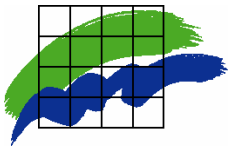

Summary on harbour porpoise monitoring 1999-2006 around Nysted and Horns Rev Offshore Wind Farms

Report to Energi E2 A/S and Vattenfall A/S

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1 Summary

Between 1999 and 2006 harbour porpoises were studied by ship surveys to evaluate their use of Horns Reef, and the potential effect of construction and operation. At both Horns Rev and Nysted Offshore Wind Farms the potential effect of construction and operation was also investigated by means of acoustic monitoring from 2001 to 2005. Only a slight decrease in porpoise abundance was found at Horns Reef during construction and no effect during operation of the wind farm was observed. A clear decrease in the echolocation activity of porpoises was found at Nysted during construction and operation of the wind farm. This effect still persisted after two years of operation, however with indications of a slow, gradual recovery. At both wind farms a substantial but short lived effect of pile driving was observed with larger responses at Nysted, where silent periods after pile driving were several days compared to hours at Horns Reef.

The stronger response Horns Rev compared to Nysted may be speculated to be caused by a higher motivation/competition to find food at Horns Rev regardless of the presence of a wind farm. Another explanation could be that the more turbulent and noisy environment at Horns Rev makes the turbines and the noise less detectable to the porpoises.

2 Background

In 1996 in the wake of the Kyoto summit the Danish government passed an action plan for energy: Energy 21, in which it was decided to establish 5,500 MW of wind power in Denmark before 2030, 4,000 MW of which was planned to be large scale offshore wind farms. This decision was followed by action in 1998 where the Minister for Environment and Energy commissioned the Danish power companies to establish 750 MW of offshore wind power in Danish waters as a demonstration project. The aim of the project was both to test the feasibility and economy of large scale offshore wind power and address potential negative effects on the marine environment by establishment of an ambitious environmental monitoring program. The demonstration project includes two wind farms (a total power of 326 MW) one at Horns Reef in the North Sea (Horns Rev Offshore Wind Farm, 80 turbines of 2 MW) and one in the south-western Baltic (Nysted Offshore Wind Farm, 72 turbines of 2.3 MW).

Horns Rev Offshore Wind Farm came in operation by the end of 2002 while Nysted Offshore Wind Farm was operational from 1 December 2003. Initial problems with the turbines at Horns Rev resulted in heavy vessel activity during most of 2003 and 2004. We therefore name 2003-2004 as "semi-operation" due to the much higher level of disturbance of the animals than under normal operation from 2005 and onwards.

The Environmental Impact Assessments on harbour porpoises for the two wind farms were carried out in 2000 following the guidelines jointly drafted by the Danish Energy Agency and the National Forest and Nature Agency (Bach et al. 2000; Tougaard et al. 2000). Since 1999 studies on the distribution and behaviour of the local harbour porpoise stocks have been studied to evaluate the effect of the wind farms. This report summarises and compares the main results from the demonstration programs and the significance of these results for other wind.

3 Harbour porpoises in the areas around the two wind farms and potential effects

Harbour porpoises are widely distributed in the Danish waters. The total population of harbour porpoises in Denmark numbered about 100,000 individuals in 1994 (Teilmann & Lowry 1996).

At the time of the environmental impact assessments little information was available on the presence of harbour porpoises in the areas around Horns Reef and Nysted. From surveys prior to the onset of the monitoring program it was known that harbour porpoises was found in both wind farm areas and that the abundance was higher in the south-eastern North Sea than in the south-western Baltic (Heide-Jørgensen et al. 1993, Bach et al. 2000, Tougaard et al. 2000, Hammond et al. 2002). Because of the relatively low abundance in the western Baltic it was decided to focus the monitoring programs on the harbour porpoises around Horns Reef. Therefore regular ship surveys as well as acoustic monitoring were carried out at Horns Reef while only acoustic monitoring was conducted at Nysted.

Satellite tagged porpoises in the south-western Baltic show that they often move over large distances and only occasionally stay within the same area for longer periods (Teilmann et al. 2004). No porpoise was tagged in the south-eastern North Sea, and none of the porpoises tagged in the inner Danish waters entered the southern North Sea. This strongly suggests that the porpoises living around the two wind farms belong to two distinct populations with no or little interaction. From the surveys it was clear that the eastern North Sea and thus also Horns Rev was home to a large number of porpoises, whereas densities in the Western Baltic and thus the area around Nysted was lower.

