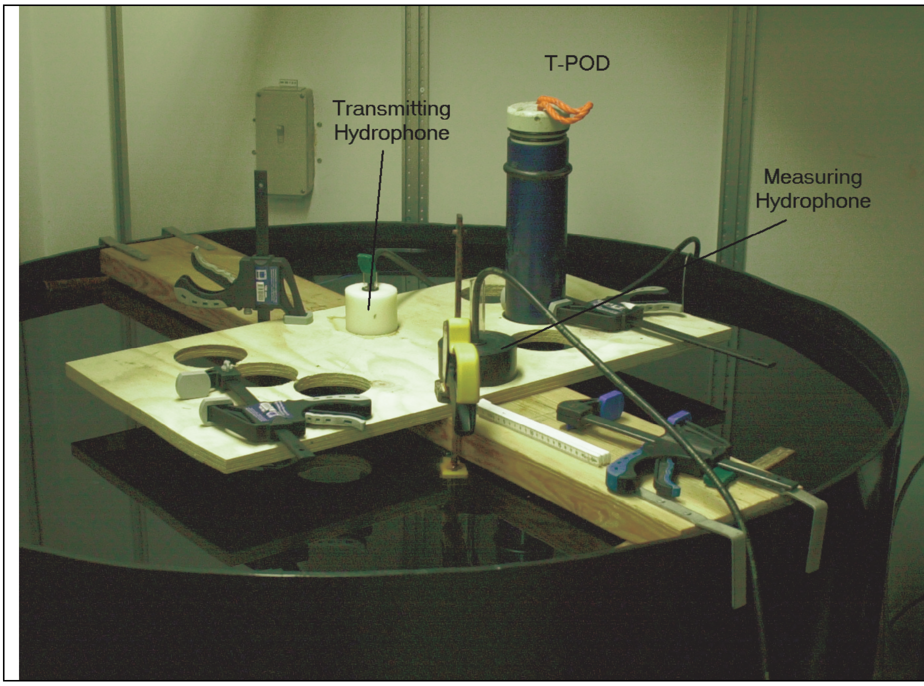


Figure 7: T-POD calibration test tank. One T-POD (out of six possible) is mounted for calibration. Transmitting hydrophone is placed in the centre of the tank. Water depth is approx. 90 cm.

**T-POD sensitivity and directionality**

The directional variation in sensitivity of the T-POD hydrophone in the horizontal plane is specified by a horizontal directivity index, $DI_H$ equation (2-1). This index is derived from Urick (1983) and Au (1993) and reduced from the usual three dimensional index to only the horizontal plane, relevant for the T-POD hydrophone. The three-dimensional directivity index expresses the difference between the intensity received by the hydrophone in an isotrophic[1] sound field and what would be received by a hydrophone perfectly omnidirectional in the horizontal plane with sensitivity equal to what is measured at the most sensitive angle of incidence. The horizontal directivity index developed here cannot be interpreted in a way as simple as the three-dimentional counterpart without some rather restrictive

[1] An isotropic sound field is a uniform sound field without directional properties, i.e. the sound intensity is the same from all directions of space.

assumptions. It is nevertheless a convenient single measure of departure from omnidirectionality.

$$DI_H = -10\log \int_0^{2\pi} \left(\frac{p(\phi)}{p_{\min}}\right)^2 d\phi \approx -10\log\left(\frac{1}{n}\sum_n \left(\frac{p}{p_{\min}}\right)^2\right) \qquad (2\text{-}1)$$

$p(\phi)$ is the horizontal receiving sensitivity at angle of incidence $\phi$. This is reduced to $n$ measurements spaced evenly in the horizontal plane ($n$ = 4 for the current measurements).

A maximal detection distance $r$ for porpoises can be calculated if the sensitivity (DT, or detection threshold) of the T-POD is known. This distance is determined from the source level (SL) of the porpoise echolocation clicks and the angle from porpoise to T-POD, through the transmission loss, TL equation (2-2).

$$DT = SL - 20\log\left(\frac{p(\varphi)}{p_0}\right) - TL, \quad TL = 20\log r + \alpha r \qquad (2\text{-}2)$$

$p(\varphi)$ is the transmission beam pattern of the porpoise signal and $\alpha$ is the sound absorption coefficient of sea water. In order to calculate the maximal possible range at which a porpoise can be detected, we consider only the situation where the animal is facing directly towards the T-POD ($\varphi = 0$), which reduces equation (2-2) to:

$$DT = SL - TL = SL - 20\log r - \alpha r \qquad (2\text{-}3)$$

DT is the sensitivity from the calibration and SL is assumed to be 170 dB re. 1 μPa (rms) (Teilmann et al. 2002b), which leaves $r$ as the only unknown. Unfortunately, the equation can only be solved numerically. The relation between T-POD sensitivity and maximal detection distance is illustrated in Figure 8.

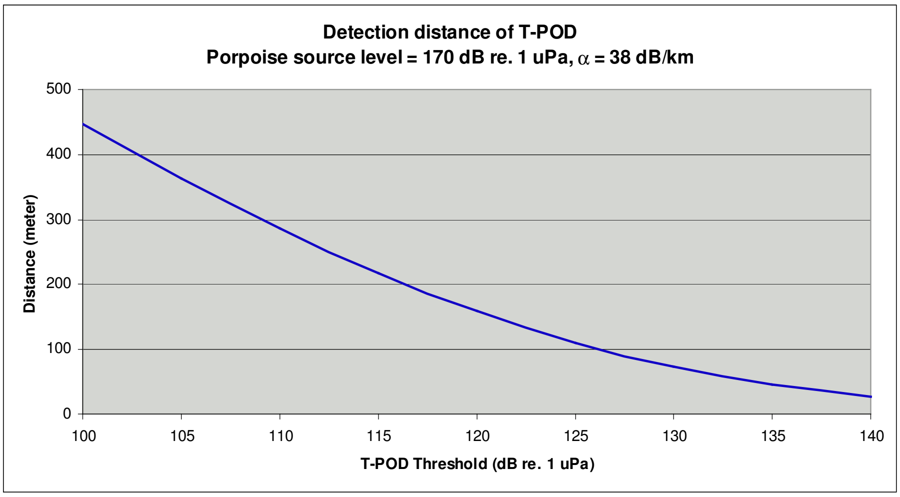


Figure 8: Relation between T-POD sensitivity (expressed as lowest sound pressure needed to detect a porpoise signal) and theoretical maximum distance at which a porpoise can be detected by the T-POD.

As the T-POD is not equally sensitive in all directions, the maximal detection distance for several angles of incidence is calculated and the RMS average, $r_e$ is calculated as

$$r_e = \sqrt{\frac{\int_0^{2\pi} r(\phi)d\phi}{4\pi}} \approx \sqrt{\frac{\sum_n r^2}{n}} \qquad (2\text{-}4)$$

where $r(\phi)$ is the maximal detection distance at angle of incidence $\phi$.

The distance $r_e$ expresses the radius of a circle with the same area as the actual area around the T-POD inside which a porpoise can be detected (see Figure 9). In other words, the area actually surveyed by the T-POD is equal to the area surveyed by a perfect omnidirectional T-POD (DI = 0) with maximal detection distance $r_e$.

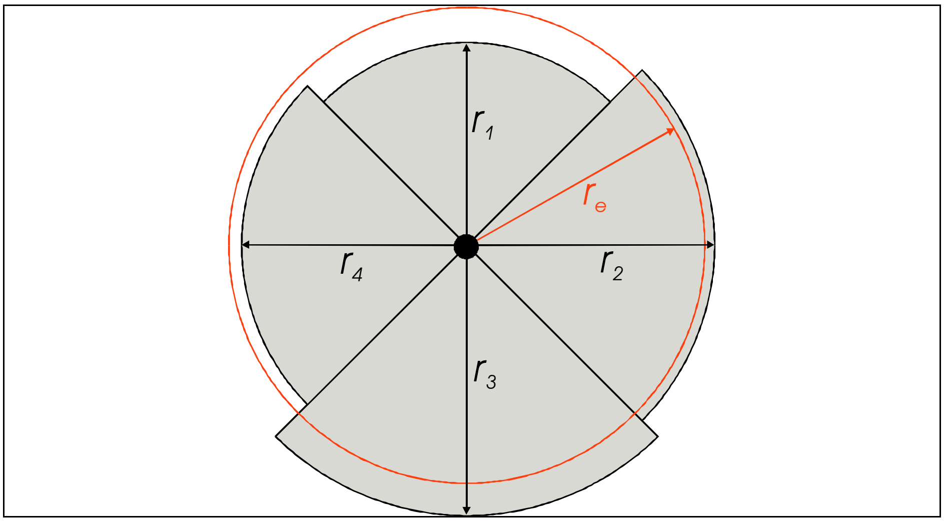


Figure 9: Average detection distance ($r_e$), calculated from four measurements of detection distances at 0, 90, 180 and 270 degrees angle of incidence. Area of red circle equals sum of the four grey sections.

## 2.2 Statistical analysis

The echolocation activity of harbour porpoises in the Nysted/Rødsand region is assessed by means of porpoise detectors (T-PODs), as described above. The first T-PODs were deployed at Nysted/Rødsand in April 2001, but the first deployments used 3 channels only for porpoise click recordings (corresponding to a duty cycle of 45%). This practise was changed in beginning of November 2001, when all 6 channels were used (duty cycle of 90%). This report presents data collected from November 2001 to December 2004. The time series obtained from the T-POD signals are incomplete due to technical problems and loss of gear following collisions with ships. However, it has generally been possible to keep the same T-PODs at the same positions throughout most of the monitoring period. Substitution of T-PODs has only occurred at 3 out of the 6 positions, resulting in a reasonably consistent data set. Time series at these 3 positions were combined from recordings using two or three different T-PODs. No T-PODs were used at more than one position.

All deployed T-PODs were of the same version equipped with an external transducer. Porpoise clicks were recorded and the average number of clicks per minute was calculated as the sum of these 6 channels, adjusted by a factor of 60/54 to correct for the actual active period of T-POD monitoring.

