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Environmental effect studies – Status more than two years after the erection of Horns Rev and Nysted Offshore Wind Farms

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Summary

With the environmental monitoring programmes at Horns Rev and Nysted Offshore Wind Farms coming to an end a pattern of the effects related to large-scale wind farms in a marine environment is starting to emerge. Being the first offshore wind farms of their sizes, it has been essential to map the effect on the environment with respect to future exploration potentials in Danish waters. Thus, an ambitious monitoring programme was launched to extract the actual effect that the construction of the wind farm would have on the environment from the potential effects predicted prior to construction. Horns Rev and Nysted Offshore Wind Farms, the two major Danish demonstration wind farms, have been the subject of a long and unbroken line of surveys. Ongoing environmental monitoring has been performed since the Environmental Impact Assessment (EIA) in 1999 and the baseline studies before erection of the wind farms in 2002-2003. The programmes will continue until the end of 2005, thus the environmental monitoring programme has gathered the most extensive existing dataset on the disturbance effects related to large-scale offshore wind farms. The PSO-funded Danish monitoring programme includes issues such as benthic flora & fauna, introduction of hard substrate habitat, fish, marine mammals and birds.

Introduction

The possibilities of utilising shallow waters for offshore turbines in Denmark were evaluated a number of years ago in collaboration between the Danish utilities and the Danish Energy Authority. An action plan was proposed in which two of the main recommendations were to concentrate offshore development within a few areas and to carry out a large-scale demonstration programme. An agreement was reached in 1998 between the Government and the production companies to establish a large-scale demonstration programme. The objective of the programme was to investigate economic, technical and environmental issues to accelerate offshore development and to open up selected areas for future wind farms.

The development of both Horns Rev and Nysted Offshore Wind Farm is a result of the agreement and in 1999, the Danish Energy Authority approved the installation in principle, and preliminary surveys and planning of the two farms could be initiated. In the summer of 2000, the EIA for both farms was submitted to the authorities, and in 2001 the application to build both wind farms was approved by the authorities, in accordance with certain conditions.

Due to the special status of the demonstration programme a comprehensive environmental monitoring programme was initiated following completion of the EIA. This monitoring programme is to be carried out in the period from 2001-2005. The monitoring programme is divided into three stages: A baseline programme carried out prior to the construction phase, a monitoring programme for the construction phase and a monitoring programme for the operation phase.

Horns Rev Offshore Wind Farm is constructed and operated by ELSAM and Nysted Offshore Wind Farm is constructed and operated by ENERGI E2.

Administration and coordination of the environmental monitoring programmes

The technical responsibility for the project descriptions and the implementation of the work rests with the environmental group. This group consists of representatives from the Danish Forest and Nature Agency, the Danish Energy Authority, Elsam and Energi E2. The environmental group thus coordinates the environmental monitoring programmes for both Horns Rev and Nysted wind farms. The decision-making process relating to the environmental monitoring programmes is characterised by openness and continuous dialogue between all parties involved.

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The demonstration projects are financed by PSO funds. PSO denotes Public Service Obligation, which in practice is funds generated from a small fraction of each consumer's electricity bill, earmarked for research and development projects.

The work of the environmental group and the results of the studies are assessed by an international panel of independent experts, IAPEME (International Advisory Panel of Experts on Marine Ecology), consisting of experts with unique competence within the individual branches of the entire monitoring programme. The experts meet once a year to evaluate the progress of the environmental monitoring programmes and to make recommendations for future monitoring. On the basis of the recommendations of the expert panel, the environmental group sets priorities for future programmes.

To ensure that as many parties as possible are heard in the debate about the environmental monitoring of the Horns Rev and Nysted wind farms, a number of organisations with particular environmental interest have been offered the opportunity to participate in a "Green Group" which meets with the environmental group approximately once a year. The Green Group comprises representatives from WWF, the Danish Society for Conservation of Nature, the Danish Outdoor Council, Greenpeace, the Danish Ornithological Society and the Danish Organisation for Renewable Energy.