Offshore wind farms can potentially affect marine mammals in several ways. The physical presence of the turbines and especially the construction activities could cause animals to avoid the area, partly or completely. The most important factor in this respect is likely to be underwater noise. Construction activities are generally noisy and especially pile driving generates very high sound pressures that may injure the animals at close range. Thus the pile driving force was slowly intensified (ramp up) and underwater acoustic alarms (porpoise pingers and seal scarer) were deployed to deter animals to safe distances during pile driving at both Horns Rev and Nysted.

Wind turbines in operation also generate noise, but at considerably lower levels than pile driving and potential effects are expected to be small and local. Construction of an offshore wind farm also creates permanent alterations to the local environment, especially on soft bottoms, where the turbine, foundations and scour protection will be colonised by algae and animals new to the area and thereby creating an artificial reef. This is likely to cause subsequent changes in the fish fauna and possibly increase the productivity of the local area. Such changes to the fish fauna and productivity are likely to be neutral or even positive to opportunistic feeders like porpoises.

4 Monitoring programs on harbour porpoises

In order to study the potential effects from the construction and operation of the wind farms on the local harbour porpoise stocks, three separate monitoring programs were carried out:

Horns Reef

1. Continuous automatic acoustic monitoring using T-PODs.
2. Regular ship surveys to determine the presence of animals in and around the wind farm.

Nysted

3. Continuous automatic acoustic monitoring using T-PODs.

Difficulties in monitoring the movements of harbour porpoises around the wind turbines with high accuracy prevented us from examining small scale behaviour and therefore only general effects of the wind farm as a whole was investigated. In future studies advanced technology may be able to determine how harbour porpoises behave around individual wind turbines and thereby also monitoring the reactions to specific disturbances.

In the following the main results from the three monitoring studies will be given. The final results of the monitoring programs at the two wind farms can be found in Tougaard et al. 2006a and Tougaard et al. 2006b.

5 Results

5.1 Acoustic monitoring

Investigations were conducted using autonomous acoustic dataloggers, T-PODs that record and store the time and length of echolocation sounds from harbour porpoises. The first T-PODs were deployed in November 2001 at Nysted and July 2001 at Horns Reef in the wind farm areas before construction started. At both sites several reference or control stations with T-PODs were used to determine the relative effect of the wind farm in a so-called statistical BACI design. Relative differences between the wind farm and a reference area were tested when comparing the baseline, construction and operation periods with each other, while taking differences in the month of sampling into account.

Four indicators were calculated on basis of the click recordings:

- *Porpoise positive minutes* (minutes with porpoise clicks recorded), which is an indication of porpoise echolocation activity and thereby relative density.
- *Waiting time* (time between groups of echolocation clicks) indicates how often porpoises enters the area.
- E*ncounter duration* indicates how long the porpoises remain in detectable range of the T-POD.
- *Number of clicks per porpoise positive minute* is an indicator of how intensive the porpoise uses its echolocation when within detectable range.

5.1.1 Horns Rev Offshore Wind Farm

At Horns Reef six T-PODs were also used for the acoustic monitoring. Two placed inside the wind Farm area and four reference stations placed up to 25 km both east and west of the wind farm serving as reference stations (Fig. 1). The reason for placing four reference stations along the entire reef was due to the hydrodynamically complex environment, making it more likely to include the natural variation in porpoise presence on the reef when averaging across stations.