The time series were divided into 3 phases: 1) a baseline from November 2001 to June 30th 2002, 2) a construction period from July 1st 2002 to November 30th 2003, and 3) an operational period from December 1st 2003 to December 2004. The operation of the wind farm will continue beyond December 2004 but the BACI analysis presented herein covers this first year of operation only and compares it to the entire baseline and construction periods.

### 2.2.1 Indicators from T-POD signals

The basis for all analyses in the following is the number of clicks recorded minute by minute by the T-PODs. This measure, denoted $x_t$, consists of many observations of zero (minutes without clicks) and relatively few observations with click recordings. Four indicators were extracted from the click counts. The click count per minute was aggregated into daily observations of:

$$\text{Click frequency} = \frac{\text{Number of minutes with clicks}}{\text{Total number of minutes}} = \frac{N\{x_t > 0\}}{N_{total}} \qquad (2\text{-}5)$$

$$\text{Click intensity} = \frac{1}{N\{x_t > 0\}} \sum_{x_t > 0} x_t \qquad (2\text{-}6)$$

Another approach was to consider the recorded click as a point process, i.e. separate events occurring within the monitored time span. Therefore $x_t$ was considered as a sequence of porpoise encounters within the T-POD range of detection separated by silent periods without any clicks recorded. Porpoise clicks were often recorded in short sequences consisting, separated by minutes without clicks. Such sequences were considered to belong to the same encounter although there were also silent periods within the sequence. A criterion of a silent period of at least 10 minutes was used to define the groups of clicks as different encounters. This threshold value was determined from graphical investigation of different time series of $x_t$. Thus, two click recordings separated by a silent period up to 9 minutes is still considered part of the same encounter. Converting the constant frequency time series into a point process resulted in two new indicators for porpoise echolocation activity.

Encounter duration = Number of minutes between two silent periods (2-7)

Waiting time = Number of minutes in a silent period >10 minutes (2-8)

These definitions imply that waiting time has a natural lower bound of 10 minutes, and that encounters potentially include periods without clicks. Encounter duration and waiting times were computed from data from each T-POD deployment individually identifying the first and last encounters and the waiting times in-between. Consequently, each deployment resulted in one more observation of encounter duration, since the silent periods at beginning and end of deployment were truncated (interrupted) observations of waiting times. Encounter duration and waiting time observations were temporally associated with the time of the midpoint observation, i.e. a silent period starting 30th of September at 12:14 and ending 1st of October at 1:43 was associated with the mean time of 30th of September 18:59 and categorised as a September observation.

### 2.2.2 Models for indicators

The indicators were analysed according to a modified BACI-design (Green 1979) that included station-specific and seasonal variation as well. Variations in the indicators, after appropriate transformation, were assumed Normal-distributed with a mean value described by the equation:

$$\mu = area + station(area) + podnr(area\ station) + month + period + area \times period \qquad (2\text{-}9)$$

where *area* describes the spatial variation between control and impact area, *station(area)* the station-specific variation nested within the two areas, *podnr(area station)* the T-POD specific variation for the three stations where the equipment was replaced, *month* the seasonal variation by means of monthly values and *period* describes the stepwise change at the onset of the construction work, whereas *area× period* describes a difference in the stepwise change between the two areas. All factors in the model are fixed effects. The latter factor of the model, also referred to as the BACI effect, therefore describes a stepwise change in the impact area different from that in the reference area. Marginal means for the different factors of the model were calculated and back-transformed to median values on the original scale. BACI effects, each having 1 numerator degree of freedom, for the relative change for the two areas between baseline and construction, between baseline and operation, and between construction and operation were also calculated explicitly as contrasts of the marginal means in the model. For example:

$$\exp(\text{BACI contrast}) = \frac{E[\text{Impact, construction}]}{E[\text{Impact, baseline}]} \cdot \frac{E[\text{Reference, baseline}]}{E[\text{Reference, construction}]} \qquad (2\text{-}10)$$

i.e. the exponential of the contrast described the relative change from the baseline to the construction period in the impact area relative to the reference area. Similar calculations were carried out for the BACI contrasts between baseline and operation as well as between construction and operation.

The T-POD specific variation was nested within stations, and similarly the station-specific variation was nested within areas in equation (2-9). This implied that the factors *area* and *station(area)* were a combination of spatial variation and T-POD specific sensitivity. However, the interaction (*area× period*) remained unaffected by this, because the T-PODs were not interchanged between stations during the study period and consequently the testing for a potential effect of the construction work in the impact area was not biased by differences in T-POD sensitivity. This hierarchical design was chosen in favour of crossing the T-POD specific variation with the spatial variation, because shifting the T-PODs between stations would require additional substantial effort with a risk of the T-POD specific variation being partly or even totally confounded with the BACI-effect (*area×period*).

Data from Station Ref. N were not used for the BACI analyses, because this position was shown to have a different temporal variation from the other stations in the baseline period (Henriksen et al., 2003) and in addition, there were relatively few monitoring days from this position. Station Ref.N is also located close to the shipping lanes used for the construction of the wind farm, and this position may potentially also be affected by the construction. Thus, the impact area included Stations E, N, W and the control area included Stations Ref.M and Ref.S. However, Station Ref.N was used for assessing the effect of pile driving activities that was carried out station wise (see below), without any assumption of similar temporal variation.

### 2.2.3 Serial correlation of data

The temporal variation in the indicators was assumed to follow an overall fixed seasonal pattern described by monthly means, but fluctuations in the harbour porpoise density in the region on a shorter time scale may potentially give rise to serial correlations in the observations. For example, if a short waiting time is observed the next waiting time is likely to be short as well. Similar arguments can be proposed for the other indicators. In order to account for any autocorrelation in the residuals we formulated a covariance structure for the random variation by means of an ARMA(1,1)-process (Chatfield 1984) subject to observations within separate deployments, i.e. complete independence was assumed across gaps in the time series. Thus, this model included an extension to the general linear theory (e.g. McCullagh and Nelder 1989) by mixing fixed and random effects.

### 2.2.4 Transformations of data

Transformations, distributions and back-transformations were selected separately for the different indicators by investigating the statistical properties of data (Table 2). The data comprised an unbalanced design, i.e. unequal numbers for the different combinations of factors in the model, and arithmetic means by averaging over groups within a given factor may therefore not reflect the “typical” response of that factor because they do not take other effects into account. Typical responses of the different factors were calculated by marginal means (Searle et al. 1980) where the variation in other factors was taken into account.

Waiting times had a natural bound of 10 minutes imposed by the encounter definition, and we therefore subtracted 10 minutes from these observations before taking the logarithm in order to derive a more typical lognormal distribution. Applying the log-transformation had the implication that additive factors as described in equation (2-9) were multiplicative on the original scale. This means that e.g. the seasonal variation was described by monthly scaling means rather than additive means. Variations in the four indicators were investigated within the framework of generalised linear models (McCullagh and Nelder 1989), and the significance of the different factors in equation (2-9) was tested using F-test (type III SS) for the normal distribution (SAS Institute 2003). The normal distribution was chosen for encounter duration as opposed to the Gamma distribution used in Henriksen et al. (2004) in order to employ a covariance structure describing temporal correlation in the observations.

Table 2: List of transformation, distributions and back-transformation employed on the four indicators for harbour porpoise echolocation activity.

| Indicator | Transformation | Distribution | Back-transformation |
|---|---|---|---|
| Daily intensity | Logarithmic – log(y) | Normal | $\exp(\mu + \sigma^2/2)$ [1] |
| Daily frequency | Angular – $\sin^{-1}(\sqrt{y})$ | Normal | Table 6 (Rohlf & Sokal, 1981) |
| Encounter duration | Logarithmic – log(y) | Normal | $\exp(\mu + \sigma^2/2)$ [1] |
| Waiting time | Logarithmic – log(y-10) | Normal | $\exp(\mu + \sigma^2/2) + 10$ [1] |

[1]The back-transformation of the logarithmic transformation can be found in e.g. McCullagh and Nelder (1989), p. 285.

### 2.2.5 Effects of pile driving operations

To investigate the short-term effect of pile driving/vibration activity in the period from August 25th to November 20th 2002, the first encounter after this specific construction activity within the wind farm area and at Gedser Harbour had ceased were identified, and the corresponding waiting times prior to these encounters were analysed. Thus, observations were categorised as 1) waiting times following pile driving activities within the wind farm, 2) waiting times following pile driving activities at Gedser Harbour, and 3) all other waiting times. For a few waiting times the pile driving activities in the wind farm and at Gedser Harbour coincided and these observation were chosen to belong to the first category. For each station the distributions of this first waiting time were analysed for these three categories. For this specific analysis the parameters of the ARMA(1,1)-process in the covariance structure were not estimated due to the limited number of observations, but set to the values obtained from analysing all data according to equation (2-9), since the number of observations in this specific period was limited. In order to account for different magnitudes of variation between waiting times for the three categories, different variance parameters for these three categories were chosen and estimated from the data.

# 3 Results

Results from laboratory calibrations and field deployments of T-PODs at Nysted/Rødsand are presented below.

## 3.1 T-POD calibration

The test results are given in *Table 3*. Thresholds are given as mean values over all four angles of incidence measured, as described in methods section. The directivity index (DI) describes how directional each T-POD is, compared to a hydrophone perfectly omnidirectional in the horizontal plane (DI = 0). The larger the DI the more directional the hydrophone.

The average maximum detection distance describes the maximum distance from the T-PODs where a harbour porpoise pointing its echolocation beam directly towards the T-POD theoretically can be detected, averaged across the four angles of incidence where measurements were made, according to equation (2-4).

*Table 3* Calibration data for T-PODs.

| T-POD number | 4 | 9 | 43 | 47 | 56 | 71 |
|---|---|---|---|---|---|---|
| Threshold (dB SPL RMS) | 124.2 | 117.0 | 122.0 | 116.7 | 120.1 | 128.7 |
| Directivity index, DI (dB) | 1.6 | 0.8 | 0.6 | 1.6 | 0.8 | 1.1 |
| Maximum detection dist. (m) | 117 | 192 | 138 | 196 | 157 | 82 |

Average maximum detection distances for T-PODs used in this study were 82-196 meters. The exact origin of the variation between the T-PODs is unknown, as they are identical in design. Likely sources are differences in hydrophone sensitivity (inherent differences between crystals and differences due to soldering and plastic housing) and differences in amplifier and electronics self noise.