The wind farms

Horns Rev offshore wind farm
The Horns Rev Offshore Wind Farm is located approx. 14-20 km west of Blåvands Huk, which is Denmark's most westerly point. The offshore wind farm at Horns Rev consists of 80 wind turbines of 2 MW (Vestas V80), and covers an area of 27.5 km^2 (including the 200 m exclusion zone around the wind farm) (Figure 1). The distance between both wind turbines and rows of turbines is 560 m. The turbine foundations, including the scour protection, cover approx. 14,500 m^2 of the seabed, which is less than 0.1% of the total area of the wind farm.

The turbines are placed on monopile foundations at water depths between 6.5 and 14.5 m. The total height of the turbine is 110 m, with a hub height of 70 m and a rotor diameter of 80 m. The minimum free height from sea level to lower wing tip is 27 m.

***Figure 1**. The offshore wind farm at Horns Rev and the cable trace to land at Hvidbjerg Strand. T marks the transformer platform.*

Nysted offshore wind farm
Nysted Offshore Wind Farm is located 10 km south of the town Nysted on Lolland, and 11-17 km west of the town Gedser on the south tip of Falster. Two barrier islands, western Rødsand and eastern Rødsand, separate the Rødsand Lagoon from Femer Belt and from the wind farm. The distance from the barrier islands to the nearest row of wind turbines is approx. 2 km.

The wind farm is located on a gently sloping seabed consisting of glacial deposits covered by thin layers of sand. The water depth in the wind farm area is between 6 m and 9.5 m. The wind farm covers an area of approx. 28 km^2 (including the 200 m exclusion zone around the wind farm). The wind farm consists of 72 turbines (figure 2) each of 2.3 MW. The total height of the turbine is 110 m, with a hub height of 69 m and a rotor diameter of 82 m. The turbines are placed in 8 north-south oriented rows separated by a distance of 850 m. Each row holds 9 turbines separated by a distance of 480 m.

The turbine foundations are gravity foundations of concrete with specially designed protection against ice. The expected erosion around the bottom plate of the foundations will be prevented by stone protection. The foundations take up an area of about 45,000 m^2, corresponding to 0.2% of the total area of the wind farm.

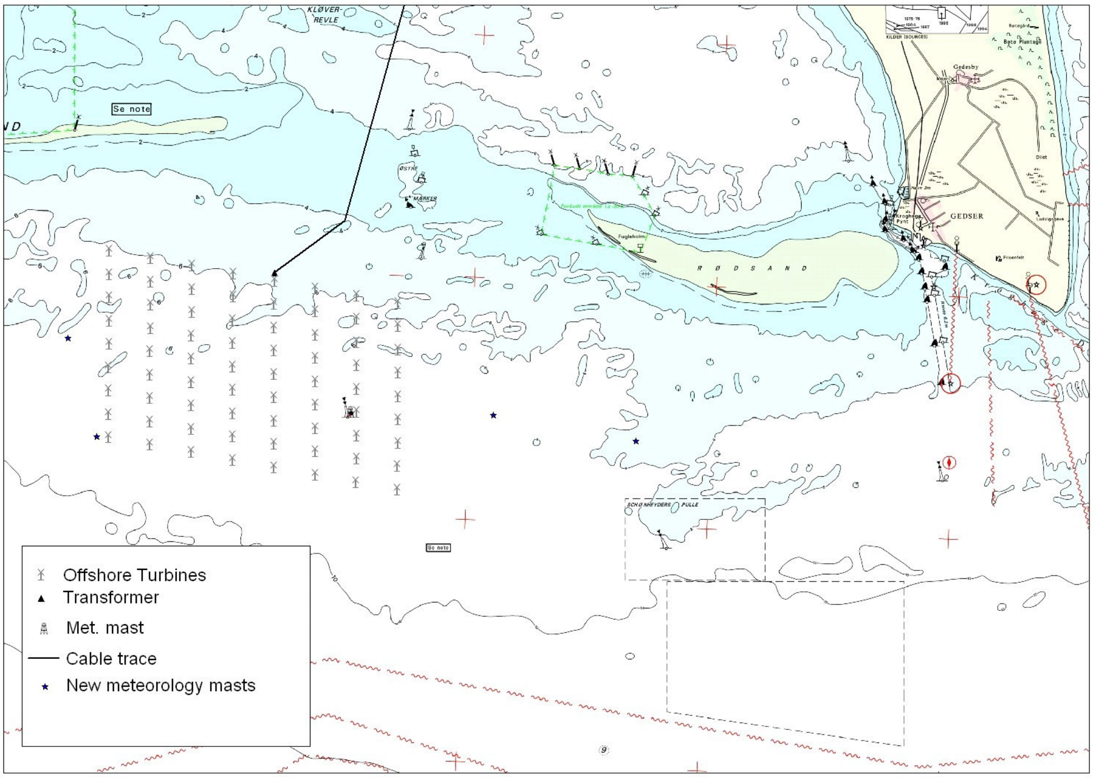

***Figure 2**. Map of the Nysted wind farm area, showing the position of the 72 wind turbines, the transformer platform, the meteorology masts and the 132 kV sea cable to land.*