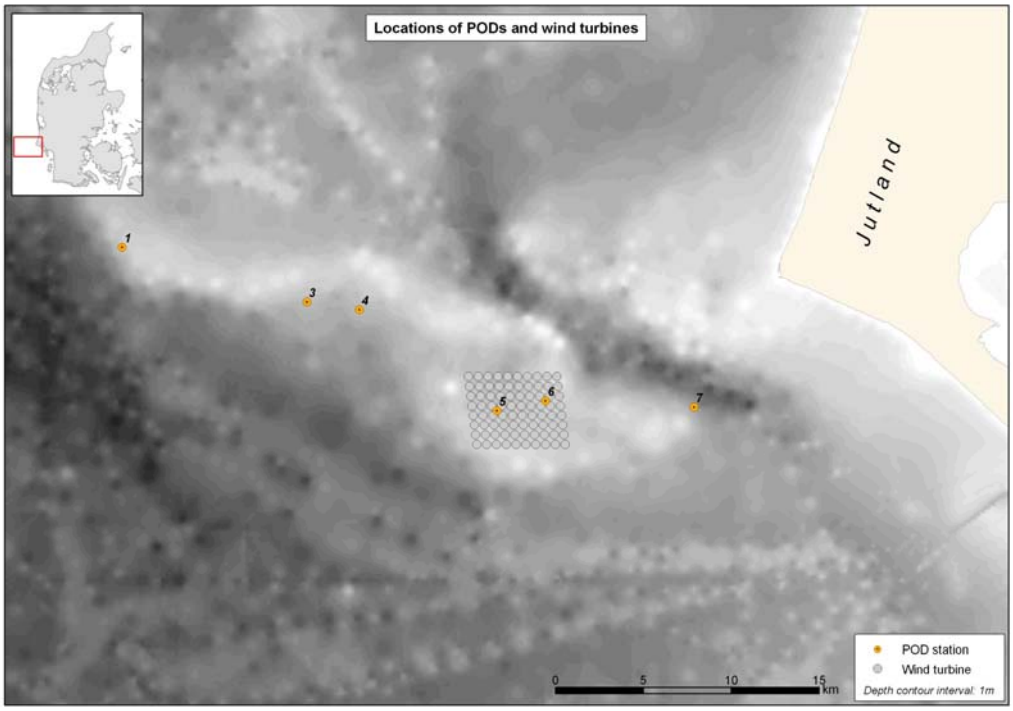

Figure 1. *Study area with individual turbines indicated with open circles and positions of the six T-POD measuring stations (see methods section). Depth indicated by shades of grey: shallow areas in white.*

At Horns Reef, acoustic recordings did not show any overall significant change in abundance in the wind farm area compared to the reference areas during construction (Fig. 2). However, there was a significant difference between semi-operation (when intensive maintenance work took place) and operation, measured on the indicator *porpoise-positive-minutes (PPM)*. PPM reached the lowest mean value in the entire monitoring period during semi-operation. During the last year of monitoring when normal operation of the wind farm started, the porpoise acoustic activity was higher in the operation phase than during baseline, but this was the case both in the wind farm and in the reference areas.