The maximal distance at which a porpoise can be detected by the T-POD depends critically on the angle between the porpoise' swimming direction and the angle to the T-POD (equation (2-2) and *Figure 10*). The porpoise signals are highly directional and the main energy is radiated out in a narrow cone 20-30 degrees wide both in the horizontal and vertical plane (Au et al. 1999). The shape of this cone is reasonably well described by a model for sound radiation from a plane piston (Au 1993, Au et al. 1999), but modelling breaks down at larger radiation angles. This is indicated in *Figure 10A*, where radiated sound pressures are assumed to be constant at angles larger than 30 degrees and at –20 dB relative to the main forward-facing lobe (Akamatsu et al. 2005). If a source level of 170 dB re 1 µPa is assumed for porpoises, the detection distances as a function of angle towards the T-POD for a T-POD with threshold of 120 dB re 1 µPa can be calculated and is shown in *Figure 10B.* It is evident that detection distances drop dramatically once the porpoise is not looking almost directly towards the T-POD may drop as low as tens of meters for angles larger than 30 degrees off-axis.

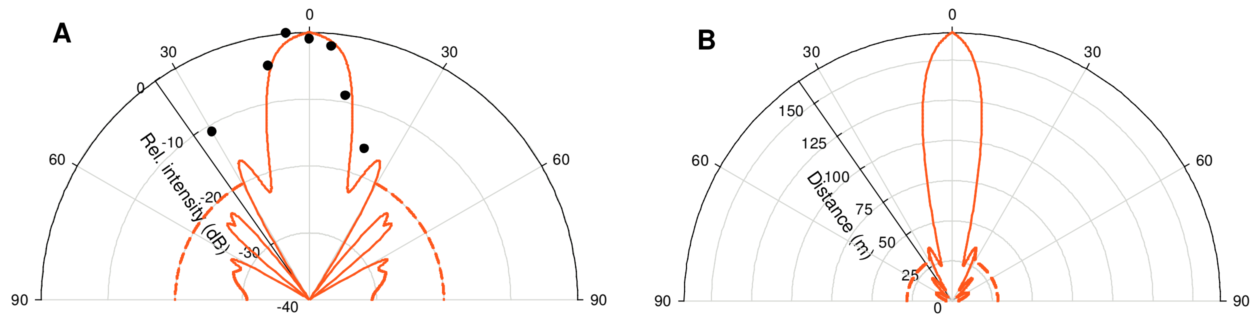


*Figure 10* A) Radiation pattern of harbour porpoise signals. Solid red line is radiation pattern calculated from a plane piston model (Au, 1993) with directivity index DI of 22.3 (Au et al, 2002), broken line assumes breakdown of plane piston model at angles higher than 30 degrees (Akamatsu et al. 2005). Black dots are actual data from Au et al. (1999). B) Theoretic detection distance at various angles of incidence (angle between direction of swimming of the porpoise and direction to T-POD), calculated according to equation (2-3) and using the directivity patterns in A). A threshold of 120 dB re. 1 uPa was assumed for the T-POD and source level of the porpoise assumed to be 170 dB re. 1 uPa. Broken line assumes breakdown of piston model at angles higher than 30 degrees.

## 3.2 T-POD deployments

Deployments of T-PODs at Nysted Offshore Wind Farm and the reference area in 2004 are shown in *Figure 11* and summarized in *Table 4*. Only data until December 22$^{nd}$ 2004 has been included in the present analysis. T-PODs were deployed on average 78% of the time in 2004, and usable data is available for 47% of the year on average (*Table 4*), with some variation among stations.

*Table 4* Summary of deployments and data collection in 2004 (until 22/12.2004) and calculated efficiencies.

| Location | Nord | West | East | Ref N | Ref M | Ref S | Total |
|---|---|---|---|---|---|---|---|
| T-POD ID | 47 + 9 | 56 | 71 | 17 | 43 | 4 + 7 | |
| Deployment days | 200 | 294 | 272 | 322 | 219 | 307 | 1614 |
| Data days | 153 | 197 | 214 | 84 | 201 | 124 | 973 |
| Deployment days/potential | 57.8% | 85.0% | 78.6% | 93.1% | 63.3% | 88.7% | 77.7% |
| Data days/deployment | 76.5% | 67.0% | 78.7% | 26.1% | 91.8% | 40.4% | 60.3% |
| Data days/potential | 44.2% | 56.9% | 61.8% | 24.3% | 58.1% | 35.8% | 46.9% |

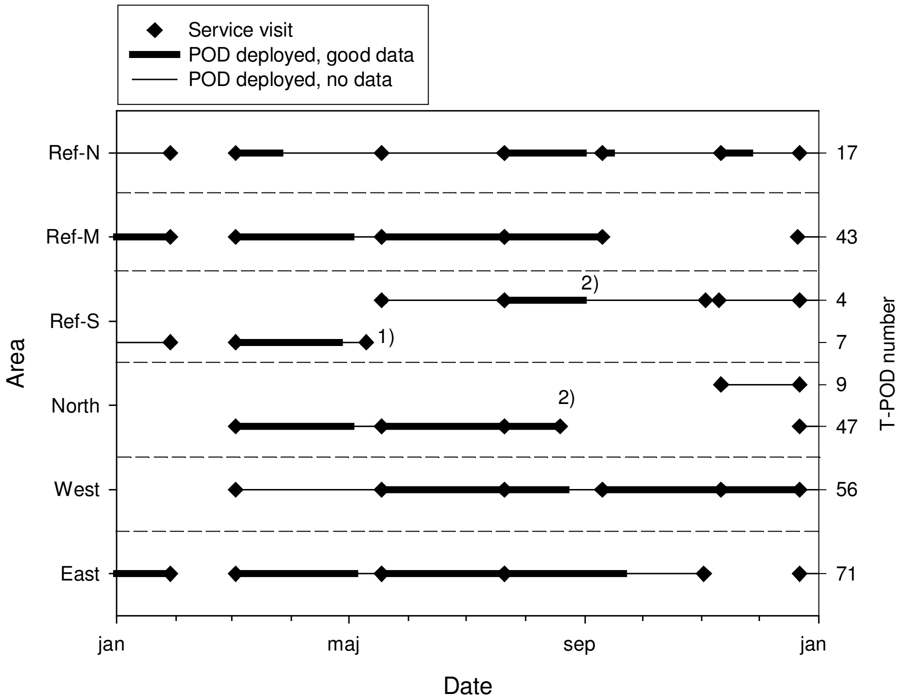


*Figure 11* Overview of deployments and data collection in 2004. Positions are indicated on the left y-axis and T-POD numbers on the right. Bold lines indicate periods where useable data were retrieved. Thin lines indicate that T-PODs were deployed, but no data retrieved. Most common reasons were low battery, full memory or problems with the T-POD hardware or software. Three T-PODs were lost in 2004 (indictaed by numbers), but were retrieved on all occasions. On one occasion (1), the T-POD was found on Langeland and returned to NERI, on the two other occasions (2) T-PODs were returned directly to Energy E2 in Gedser by local fishermen.

Three T-PODs were lost while deployed in 2004. Luckily, they were all recovered, either by local fishermen or found washed ashore on the beach.

An example of data collected in 2004 is shown in *Figure 12*. This figure shows the number of clicks recorded in 10-minute intervals during the day, for all days in 2004 where data is available for this station. Two features are immediately visible: the low number of porpoise clicks recorded in winter and the marked diurnal pattern in the summer months, where activity is higher during the night than during the day.

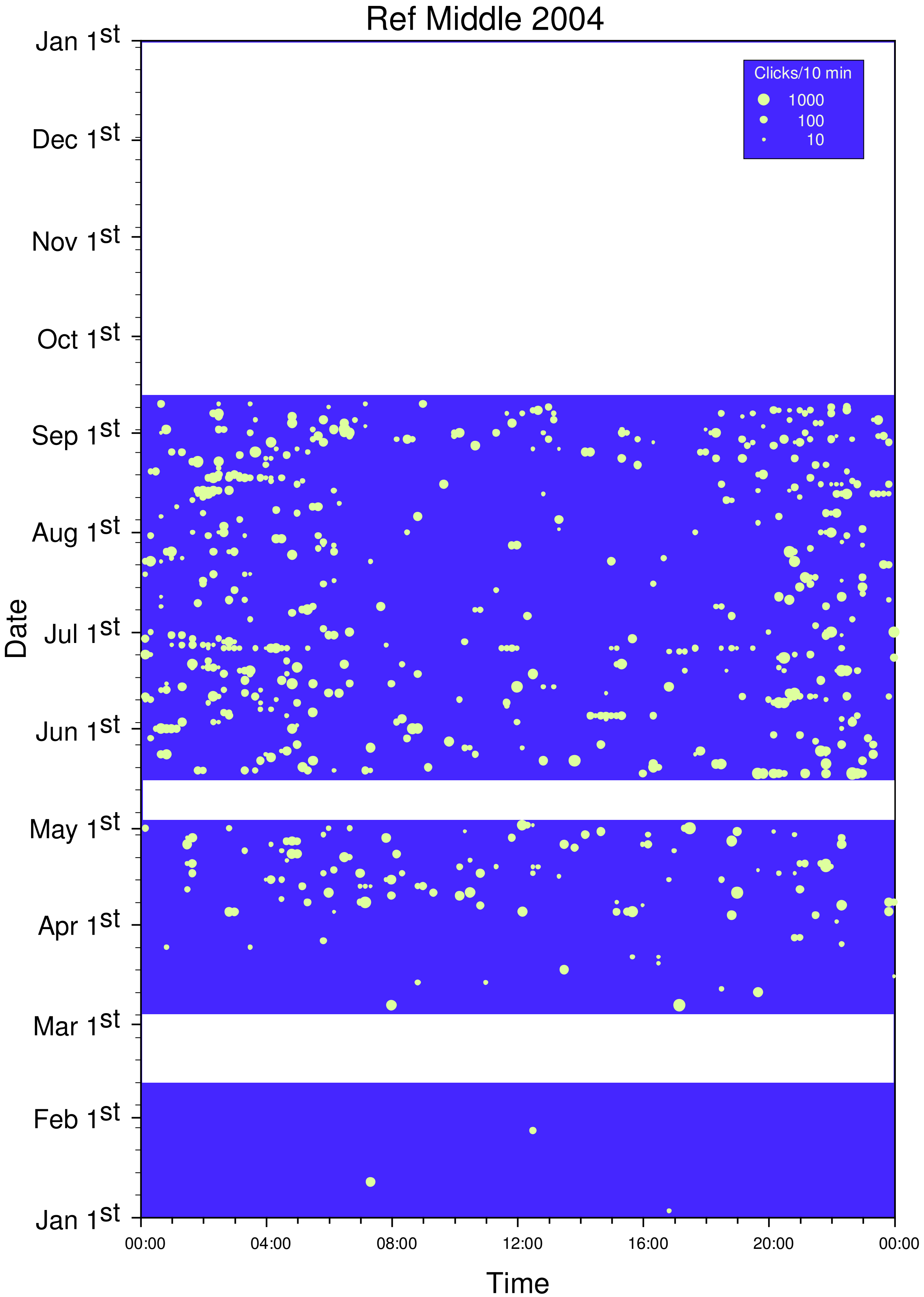


*Figure 12* Dot-raster illustrating all clicks recorded by T-POD 43 on the reference M position in 2004. The size of each dot indicates the number of clicks detected in a 10-minute period. Blank areas indicate periods where no data were collected.