Issues investigated in the monitoring programme – an overview

The projects in the demonstration programme apply to the BACI design. BACI denotes “Before After Control Impact”. BACI is a schematic method for tracing environmental effects from substantial man-made changes to the environment (Green 1979). The aim of the method is to estimate the state of the environment before and after any change and in particular to compare changes at reference sites (or control sites) with the actual area of impact.

As mentioned earlier, the monitoring programme is divided into three stages consisting of two years of baseline (Before) monitoring, monitoring during the construction and two years of monitoring during the operation phase (After).

The EIA and baseline programmes provide large data sets for baseline studies in both the designated wind farm areas and in reference areas. For obvious reasons, some programmes had to await the actual construction of the wind farm. This included the assessment of bird collision risk with turbine blades and artificial reef effects due to the introduction of hard bottom substrate.

The following programmes have been carried out at Horns Rev Offshore Wind Farm:

Project	Year of monitoring
Visualisation and socio-economic investigation	1999, 2000, 2003, 2004, 2005
Hydrography	1999
Benthic fauna and flora in the farm area	1999, 2000, 2001, 2003, 2004
Fish in the farm area	1999, 2002, 2004, 2005
Fish, sand eel	2002, 2004
Monitoring of harbour porpoises	1999, 2000, 2001, 2002, 2003, 2004, 2005
Monitoring of seals	1999, 2002, 2003, 2004, 2005
Monitoring of birds	1999, 2000, 2001, 2002, 2003, 2004, 2005
Development of new habitats	2003, 2004, 2005

Table 1. *List of the programmes carried out at Horns Rev Offshore Wind Farm, including the years of monitoring.*

The following programmes have been carried out at Nysted Offshore Wind Farm:

Project	Year of monitoring
Visualisation and socio-economic investigation	1999, 2000, 2003, 2004, 2005
Hydrography and coastal morphology	1999, 2000, 2001, 2002, 2003
Benthic Fauna and flora along 132 kV cable	1999, 2000, 2001, 2002, 2003, 2004
Benthic Fauna and flora in the farm area	1999, 2001, 2005
Fish in the farm area	1999, 2001, 2004, 2005
Electromagnetic fields and possible effect on fish	2001, 2002, 2003, 2004, 2005
Monitoring of harbour porpoises	2001, 2002, 2003, 2004, 2005
Monitoring of seals	1999, 2002, 2003, 2004, 2005
Monitoring of birds	1999, 2000, 2001, 2002, 2003, 2004, 2005
Development of new habitats	2003, 2004, 2005

Table 2. *List of the programmes carried out at Nysted wind farm programmes, including the years of monitoring.*

As mentioned earlier, the environmental studies are to be carried out at Nysted and Horns Rev in the period 2000-2005 under the permitting terms for wind farm construction at the two sites, granted by the Danish authorities.

Bottom flora & fauna

The excavation and sluicing activities during the construction phase will cause destruction and disturbance of the bottom fauna and flora. Excavation activities will cause both increased sediment spills in an area around the activity and increased turbidity of the water. Increased turbidity can cause clogging and destruction of the feeding organs of the benthic organisms, making them unable to feed. Increased sedimentation of suspended material can cause shading of the benthic vegetation. The surveys on bottom flora and fauna in both wind farms include photo sampling and collection of quantitative samples of benthic flora and fauna.