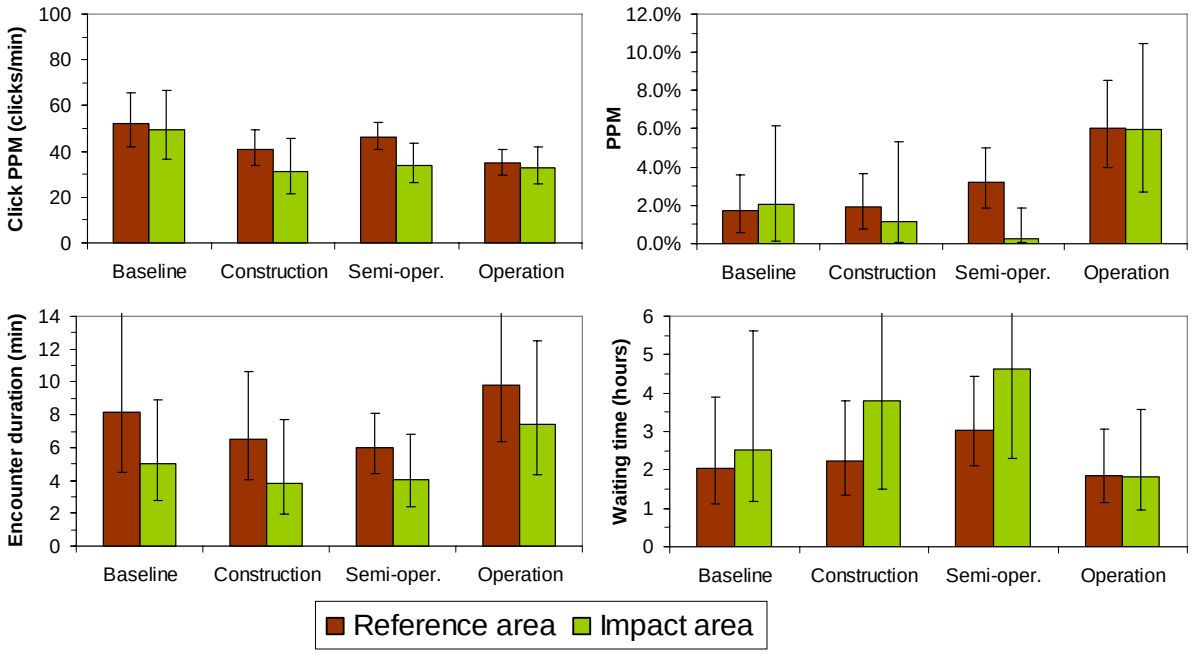

Figure 2. *Acoustic results from Horns Rev Offshore Wind Farm. Mean values for waiting time, porpoise positive minutes (PPM), Clicks/PPM and encounter duration divided by the reference and impact (wind farm) areas. Values are separated into four periods: baseline, construction, semi-operation, and operation. Semi-operation covers a period following construction, where intensive maintenance and service operations occurred and the turbines thus were not operating at full capacity. Error bars indicate 95% confidence limits for the mean values.*

Similar to the Nysted area acoustic activity on Horns Rev was high with shorter waiting times in late spring, summer and autumn (April-October), whereas low echolocation activity was found in winter and early spring (November-March)(Fig. 3).

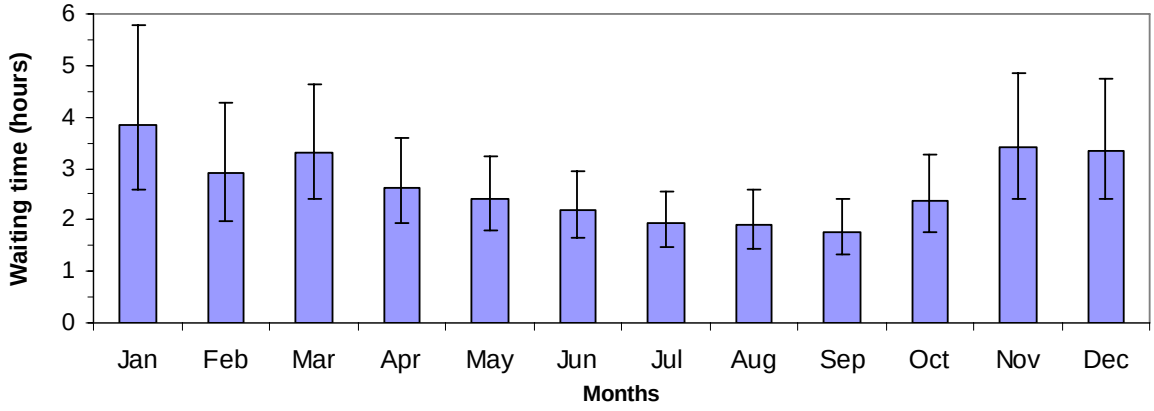

Figure 3. *Monthly mean waiting time. Error bars indicate 95% confidence limits for the mean values.*

5.1.2 Nysted Offshore Wind Farm

For the purpose of acoustic monitoring three T-PODs were placed inside the wind Farm area before, during and after the wind farm was constructed. At the same time three T-PODs were placed 10 km east of the wind farm serving as reference stations (Fig. 4). The reference stations were placed in an area with similar depth and distance to shore to resemble the same natural ecological variation as the wind farm area and at the same time be undisturbed by the activities in the wind farm.