### 3.2.1 Daily statistics

Daily click frequencies and intensities were calculated from the POD data (*Figure 13*). There was a total of 2693 days with T-POD monitoring data from the 6 positions with 606, 370, 606, 235, 593, 283 days at station E, N, W, Ref. N, Ref. M, Ref. S, respectively. The numbers of monitoring days for the three considered periods were 368, 1249 and 1076 for the baseline, construction and operation period, respectively. About 40% or 1078 monitoring days did not contain any clicks (click frequency of zero) and daily click intensities could thus not be calculated for these days.

Temporal variations and variation between positions and PODs were relatively smaller for intensities compared to frequencies. For the 6 stations the coefficients of variation (CV) varied between 53% and 103% for click intensity and between 124% and 363% for click frequency. The baseline had the lowest relative variation with CVs 61% and 112% for click intensity and frequency, respectively. These values increased during the construction period to 85% and 204%, and to 88% and 311% during the operation period. There were three substitutions of T-PODs during the construction period and two substitution of T-PODs during the operation period. The average click frequency in the construction and operation periods were only 24% and 29% of that from the baseline, whereas the average click intensity remained at almost the same level (~40 clicks/minute) through the entire monitoring period. The decrease in click frequencies appeared most pronounced for the three stations in the impact area (*Table 6* and *Figure 15*).

### 3.2.2 Encounter statistics

Encounter duration (n=5566) and waiting time between encounters (n=5521) were calculated from the POD data (*Figure 14*). The lowest number of encounters were observed at Station N (n=426) and Ref. N (n=532), whereas Station Ref. M had the highest number of encounters (n=1593). Encounter observations were evenly distributed between the baseline (n=1734), the construction period (n=1995), and the operation period (n=1837), although there were about 3 times more monitoring days in both the construction and operation periods compared to the baseline. There were inevitably fewer waiting times than encounters since the first and last silent period of each separate T-POD recording were not considered waiting time observations.

The relative variation in encounter duration (137-249% for the 6 positions) and waiting time (173-335% for the 6 positions) were larger than for the daily click intensity and, to some extent, the daily frequency, however, there were also approximately more than twice as many observations. Both duration and waiting time distributions were strongly skewed to the right with observations exceeding 1 hour for encounter duration and 10 days for waiting time (*Figure 14*). The coefficient of variation increased from baseline to the construction period and decreased from the construction period to the operation period for both encounter duration and waiting time.

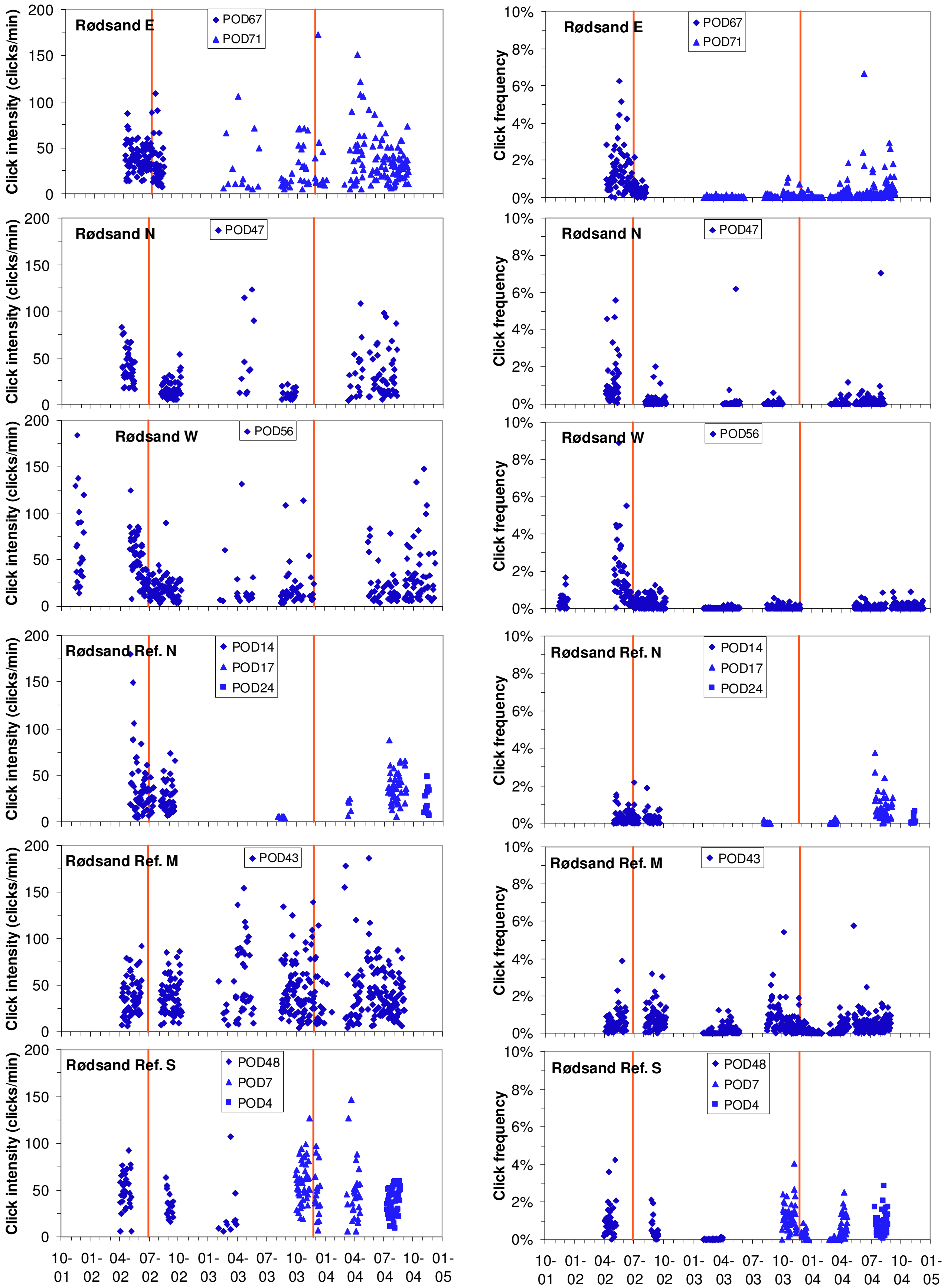


*Figure 13* Daily click intensity (left panel) and click frequency (right panel) extracted from T-POD data collected at Rødsand from November 14th 2001 to December 21 2004. Different symbols mark observations derived from different T-PODs. The two vertical lines indicate the start and end of the construction period. Eight daily click intensities and one daily frequency exceeded the plotting range (not shown).