Horns Rev Offshore Wind Farm
For Horns Rev, the first post-construction investigations in 2003 showed that changes in the composition of the sediment and the flora and fauna of the seabed between the wind turbines were seen both within and outside the wind farm area. This indicated that these changes are more a result of natural changes than a result of the presence of the wind farm (Bio/consult 2004a). The latest surveys however indicate that there is a slight tendency toward an increase in the abundance of the most common species in the impact area relative to the reference areas. This increase was observed in spite of the registered increase in fish abundance in the wind farm area, on the other hand seabirds prefer to forage outside the wind farm reducing the predation pressure within the wind farm. The increase observed in the wind farm area could not be detected in the reference areas where the abundance of the most common species has remained unchanged in post-construction years (Bio/consult 2005a).

Nysted Offshore Wind farm
The marine biological survey on benthic flora and fauna carried out in the wind farm area of Nysted offshore wind farm will be finalised in 2005, and the results on the effects of the construction of the wind farm will be available in spring 2006. Surveys of benthic in-fauna, eelgrass and macroalgae along the 132 kV cable trench in the Lagoon of Rødsand have been carried out, and the surveys before and after the seabed construction work showed a significant reduction of the shoot density and biomass of eelgrass and a change in the structure of the benthic in-fauna as a combined response to sediment spill and temporary burial. The negative impacts on eelgrass of dredging activities in 2002-2003 were short term, as the re-colonisation of eelgrass and recovery of the eelgrass populations was completed in October 2004. Complete recovery of populations of macroalgae and invertebrates close to the cable trench is expected in the near future. (DHI 2005a).

Development of new habitats on foundations and scour protection

The foundations and the scour protection of stones around the foundations of the turbines in Horns Rev and Nysted offshore wind farms have a total surface area of about four hectares in each wind farm. These new hard physical structures have been introduced into both sites, where the natural seabed consists mainly of sand.

When new hard structures are introduced into the marine environment, they will act as substrate for sessile organisms that will colonise it and develop a fouling community. This community may be more or less diverse, depending on the characteristics of the substrate and a number of environmental factors including salinity and exposure to waves. The community will include sessile animal and plant species as well as small mobile invertebrates. Small fish species are likely to be associated with the community too. Furthermore, larger benthic or pelagic fish as well as sea birds may be attracted from the surrounding areas (DHI, 2003). On this background an investigation of the fouling community in both the Horns Rev and Nysted offshore wind farms was initiated in 2003, and continues throughout 2004 and 2005 to follow the epifaunal development on the hard structures after the erection of the wind farms.

Horns Rev Offshore Wind Farm
Due to the fact that the meteorological masts erected prior to the construction of the wind farm was not heavily vegetated - which was thought to be either a result of underwater “sandblasting” of the turbine tower by suspended sediment or a result of intensive grazing by the Barnacle *balanus improvisus* – it was not anticipated that the construction of the wind turbine foundations and erosion protection would provide shelter for a number of species of animals and plants, i.e. that a kind of artificial reef would be created.

This assumption, however, soon proved to be wrong: so far, investigations have confirmed that intensive fouling is taking place, and the biomass around the foundations had increased by a factor 8 in 2004 and a factor 60 in 2005 compared to the surrounding soft seabed (Bio/consult 2004b, Bio/consult 2005b).

Introduction of epifouling communities has increased the general biodiversity in the wind farm area, and progress succession in the benthic community and biodiversity has been observed between 2003 and 2004 (Bio/consult 2005b).

Special attention should be directed towards the reintroduction of two otherwise extinct species in the Horns Rev area; the bristle worm *Sabellaria*, presumably the ross worm *S. spinulosa*, and the white weed *Sertularia cupressina*, which are both regarded as threatened or red listed in the Wadden Sea area (Bio/consult 2005b).

Succession in community structure was demonstrated and some primary colonisers were less abundant in 2004 compared to 2003, which might be a result of predation and competition for space. It is anticipated that stability in fouling communities will not be attained within the next 5-6 years. Heavy storms and severe winters may even prolong this process (Bio/consult 2005b).

Nysted Offshore Wind farm
The salinity in the area of Nysted is low in comparison to the Horns Rev area, and the diversity of the fouling community was therefore also found to be lesser, consisting primarily of common mussels, barnacles and macroalgae and associated mobile species of crustaceans and fish. This community was developed during the first reproductive season. Common mussels and barnacles were the quantitatively dominant organisms, and the biomass on the vertical concrete shafts was about ten times higher than on the stones. The community of macroalgae on the scour protection was dominated by red algae (DHI, 2003).