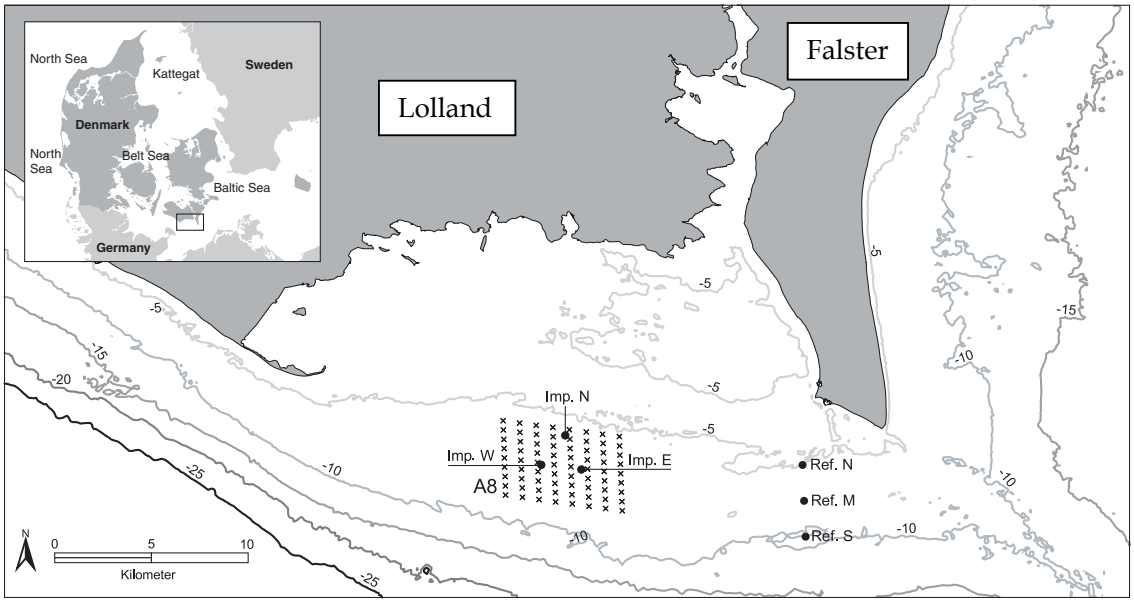

Figure 4. *Study area at Nysted Offshore Wind Farm. Wind turbines are indicated with x and T-POD monitoring stations with solid circles. Three stations (Imp. W, Imp. N and Imp. E) are located inside the wind farm and three stations (Ref. N, Ref. M and Ref. S) are located in a reference area about 10 km east of the wind farm. Foundation A8 where pile driving took place is located in the south-western corner of the wind farm.*

During the baseline period at Nysted there was no difference in neither *waiting time, n*or number of *porpoise positive minutes* between the reference and impact area (Fig. 5). During construction and the first two years of operation *waiting time* increased and *porpoise positive minutes* decreased considerably in the wind farm area, indicating that fewer porpoises were present in the wind farm area in these periods. A smaller, yet still significant increase in *waiting time* and decrease in *porpoise positive minutes* was also observed in the reference area, possibly signifying a general effect of the wind farm construction on porpoise at least 10 km away from the Nysted Offshore Wind Farm. However, this may also have been due to a localised effect from a ship traffic corridor near by the reference area during the construction phase.

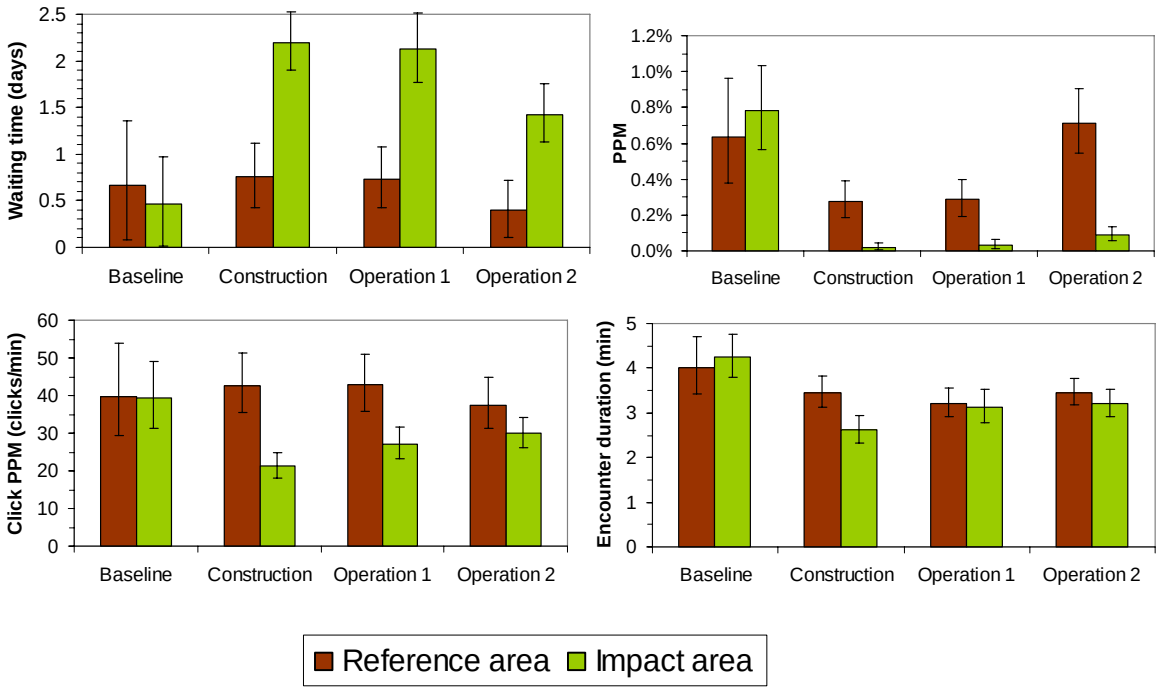

Figure 5. *Acoustic results from Nysted Offshore Wind Farm. Mean values for waiting time, porpoise positive minutes (PPM), Clicks/PPM and encounter duration divided by the reference and impact (wind farm) areas. Error bars indicate 95% confidence limits for the mean values.*