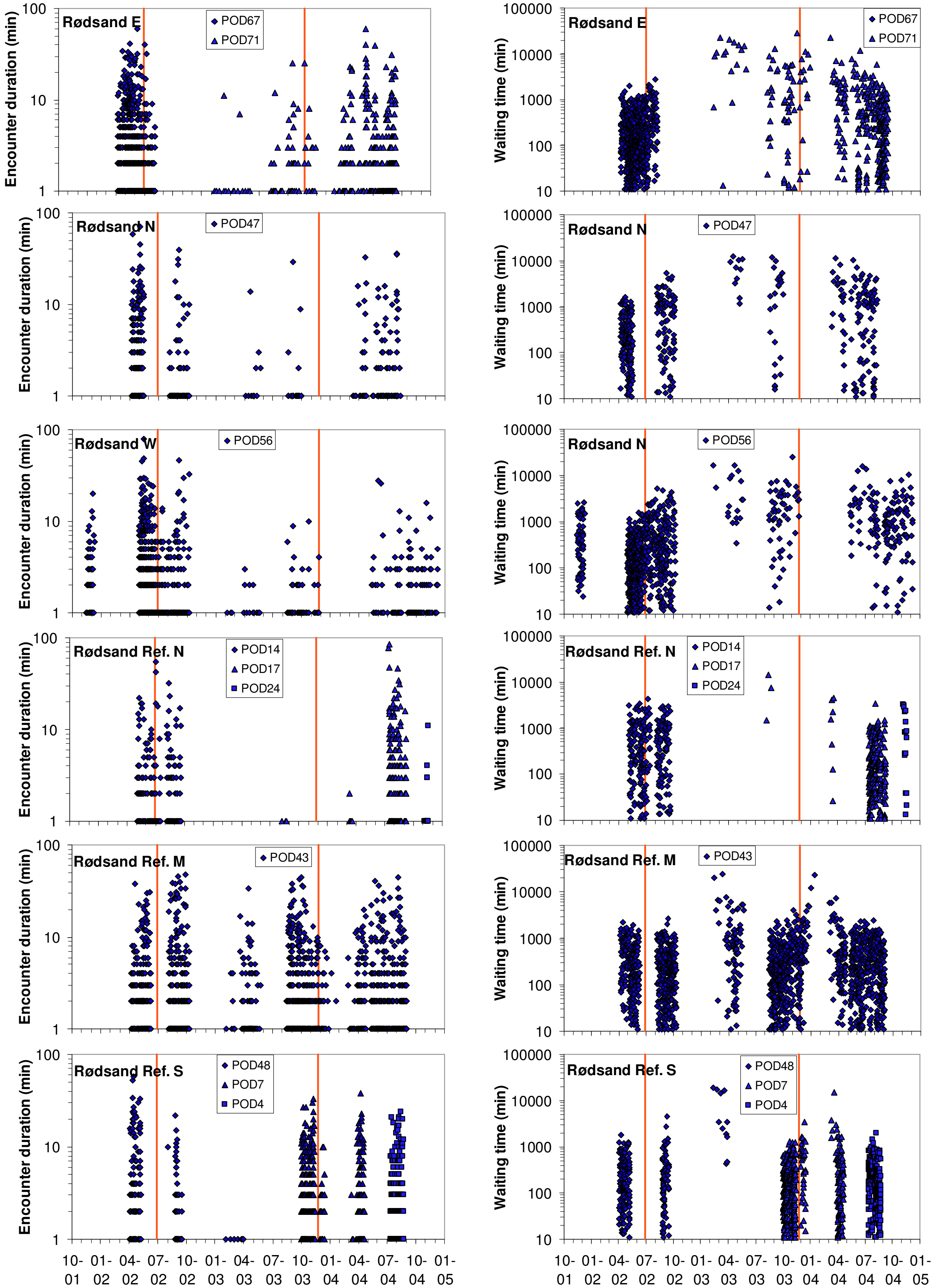


*Figure 14* Encounter duration (left panel) and waiting time (right panel) extracted from T-POD data collected at Rødsand during November 2001-December 2004. Different symbols mark observations derived from different T-PODs. Vertical lines indicate the start and end of the construction period. Three encounter observations and one waiting time exceeded the plotting range (not shown). Note the log-scale on the y-axis.

The average encounter duration decreased by approx. 19% from baseline to the construction and operation periods, which had similar average encounter durations. The average waiting time was almost three times longer in the construction period than in the baseline, whereas the average waiting time decreased from the construction to the operation period by 14%. Increasing waiting times appeared most pronounced for the three stations in the impact area (*Table 6* and *Figure 15*).

### 3.2.3 Changes between area and periods

The factors *area*, *period* and *month* in equation (2-9) describing the variations in the four indicators were all significant except *month* for encounter duration (*Table 5*). The station-specific variation within the two areas was significant for waiting time only, and similarly the T-POD specific variation was significant for daily click frequency only. Thus, witht the exeption of waiting time, there were no significant differences among the three positions within each area and with the exeption of click frequency, there were no significant differences amond different T-PODs placed at the same position.

The daily indicators had the highest coefficients of determination ($R^2$), but the general low ability to predict individual observations for encounter duration and waiting time was compensated by more observations. The indicator levels obtained from equation (2-9) are generally lower than those reported in Henriksen et al. (2004), since the marginal means included January (a low activity month) as well, whereas the estimates in Henriksen et al. (2004) covered February-December only.

*Table 5* Analysis of variation for the four indicators. The coefficient of determination ($R^2$) and p-values for the different factors in equation (2-9) are given. All data from the baseline, construction and operation periods were used except for recordings at Station Ref.N. Significant p-values indicated with bold.

| Indicator | $R^2$ | *Area* | *Station (area)* | *Period* | *Area xperiod* | *Month* | *PODnr (station area)* |
|---|---|---|---|---|---|---|---|
| Daily click intensity | 0.2052 | **0.0003** | 0.1817 | **0.0212** | **0.0062** | **0.0237** | 0.5215 |
| Daily click frequency | 0.4633 | **0.0003** | 0.0813 | **<0.0001** | 0.0797 | **<0.0001** | **0.0440** |
| Encounter duration | 0.0381 | **0.0300** | 0.1792 | **0.0125** | **0.0218** | 0.3866 | 0.3508 |
| Waiting time | 0.1418 | **<0.0001** | **0.0141** | **<0.0001** | **<0.0001** | **<0.0001** | 0.0827 |

The daily click intensity was at the same level (~42-45 clicks per minute) for both the control and the impact area during the baseline period, but in the construction period the daily intensity in the impact area was reduced by 50%, whereas a smaller decrease was observed in the control area (*Table 6* and *Figure 15*). From the construction period to the operation period the daily intensity increased by 35% in the impact area, whereas it decreased by 6% in the control area. Consequently, the BACI effect showed significant relative decreases of 48% (using equation (2-10)) in the impact area from baseline to the construction, whereas there was no relative change from baseline to the operation period. However, there was a significant relative increase in the impact area of 44% from the construction to the operation period.

*Table 6* Analysis of variation for the four indicators. Mean values for combinations of *area* and *period* back-transformed to the original scale are given for combinations of the two areas (control and impact) and the three periods (baseline, construction and operation). All data from the baseline, construction and operation periods were used except for recordings at Station Ref.N. The values are shown as bar graphs in *Figure 15*.

| Indicator | Period | Control | Impact | Both |
|---|---|---|---|---|
| Daily click intensity | Baseline | 44.6 | 42.2 | 43.4 |
| (clicks/min) | Construction | 43.3 | 21.3 | 30.4 |
| | Operation | 40.7 | 28.8 | 34.2 |
| | Entire period | 42.8 | 29.6 | |
| Daily click frequency | Baseline | 0.81% | 0.60% | 0.70% |
| | Construction | 0.35% | 0.03% | 0.15% |
| | Operation | 0.26% | 0.07% | 0.15% |
| | Entire period | 0.44% | 0.16% | |
| Encounter duration | Baseline | 3.8 | 3.8 | 3.8 |
| (minutes) | Construction | 3.5 | 2.6 | 3.0 |
| | Operation | 3.1 | 3.0 | 3.0 |
| | Entire period | 3.4 | 3.1 | |
| Waiting time | Baseline | 15.9 | 12.4 | 14.0 |
| (hours) | Construction | 23.0 | 68.1 | 39.6 |
| | Operation | 20.3 | 59.9 | 34.9 |
| | Entire period | 19.5 | 36.9 | |

The daily click frequency was slightly lower in the impact area during the baseline period (mean of 8.6 minutes with porpoise clicks per day), but it declined to a mean of 0.44 minutes with porpoise clicks per day (*Table 6*). This decrease was approximately a factor of 20. The daily frequency also decreased for the two stations in the control area, although this decrease was considerably less (factor of 2). From the construction period to the operation period the daily frequency continued to decrease (slightly) in the control area, whereas it remained at the same level in the impact area. Thus, as indicated by the calculated contrast the decline in daily frequency within the impact area was relatively large from the baseline to the construction period, although this contrast was not significant at the 5% significance level. There were indications of a small, however not significant, relative increase in the daily frequency of the impact area from the construction to the operation period.

Levels of encounter duration were similar in the control and impact area during the baseline period with a mean of 3.8 minutes and during the operation period with a mean of 3.0 minutes. During the construction period the encounter duration decreased significantly in both the control and impact area, with a larger decrease in the impact area however. In the operation period the encounter duration continued to decrease in the control area whereas it increased in the impact area to the same level of the control area. Thus, there was a relative decrease in encounter duration of 24% in the impact area from baseline to the construction period and a relative increase of 28% from the construction period to the operation period. From the baseline to the operation period there was relative change. There was, however, a general decrease for the mean encounter duration that occurred in the transition from baseline to the construction period.

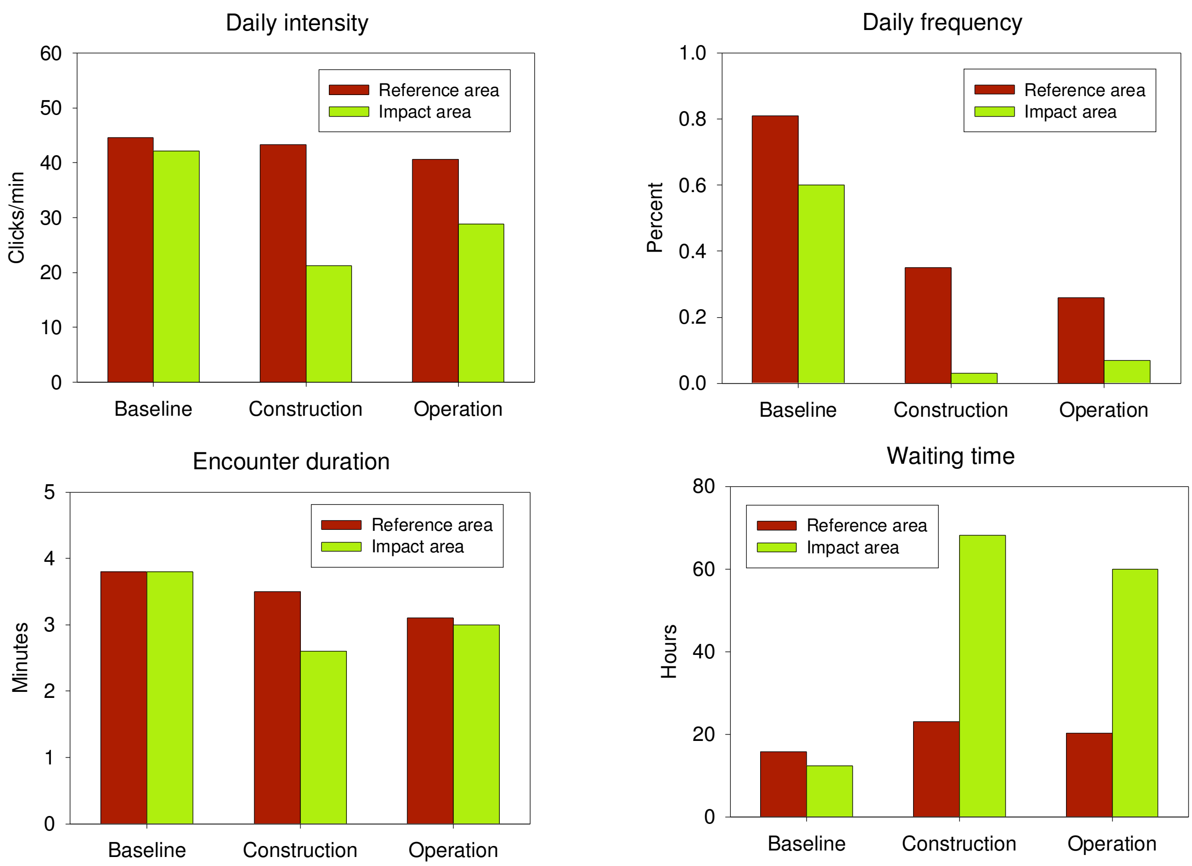


*Figure 15* Mean values for combinations of *area* and *period* back-transformed to the original scale are given for combinations of the two areas (control and impact) and the three periods (baseline, construction and operation). Same data as in *Table 6*.