Common mussels (*Mytilus edulis*) and barnacles (*Balanus improvisus*) dominated the fouling community in the wind farm in 2004. The biomass of the community has increased significantly since 2003 due to rapid growth of the mussels. However, the biomass on shafts and stones was still below the biomass at the monitoring mast deployed in 1997 and at Schönheiders Pulle which is the reference site. Schönheiders Pulle is a natural hard bottom community on a stone reef situated about 5km southeast of the wind farm. It is expected that the biomass on the shafts will approach the maximum level for mussel populations in the area during the next year.

The structure of the fouling community was uniform around the foundations but changed with depth on both shafts and stones. The number and biomass of the dominant species of mussels, barnacles and the amphipod *Gammarus sp*. was lower in deeper water and other species of crustaceans increased with depth. These changes in community structure were attributed to depth-related hydrographic changes. The community of macroalgae was dominated by red algae but the number of species was low. Macroalgae has disappeared from the shafts since 2003 and has been excluded by the rapid growth of the mussels with the exception of the transformer station, where algae were attached to patches with no or few mussels on the shafts. The community of macroalgae at Schönheiders Pulle was similar, irrespective of the depth and similar to the community on stones in the wind farm when assessment was based on biomass. (DHI, 2005b).

Fish

Since sand eel is an important species to the commercial fishermen at Horns Rev, possible effects from the development of the wind farm was a concern and has thus been investigated before and after construction of the wind farm in 2002 and 2004 respectively.

Specifically sand eels are prone to be affected by potential changes in the sediment composition; if the fine-grained sediment classes (silt/clay/very fine sand) increase above 6% this species will completely abandon the area.

There are no indications that the construction of the wind farm has had any effect on the sediment composition in the wind farm area. More specifically, there was no indication that the content of the finest particles, the Wentworth sediment classes silt/clay and very fine sand, had increased in the impact area from 2002 to 2004. In this respect the construction of the wind farm is not likely to have had any effect on sand eels in the the wind farm area (DIFRES 2004).

At all locations fished during both years a marked increase in density of sand eels (all species combined) was observed in the impact area from 2002 to 2004. This increase coincides with a small decrease in densities in the control area (away from the wind farm/impact area). Average densities of sand eels in the impact area increased about 300% from 2002 to 2004, whereas densities decreased about 20% in the control area. It is therefore concluded that the construction of the wind farm has had no negative impact on sand eels in the wind farm area (DIFRES 2004).

As mentioned above the colonisation on the turbine towers and scour protection has led to an increase in the amount of food available to fish, and the fish population is thus expected to increase (Bio/consult 2004b). Video material has already shown that there is an increase in the number of fish species observed around the foundations. An acoustic line transect survey in 2004/2005 will provide additional quantitative data to back the assumption that the introduction of the hard substrate habitat seems to attract fish.

In 2004 a hydroacoustic fish-monitoring programme was launched both at Horns Rev and Nysted to investigate if the foundations/scour protection did in fact have the expected attracting effect on the fish community and if the wind farm area in general serves as a refuge for fish. Four transects were surveyed within the Horns Rev wind farm as close to the turbine foundations as possible. A significantly higher density of fish near turbine foundations (hard bottom substrates) was only found in one out of the four transects surveyed. The results also indicated that the offshore wind farm attracts fish beyond a distance of 500 m (Bio/consult 2004c). Another survey in 2005 will provide additional information about the possible attraction of fish to the wind farm. A hydroacoustic survey using a stationary set-up was tested in 2004 in Nysted Offshore Wind Farm and the survey is continued as a transect survey in 2005. Final reports on fish will be available in the autumn of 2005.

Marine mammals – harbour porpoises

Construction and operation of an offshore wind farm can potentially affect marine mammals in the area due to the noise and disturbances caused by the construction work, the maintenance work during the operation phase and the physical presence of the turbines.

The aim of the porpoise project is to identify the effect of the construction and operation of the wind farm on the porpoises in the area. Specially designed underwater microphones, also called hydrophones or PODs (Porpoise Detectors) are used to record the sounds used by the porpoises for communication, foraging and orientation. The intensity and patterns of these sounds are used as an indicator of the porpoises' presence in the wind farm. Both at Horns Rev and Nysted, PODs are placed in the farm area and in a reference area.