Although the indicators are still significantly affected two years after completion of the wind farm, there is a tendency towards return to baseline (pre-construction) levels in waiting time and *porpoise positive minutes* in the wind farm area. Activity in the reference area was back to baseline levels two years after end of construction. This likely indicates that some porpoises have gradually habituated and returned to the wind farm during the first two years of operation.

Encounter duration and number of *clicks per porpoise positive minute* decreased significantly from baseline to construction period in the wind farm area (see figure above), suggesting that not only were there fewer porpoises in the area during construction, their echolocation behaviour may also have been affected. This effect disappeared in the second year of operation, indicating that the acoustic behaviour of porpoises in the wind farm area returned to baseline levels.

The seasonal variation in acoustic activity in the general Nysted area showed the highest activities and shortest waiting times in late spring, summer and autumn (April-November), whereas the lowest echolocation activity was found in winter and early spring (December-March)(Fig. 6).

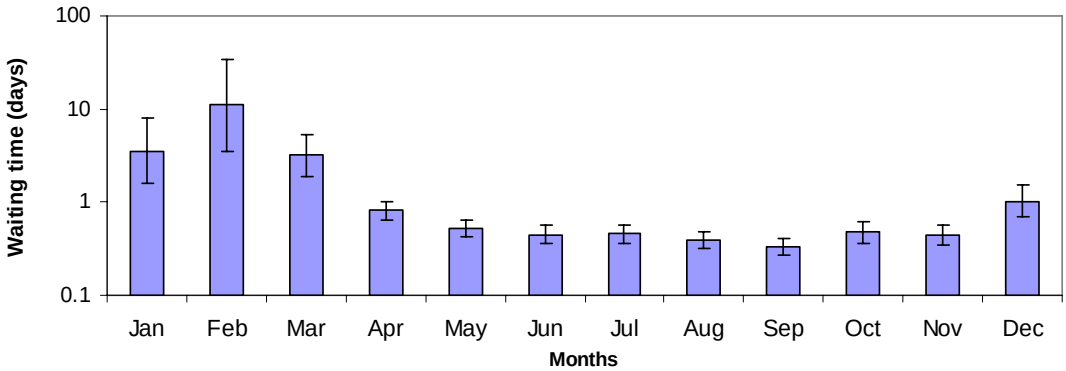

Figure 6. *Monthly mean waiting time. Error bars indicate 95% confidence limits for the mean values.*

5.2 Ship surveys at Horns Reef

Systematic ship surveys covered the wind farm and the rest of Horns Rev. Thirty surveys of 1-3 days duration were conducted between 1999 and 2006. Surveys were only carried out in light winds to make observations of porpoises possible. Porpoise observations, salinity, temperature, depth and tide were recorded and used in development of a spatial model of distribution of porpoises on individual surveys. This made it possible to construct maps of porpoise density covering the entire survey area. From the density maps a comparison of the relative density of porpoises inside the wind farm was compared to three zones progressively more distant from the wind farm (Fig. 7).