For waiting times the control and impact area had similar levels (12-16 hours) during the baseline, and both areas experienced increasing waiting times during the construction period. The increase was much larger in the impact area, however. During construction the mean waiting time was 23 hours in the control area and 68 hours in the impact area, i.e. almost three times larger. During the operational period the mean waiting time had decreased to 20 and 60 hours for the control and impact area, respectively. The was no relative change between the areas from the construction to the operation period, but waiting times in the impact area increased relatively by factor of 4 from the baseline to the construction and operation periods.

*Table 7* Analysis of variation for the four indicators. Contrasts of the BACI analysis and their p-values are given for the three combinations of periods (baseline, construction and operation). All data from the baseline, construction and operation periods were used except for recordings at Station Ref.N. Significant p-values indicated in bold.

| | BACI | Estimate | p-value |
|---|---|---|---|
| Daily click intensity | Baseline vs. Construction | -0.6524 | **0.0014** |
| | Baseline vs. Operation | -0.2899 | 0.2185 |
| | Construction vs. Operation | 0.3625 | **0.0295** |
| Daily click frequency | Baseline vs. Construction | -0.0291 | 0.0540 |
| | Baseline vs. Operation | -0.0129 | 0.4254 |
| | Construction vs. Operation | 0.0163 | 0.1185 |
| Encounter duration | Baseline vs. Construction | -0.2800 | **0.0184** |
| | Baseline vs. Operation | -0.0346 | 0.7920 |
| | Construction vs. Operation | 0.2454 | **0.0302** |
| Waiting time | Baseline vs. Construction | 1.3373 | **<0.0001** |
| | Baseline vs. Operation | 1.3342 | **0.0002** |
| | Construction vs. Operation | -0.0031 | 0.9915 |

### 3.2.4 Variation across seasons, stations and T-PODs

Significant seasonal variation with distinctive and corresponding patterns were seen for daily intensity, daily frequency and waiting time, most pronounced for daily click frequency and waiting time (*Figure 16* and *Table 5*).

Mean click intensities varied from 22 to 50 clicks per minute with the lowest values in January-March. Mean click frequencies were low in January-March (ca. 0.08-0.10%) peaking in September with a mean of 0.54%. Encounter duration was also low during January-March (means between 2.2 and 3.0 minutes), whereas it was around 3.5 minutes for the rest of the year with the longest mean duration in May (3.9 minutes), although these differences were not significant. Mean waiting times were >1 day in December-March with the highest mean value in January (14.6 days). From July to October the mean waiting time was less than 12 hours with the shortest mean waiting time observed in September (6.9 hours). Thus, the highest echolocation activities were observed in July-October, whereas the lowest echolocation activity was found in winter (December-March).

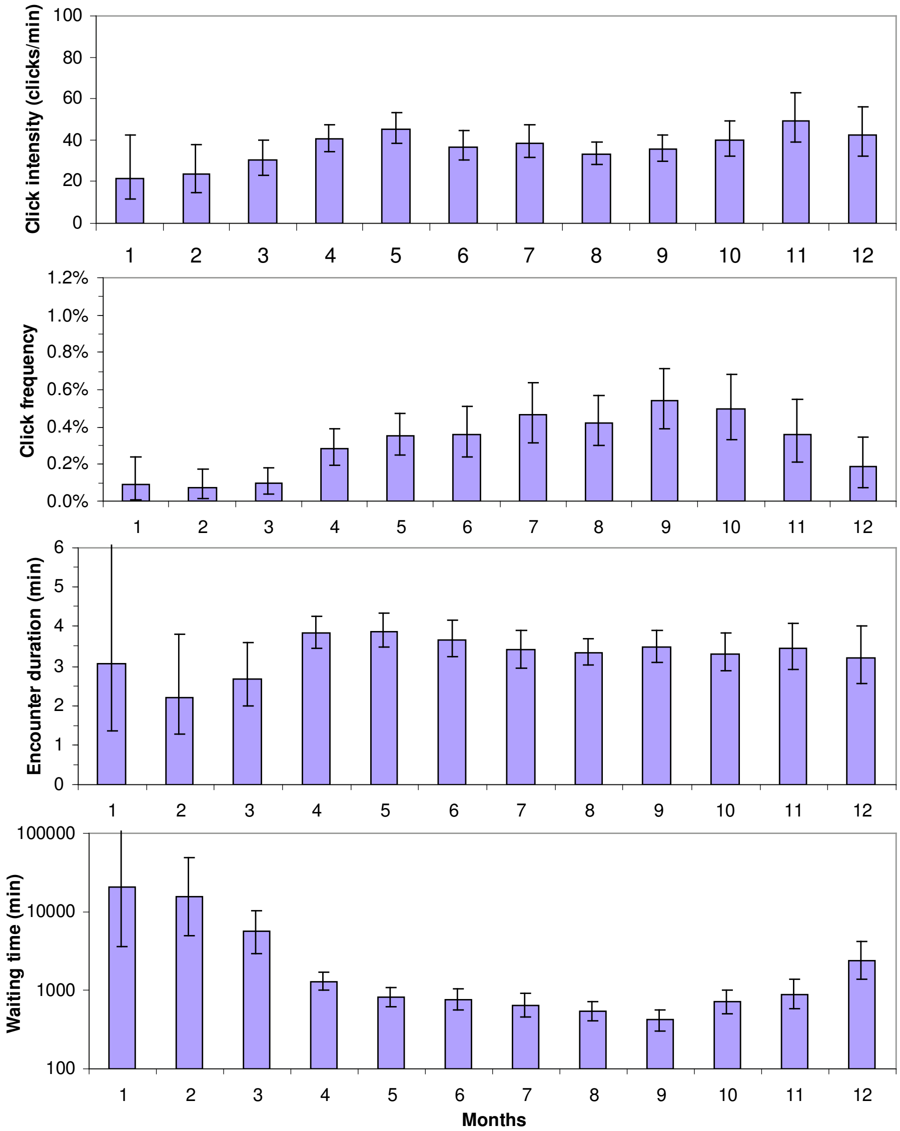


*Figure 16* Seasonal means for the four indicators after back-transformation. Error bars indicate 95% confidence limits for the mean values. Variations caused by other significant sources of variation in equation (2-9) have been accounted for by calculating the marginal means.

Overall, the echolocation activity level during the entire study period was relatively higher in the control area (*Table 6* and *Figure 17*). Differences among stations within areas and T-PODs within stations where only significant for waiting time (among stations) and daily click frequency (among T-PODs) (*Table 5*). The replacement of T-PODs at stations Ref.S and E introduced changes in the daily click frequency (*Figure 17*). For waiting times spatial gradients were found with shorter waiting times at Station Ref. S compared to Ref. M, and similarly shorter waiting times at Station E compared to station N and W (*Figure 17*).

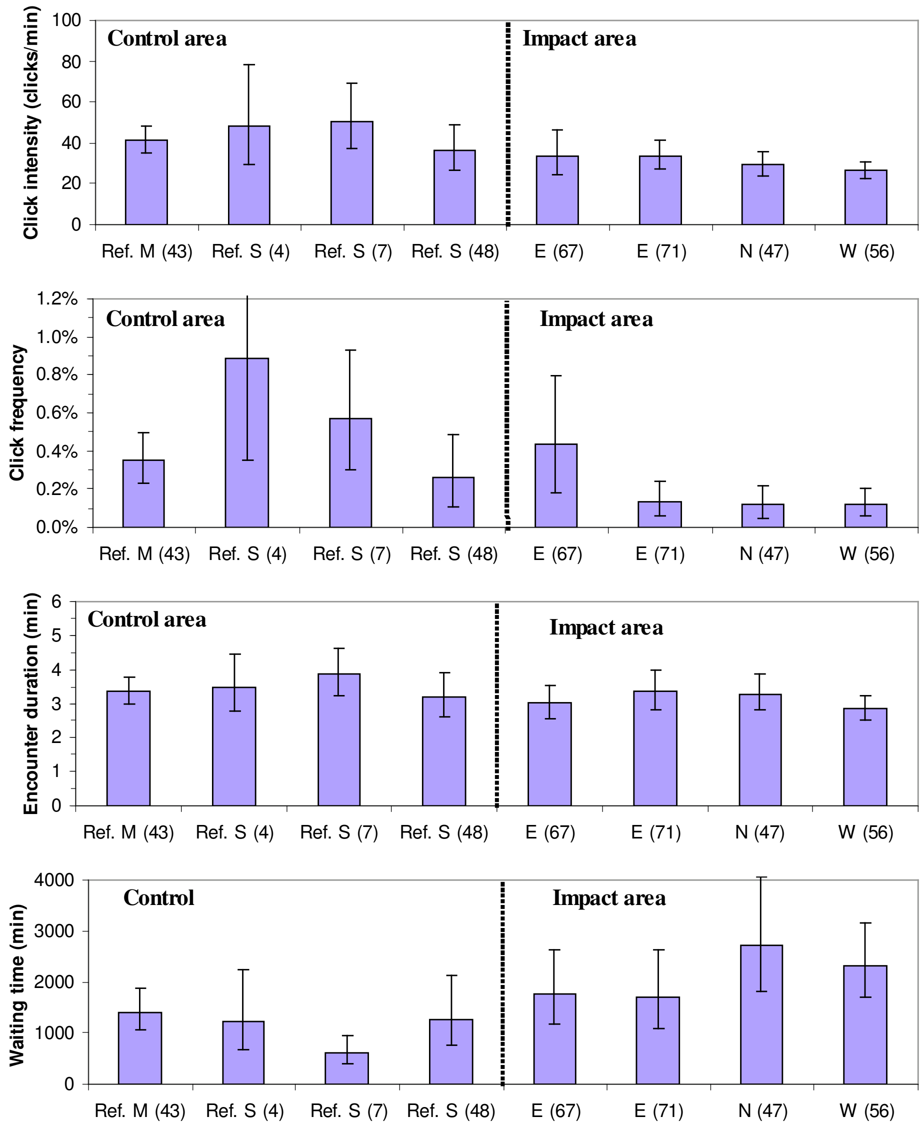


*Figure 17* Station-specific and T-POD-specific means (nested within stations) for the four indicators after back-transformation. The POD id is given in braces. Error bars indicate 95% confidence limits for the mean values. Variations caused by other significant sources of variation in equation (2-9) have been accounted for by calculating the marginal means. Station Ref N excluded from analysis.