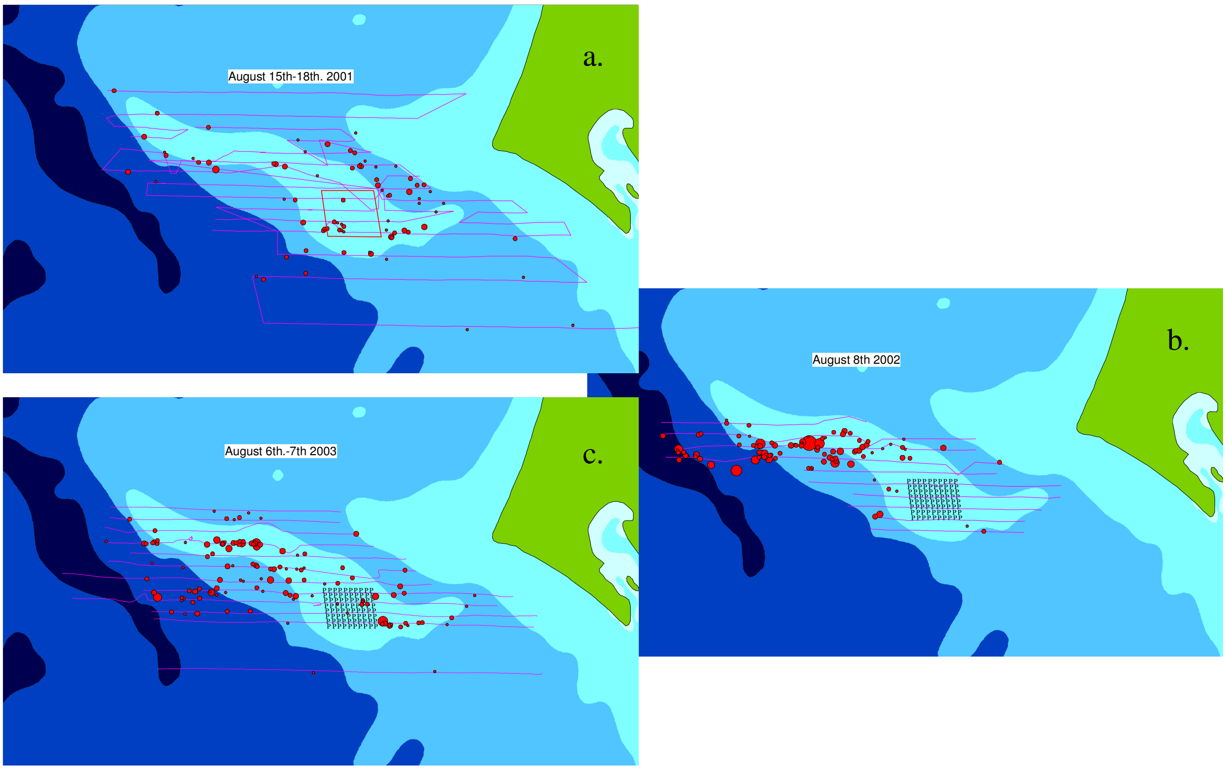

Figure 3. *Relative densities of harbour porpoises recorded in surveys before (a), during (b) and after (c) construction.*

Horns Rev Offshore Wind farm
As the construction work include noisy activities such as monopile and sheet piling both porpoise and seal deterrents were used to protect porpoises and seals from hearing damage. The deterrent scares the animals away from the site before the noisy activity of pile driving begins.

For porpoises at Horns Rev, the mitigation measures appear to have been fruitful. Data from underwater hydrophones (PODs – Porpoise Detectors) registering the clicks emitted from the porpoises have shown that the porpoise activity, after dropping during the ramming process when the scaring devices were active, increases within a few hours after the process ceases. This result conflicts with the visual ship-based observations made during the construction phase, which recorded fewer animals compared to periods before and after the construction (NERI, 2004a). See figure 3. These conflicting results do not have an obvious explanation, but could be ascribed to the fact that the surveys could only be performed during daylight hours and in relatively good weather conditions whereas PODs monitor continuously. Good conditions also favour construction activities, thus this could give bias to the visual survey data.