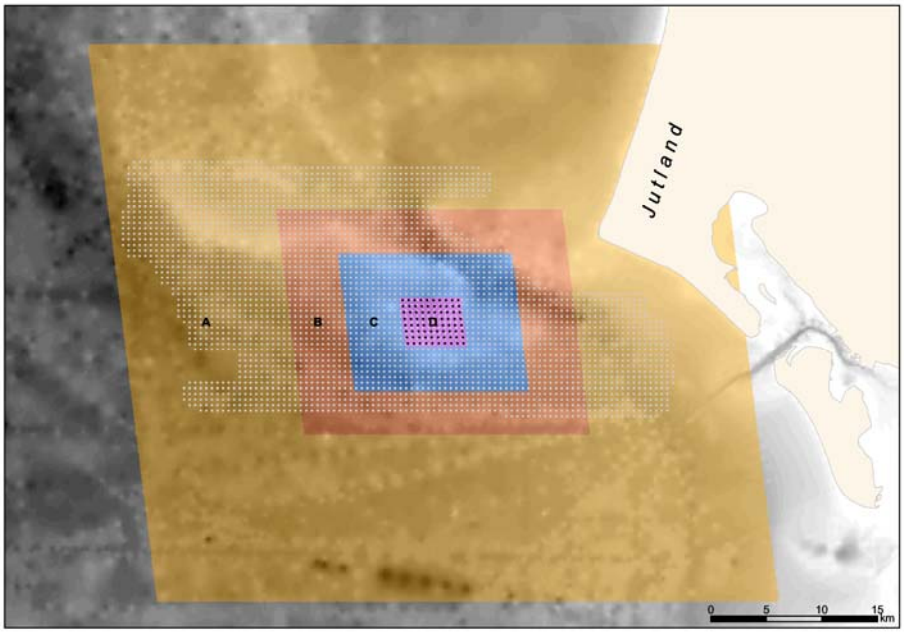

Figure 7. *Zones (A-D) used for statistical test of chance in distribution of harbour porpoises on Horns Reef. Only the parts of the four zones within the surveyed area (indicated by white dots) were included in the analysis. Each white dot represents one grid cell of the spatial model. The purple square indicates the wind farm area.*

The ship surveys at Horns Rev showed that porpoises were found throughout the survey area, both before, during and after construction of the wind farm. The porpoises tended to concentrate on the reef and only few animals were observed in the deeper areas south of the reef. During construction few observations of porpoises were made in the wind farm. There was a substantial variation in number of animals counted per survey. This variation was consistent with the acoustic monitoring with generally fewer animals observed in winter and more animals during the summer months.

The results from the ship surveys at Horns Reef point in the same direction as the acoustic data, i.e. a weak negative and local effect of the wind farm during construction but otherwise no significant changes (Fig. 8). Also ship survey data indicate more porpoises in the area as a whole during the operational period than for any other of the periods, baseline included.

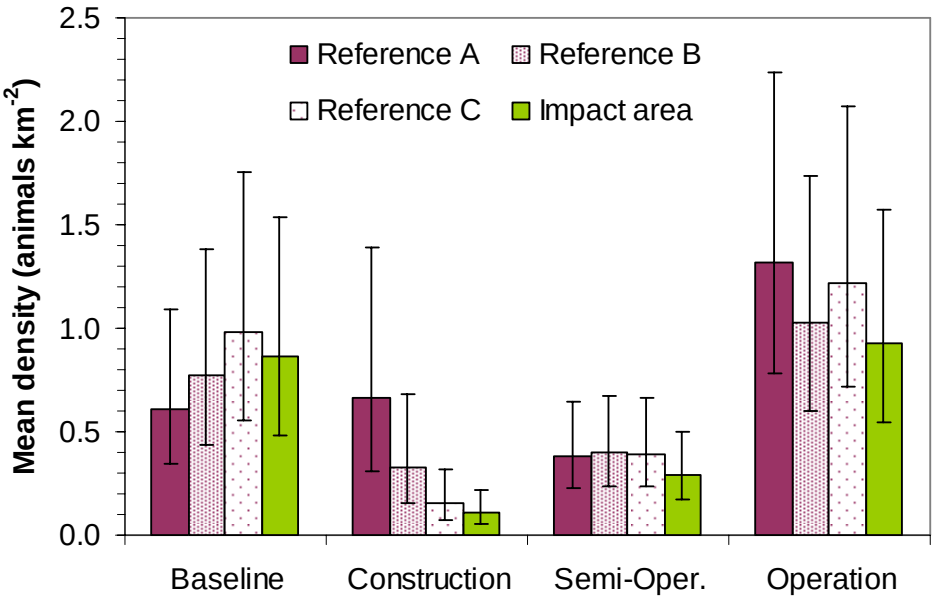

Figure 8. *Estimated mean densities based on the spatial model for combinations of the 4 areas and 4 periods. Error bars show the 95% confidence intervals for the estimated mean densities.*

6 Conclusion

During the most comprehensive study ever, assessing the effect of offshore wind farms on harbour porpoises, state of the art technology has been used. This has given us tremendous amounts of data and a wealth of new information about harbour porpoise responses to wind farms.