## 3.3 Pile drivings - revisited

Between August 25th and October 12th 2002, the period with pile driving activity, five out of the six T-PODs were logging harbour porpoise echolocation activity, and all these five T-PODs were operational during the short pile driving activity at Gedser Harbour from September 5th to 12th 2002. The waiting times after pile driving activities had ceased was approximately the same for pile drivings taking place at the A8 foundation within the wind farm and pile drivings in Gedser Harbour (*Figure 18*). There was a significant variation in waiting times at four out of the five stations (exception was Station N that recorded only two waiting times following pile driving at Gedser Harbour) depending on whether pile driving activity had taken place prior to the observation (*Table 8*). For all of the four stations there was a significant increase in waiting times when pile driving took place, irrespective of the pile driving location (the eight contrasts for pile driving versus no pile driving were all significant, *Table 9*). For three of the four stations there was no difference in waiting time when comparing pile drivings in the wind farm and pile drivings at Gedser Harbour. Only at Station Ref. N were the waiting times longer when pile driving took place in the wind farm compared to pile driving at Gedser Harbour, although a similar result, on the verge of being significant, was observed for Station W as well.

*Table 8* Variation in waiting times analysed by F-test for the three pile driving categories (No pile driving, pile driving at Gedser Harbour, pile driving in the wind farm) and at the five stations. Contrasts (t-tests) between the three categories are listed in *Table 9***.** No data were availabe from station East in this particular period.

| Station | *df's* | *F - test* | *p* |
|---|---|---|---|
| N | 2, 1 | 29.21 | 0.1297 |
| W | 2, 15.3 | 29.38 | **<0.0001** |
| Ref N | 2, 20.9 | 30.62 | **<0.0001** |
| Ref M | 2, 12.6 | 19.62 | **0.0001** |
| Ref S | 2, 9.6 | 24.94 | **0.0002** |

Waiting times after pile driving activity in the wind farm area increased significantly by 19.4, 42.3, 16.2, 4.6 and 14.1 hours for stations N, W, Ref.N, Ref.M, and Ref.S, respectively. Waiting times after pile driving activity at Gedser Harbour increased significantly by 7.1, 3.6, 3.8, and 17.4 hours for stations W, Ref.N, Ref.M, and Ref.S, respectively. The increases in mean waiting time ranged from 27% at Station Ref.N to 491% at Station W. The smallest change during pile driving at Gedser Harbour actually occurred at the T-POD deployed closest to the harbour.

*Table 9* Contrasts (t-test) between the three pile driving categories tested stationwise. *Estimate* indicates the magnitude of the difference in log-transformed units and cannot in a simple way be back-transformed into waiting time. Positive values indicate that waiting time in category 1 is longer than waiting time in category 2, negative values the opposite. Significant p-values indicated in bold. No data were availabe from station East in this particular period.

| Station | Category 1 | Category 2 | *df's* | *Estimate* | *t - test* | *p* |
|---|---|---|---|---|---|---|
| N | Gedser Harbour | No pile driving | 1.64 | 2.2255 | 4.25 | 0.0718 |
| | A8 foundation | No pile driving | 62.6 | 2.2376 | 7.50 | **<0.0001** |
| | A8 foundation | Gedser Harbour | 1.29 | 0.0121 | 0.02 | 0.9837 |
| W | Gedser Harbour | No pile driving | 5.37 | 1.5914 | 3.22 | **0.0212** |
| | A8 foundation | No pile driving | 21.5 | 2.6762 | 7.44 | **<0.0001** |
| | A8 foundation | Gedser Harbour | 1.96 | 1.0849 | 1.96 | 0.0860 |
| Ref N | Gedser Harbour | No pile driving | 44.2 | 1.8463 | 6.19 | **<0.0001** |
| | A8 foundation | No pile driving | 49.8 | 2.3606 | 7.77 | **<0.0001** |
| | A8 foundation | Gedser Harbour | 12.1 | 0.5144 | 3.20 | **0.0076** |
| Ref M | Gedser Harbour | No pile driving | 3.82 | 1.5273 | 4.72 | **0.0103** |
| | A8 foundation | No pile driving | 27.9 | 1.2315 | 4.74 | **<0.0001** |
| | A8 foundation | Gedser Harbour | 7.26 | -0.2958 | -0.77 | 0.4667 |
| Ref S | Gedser Harbour | No pile driving | 4.38 | 2.3649 | 5.94 | **0.0030** |
| | A8 foundation | No pile driving | 11.7 | 1.8909 | 4.80 | **0.0005** |
| | A8 foundation | Gedser Harbour | 8.64 | -0.4739 | -0.93 | 0.3769 |

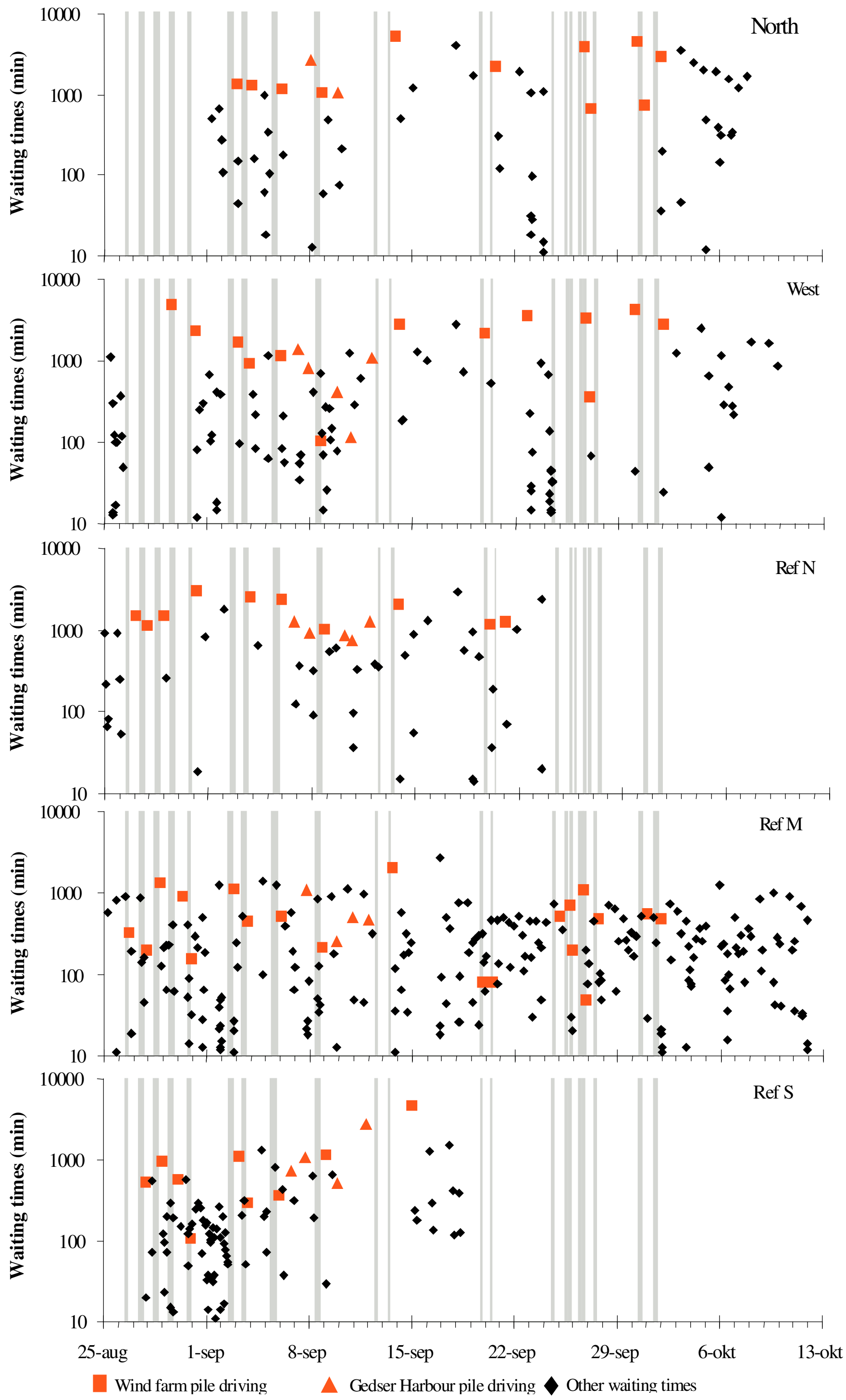


*Figure 18* Waiting times (symbols) at the five stations in the period of pile drivings. Note the logarithmic scale. Pile driving/vibration activities at foundation A8 are indicated by vertical grey lines.

# 4 Discussion

The discussion is separated into a general discussion of the results from 2004 and specific discussions on effects of pile drivings.

## 4.1 Effects of construction and operation

Both the wind farm area and the reference area experienced a drastic decrease in the porpoise echolocation activity from baseline to the construction period as a whole, as documented in the previous report (Henriksen et al., 2004) and evident from *Figure 15*. This decrease in echolocation activity was significantly larger in the impact area than in the control area.