6.1 Comparison between the two wind farms

The effects on porpoises were mainly connected to the construction phase, and only for porpoises at Nysted did the negative effect persist through the first two years of operation. At Horns Rev, which is an important area to porpoises and with generally higher densities of animals, there was a weak negative effect of the construction period as a whole and strong, but short lived reactions to pile driving operations. At Nysted, an area with lower porpoise density, there were strong negative reactions to the construction, where animals left the wind farm area almost completely. Also the reference site 10 km away appeared affected. Similar to Horns Rev strong responses in acoustic activity were observed during pile driving operations. Recovery from pile drivings took significantly longer than at Horns Rev. After two years of operation the porpoise activity in the reference area has returned to baseline levels, but activity in the wind farm is still lower than expected.

Whereas the disturbance during construction was anticipated in the impact assessment, the slow recovery at Nysted was unexpected. The population effect of constructing and operating the two wind farms has not been assessed. In general however, one can say that at Horns Rev a large number of animals were affected, but for a limited period of time (construction period) and that

even more animals were affected for an even shorter time during pile drivings. At Nysted a comparatively lower number of porpoises were affected at any time due to the lower density of porpoises in the south-western Baltic. However, when evaluating the total impact from the entire study period, a higher proportion of the population at Nysted was probably affected because the response to the wind farm was stronger and because the duration of the disturbance was considerably longer than at Horns Rev.

The monitoring programs were designed to show if the animals avoided the wind farm areas during construction and operation of the wind farms. Therefore it is not possible to conclude on what specific factors like noise, presence of the turbines, boat traffic or change in prey availability are responsible for the observed effects. The only exception is pile drivings, where significant responses were observed for porpoises. However, it is likely that the most important negative effect on porpoises, most pronounced at Nysted Offshore Wind Farm, was a combination of disturbance from the different construction activities, involving boat traffic, with associated underwater noise, as well as disturbance to the seabed with resuspension of sediment etc. Secondary effects, where prey species of fish were deterred by the construction activities are also possible. There are no clear explanations to the slow recovery at Nysted and why this was not observed at Horns Rev. Whether the difference in construction methods between the two wind farms (pile driving at Horns Rev and gravitation foundations at Nysted) affected the porpoises differently is also unknown.

One possible explanation to the larger response at Nysted may be that the area is a less important habitat to porpoises than Horns Rev and that the lower porpoise density at Nysted implies less competition for food resources and thereby that the porpoises do not necessarily have a strong incentive to search for food in an area with disturbances. In other words, the porpoises at Horns Rev may be more tolerant to disturbance, because the area is of great importance, whereas the porpoises around Nysted are not particularly interested in the area and will simply avoid it if disturbed, without any larger consequences than the need to swim around the area. Another possible explanation is that the Nysted wind farm is located in a relatively sheltered area, whereas Horns Rev has a high exposure to wind and waves resulting in higher background noise. Thus, the relative noise level from the turbines is higher and audible to the porpoises at greater distances at Nysted than at Horns Rev.

Since the effects on harbour porpoises were different in magnitude at the two wind farms, it can be concluded that the same species may react differently to similar disturbances, i.e. wind farms. This is an important conclusion in future monitoring of wind farms. Until more information is available on the actual cause of the observed difference no generalisation of the results to other wind farms can be recommended.

In 2005 a project studying the presence of porpoises around Horns Rev and Nysted wind farms were conducted by University of Hamburg and Bioconsult SH Germany. Rows of five TPODs was used, extending from inside the wind farm to 1200m away from the outer edge of the wind farm. The preliminary results indicate that at Nysted, porpoise echolocation activity was higher outside the wind farm than in the wind farm. At Horns Rev the results were inconclusive. Further data analysis and more data may explain the difference between the two wind farms.

Cumulative effects are an important issue when more wind farms are built within the same range of a harbour porpoise population in the future. This effect cannot be evaluated on the basis of one wind farm but monitoring both the population development changes in distribution around several wind farms will show if there is a linear relationship between the number of wind farms or turbines and the effects given in this study.

List of major findings in the studies of harbour porpoises:

1) Strong reactions to pile drivings at both wind farms.
2) Weak reaction to the combined construction period at Horns Rev
3) Strong reaction to the combined construction period at Nysted
4) No reaction in the operation period at Horns Rev
5) The strong reaction during construction persisted during the first two years of operation at Nysted but with a tendency of recovery.

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