It is worth noting that the indicators most strongly affected by construction and operation of the wind farm are daily frequency and waiting time. Both these indicators are indicative of harbour porpoise presence: The fraction of the day porpoises can be heard and duration of intervals between visits of individual animals or groups of animals, respectively. The two other indicators, daily intensity and encounter duration are indicative of the behaviour of harbour porpoises: the rate of click production *when* porpoises are present, and the duration the animals remain in the vicinity of the T-POD, *when* present, respectively. The fact that the two former indicators are the most strongly affected suggests that it is the presence of animals more than their behaviour, which has been disturbed by the construction and operation of the wind farm. Fewer animals visited both the wind farm and the control area compared to the baseline period, but once the animals were in the areas, their acoustic behaviour were not strongly affected.

Results from the BACI analysis (*Table 7*) support these conclusions. Three of the four indicators showed significant changes from baseline to construction and the fourth (daily frequency) displayed the same tendency, although not significant. This suggests that both abundance and behaviour of porpoises were affected by the construction of the wind farm. Moving from construction to operation of the wind farm resulted in a change in the indicators towards baseline levels. For daily intensity and encounter duration the levels during the first year of operation were not significantly different from the levels in baseline in the BACI test. This was not the case for waiting time. The small decrease in waiting time from construction to first year of operation is not significant and median waiting times in 2004 were approximately five times longer than during baseline. The same tendency was observed in daily frequency, although none of the contrasts of the BACI test were significant. Daily frequencies during both construction and first year of operation were very low, with many days without any clicks recorded. This results in a very high serial correlation of the data and the correction for this autocorrelation removes much of the power of the test. Waiting times on the other hand are not serially correlated to the same degree and this indicator should thus provide a more robust picture of changes in abundance.

The abundance of porpoises in the wind farm area thus remained low in 2004, the first year of operation, at levels not significantly different from the construction period. Porpoises were not absent from the wind farm however, and when present their acoustic behaviour was not significantly different from baseline behaviour.

A displacement of porpoises from the wind farm area was anticipated already in the environmental impact assessment (Bach et al, 2000). At the same time however, it was also predicted that porpoises would return to the wind farm area after end of the construction activities and that there would be no permanent effects of the operating wind farm on abundance and behaviour of porpoises. As a return to baseline levels are not evident from the results from the first year of operation, as presented here, it becomes central to understand what underlies these results and whether there are in fact permanent effects of the wind farm on porpoises. It must be stressed clearly however, that indications are preliminary, based on only the first year of operation of the wind farm and as the monitoring program continues, final conclusions will have to await its completion by end of 2005. Possible explanations will be discussed below.

From the onset of the monitoring program there has been only limited changes in the setup and general methodology. No changes in positions of the six stations, methods of deployment and setup of T-PODs has taken place since the onset of the baseline monitoring. Only exception is the very first period of monitoring (in 2001), and for the same reasons these data were excluded from analysis. On three of the six positions the same T-POD has been in use for the entire monitoring period. At the remaining three stations there has been replacements of lost T-PODs, but the variation introduced by this was incorporated into the model and is thus unlikely to explain the lack of recovery observed in waiting times from construction to operation. There is thus little doubt that the decrease observed reflects a genuine decrease in the presence of porpoises in the area from 2001/2002 (baseline) to 2004 (first year of operation).

A general decline in porpoise density of the western Baltic Sea during the three years of monitoring would affect both the impact and the control area. This possible explanation fails to explain that strongest effects were seen in the wind farm area and during construction of the wind farm. The fact that strongest impact is seen in the wind farm area also speaks against the dredging activities at the entrance to Gedser harbour as responsible for the effect. The dredging activities were concurrent with both construction and first year of operation, but occurred very close to the reference area and if they have a significant impact on porpoises, this effect ought to be strongest in the reference area. Thus circumstances points to the wind farm itself and the construction activities as responsible for the decline in porpoise abundance observed.

If we accept that the decline observed is due to the wind farm, the low levels observed in 2004 relative to baseline could either be due to a very slow recovery from the construction activities or it could be a more permanent effect of the operating wind farm. Relatively little is known for harbour porpoises on recovery from disturbances in the wild and habituation to novel stimuli or changes in the local environment. At this point we can thus only speculate on the time frame of recovery from construction activities and hope that data collected in 2005 will shed more light on this question.

If there is a permanent effect of the wind farm on the presence of porpoises this can be due to some resource (typically food) that the porpoises obtained in the area no longer is present in the same amount as before. It could also be because porpoises are deterred from the area by the presence of the wind turbines or some other factor associated with the operation it. A combination of both factors is of course also possible.

Very little is known about habitat selection and habitat use by harbour porpoises. It is thus not known why porpoises were in the Nysted/Rødsand area before construction of the wind farm started. They may have used the area for foraging, it may have played a role in reproduction (mating and/or birth and nursing), or it may simply have been a transit area connecting other, more important areas. From the baseline T-POD recordings and other T-POD studies in the region, the Nysted/Rødsand area appears to be a low-density area with respect to porpoises. Significantly higher echolocation activity levels has been recorded on the eastern side of the island Falster (Gedser Rev, Teilmann et al., 2002a). Satellite telemetry studies of porpoises show similar patterns, with most positions received to the west, east and south of the Nysted/Rødsand area and comparatively few positions from the area immediately south of Rødsand (Teilmann et al, 2004). These observations speak against the Nysted/Rødsand area as an important habitat for porpoises and whatever attracts the animals to the area is probably not present in large quantities. It thus remains a possibility that some food resource has become more scarce due to the local changes in the environment caused by the construction and presence of the turbines and that this can explain the decrease in porpoise abundance observed. Against this speaks the decrease also observed in the control area. The local environment in the reference area is unlikely to have been affected by the presence of the turbines.

A deterring effect of the turbines thus remains as a possible explanation. There is no reason to expect porpoises to avoid the area simply because of the physical presence of the turbines. The turbines are widely spaced, covered in algae and epifauna and thus not fundamentally different from the surroundings porpoises normally navigate. Porpoises are capable of navigating very narrow and shallow areas and can often be seen foraging actively within the surf zone of beaches a few meters from the water line. Concern has been raised however, about the possible deterring effects of underwater noise radiated from the turbine foundations. No actual measurements of radiated underwater noise from the turbines at Nysted are available. Measurements at other wind farms, including on the same type of turbines and foundations at Middelgrunden (Henriksen, 2001; Madsen et al. 2005) does not suggest reason for serious concern. As stated in the introduction, the maximal distance at which a porpoise can hear the turbines at Middelgrunden were estimated to be about 100 meters or less, and the distance at which the behaviour of the porpoise is affected by the turbine noise is likely to be substantially smaller. From the available measurements it thus appears unlikely that the turbine noise should be responsible for the reduction in porpoise abundance, especially since the control area, located 10 km away was also affected. This leaves boat traffic as a candidate for disturbance. Fast service boats frequently visit the wind farm for maintenance and service and as they sail out from Gedser harbour and pass through or close by the control area, they have the potential to affect porpoises here as well. Fast ships are known to generate high underwater noise levels (e.g. Richardson et al. 1995) that could potentially deter porpoises from the areas. Effects of boat traffic on porpoises is poorly documented however, and there is not basis for generally stating that high ship traffic deter harbour porpoises. Some of the highest densities of porpoises in Danish waters are found in the northern Lillebælt and northern Storebælt, areas that have some of the highest levels of commercial shipping and leisure boat traffic (Heide-Jørgensen et al. 1992; Hammond et al., 1995; Kinze et al., 2003).

## 4.2 Effects of pile drivings

Waiting times were significantly longer at four out of six stations after pile drivings, both at the A8 foundation in the wind farm and at the breakwater in Gedser Harbour. Only limited data were available for the fifth station (station N) and no data were available at all for the sixth (station E). With the exception of station Ref N, there were no significant differences in reactions to the two different pile drivings. Some important conclusions can be drawn from these results. First of all the results from Gedser Harbour supports the previous observations of strong effects of pile drivings on porpoises seen in connection with the A8 foundation pile drivings/vibrations (Henriksen et al, 2004). Both pile driving operations caused measurable effects in the entire monitoring area, i.e. both wind farm and reference area and of comparable magnitude. Pile drivings are known to generate high levels of underwater sound and this is the most likely explanation for the effects observed.

An important difference between the two pile driving operations is that no mitigation procedures were employed in Gedser Harbour whereas pingers and seal scarers were deployed prior to each pile driving at the A8 foundation. Although source levels from pingers and seal scarer are considerably lower than what can be expected from the pile driving/vibration itself, the fact that they were deployed prior to the pile drivings raises the potential possibility that the effects observed were caused by the mitigation procedure and not the pile driving/vibration operation. This possible explanation can now be ruled out as the effects observed from the pile drivings in Gedser Habour were indistinguisable from the effects seen in connection with the A8 pile drivings/vibrations. This does not mean that mitigations were without effect however, as the desired effect of the mitigations is to deter marine mammals (seals and porpoises) from the immediate vicinity of the construction site and thus protect them from physical and/or physiological damage from the pile driving sounds. With the current setup for monitoring it is not possible to assess the effectiveness of the mitigation procedures.

# 5 Conclusion

Conclusions from monitoring during the first year of operation of the wind farm must be considered preliminary, as monitoring continues. Conclusions on animal abundance and behaviour during 2004 are nevertheless very clear. No significant increase in abundance of porpoises in the wind farm area was seen in 2004 relative to the construction period and levels are still about a factor 5 lower than during baseline monitoring. Porpoises were not absent from the wind farm however, and when present, their acoustic behaviour was not significantly different from baseline behaviour. All indicators analysed points to the wind farm as the direct or indirect cause of the decline (strongest effects consistently observed in wind farm area compared to reference area). The reason why fewer porpoises frequented the wind farm during its first year of operation is unknown and it is too early to establish whether the effect is permanent or recovery to baseline levels is slower than originally anticipated in the EIA.

A significant effect of pile drivings/vibrations has previously been demonstrated (Carstensen et al. 2005). The inclusion of data from pile drivings in Gedser Harbour in 2003 has strenghtened this conclusion, as similar strong negative effects on porpoise abundance were observed. The fact that no mitigations were used at the pile drivings in Gedser Harbour demonstrates that impact on porpoises observed also from the pile drivings inside the wind farm were related to the pile drivings and not merely an effect of the mitigations (pingers and seal scarer). This does not however, imply that mitigations were not effective in fulfilling their purpose, which is deterring animals out to safe distances before onset of pile drivings.

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