The analyses performed on the 2004 data have added only little to conclusions from previous years. The 2004 analyses have, however, improved the understanding of the complexity and dynamics of the Horns Reef area and the factors which may govern the fine-scale distribution of harbour porpoises in the area. As the situation stands at this point the conclusions that can be drawn on general effects of the operating wind farm are very weak. The analyses of POD data and survey data from the construction period as a whole and the following operational period point to a weak or absent negative effect, but it should be stressed that this conclusion is very weak and could well change after final analysis of the entire dataset in 2006 (NERI, 2005a).

Nysted Offshore Wind farm
Compared to Horns Rev, which is an international hot spot for porpoises, the Nysted area is only of marginal importance to porpoises. Porpoises are found in the area around Rødsand all year round but the population is relatively small and the area is considered to function mainly as a transitional area between areas with larger food supplies. The population in the Rødsand area is estimated to be between 100 and 500 individuals (NERI & Ornis Consult, 2002; NERI 2003a; NERI 2004e).

The results from the survey at Nysted showed that the increased ship traffic and construction activities reduced the porpoise activity in the wind farm area during the construction phase. In connection with construction of a single turbine's foundation, sheet piling was carried out over a period of three months. This is an extremely noisy activity under the water, and to protect the porpoises and seals from hearing damage, the previously mentioned deterrents devices were used. The effect of pile driving on porpoise activity in the area was analysed and revealed less porpoise activity in the periods during sheet pile driving both in the wind farm area and the reference area.

One would expect that the porpoise activity in the area during the operation phase will return to the levels measured prior to the construction phase of the project, when the activities and the presence of people and ships decrease in the area. However, 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. (DMU 2005d).

The reason why different reactions to the construction work are found at Horns Rev and Nysted respectively can be explained by the difference in the size of the two porpoise populations and the area use, e.g. the Horns Rev area is more attractive with regard to foraging, than the Nysted area.

After the studies in 2005 are analysed, more conclusions can be drawn about the porpoise activity during operation of both wind farms.

Marine mammals – seals

The harbour seal (*Phoca vitulina*) and also the grey seal (*Halichoerus grypus*) breed in Danish waters. The most significant impacts on seals are expected to come from the physical presence of the wind turbines, the noise from ships and construction works, as well as the temporary or permanent loss of habitats near offshore wind farms.

Seals use sound to communicate and perhaps for hunting both on the surface and underwater. The seals' ability to communicate can be affected by the noise generated by the construction work and the operation of the wind turbines and may cause them to leave the wind farm area.

The seal study included satellite tagging of seals both in the Horns Rev and Nysted areas. The objective of the study is to provide information on site fidelity, migration and kernel (a probability of density) home range (or area use) of harbour and grey seals prior to the construction of the offshore wind farm.

Horns Rev Offshore Wind farm
Studies in 2002 prior to construction showed that seals pass the Horns Rev area on their way to and from foraging areas in the North Sea, while they do not seem to stay in the area itself for longer periods of time. A few seals have been captured and equipped with a "headset" containing an ARGOS transmitter. The transmitter is glued onto the head of the seal, and the system registers the position of the seals whenever the seal surfaces to breathe. The transmitter falls off after a few months, as the seal's fur grows (NERI, 2002a).

At Nysted, 10 seals were tagged with the ARGOS transmitter in 2002. The results show that the wind farm area is of greater importance to the harbour seal than to the grey seal, as harbour seals reside more in the area around Rødsand, while grey seals utilise a much larger area during certain periods of the year (NERI, 2002b).

Unfortunately the ARGOS transmitter has some shortcomings related to its precision, which in the worst case can drop below a few kilometres (NERI, 2002a). This means that it cannot be clarified whether the seals swim through or pass by the wind farm area. Therefore a new high-resolution transmitter type using GPS/GSM technology was tested in 2003 (Fisheries and Maritime Museum and NERI, 2004). Regrettably, the transmitter suffered from technical difficulties and the programme was temporarily suspended until the autumn of 2004 when the seal monitoring at Horns Rev was revived in a co-operation between the University of Kiel, Germany and the Fisheries and Maritime Museum, Denmark. In winter 2004/05, 19 seals were tagged with the sophisticated German data loggers and/or the traditional SPOT transmitters. The transmitters will fall of when the seals are moulting in late summer 2005 and the data processing can begin. The advanced German data loggers will provide detailed information about the seals' movements and diving patterns, which also gives information about the behaviour of the seals. The final seal survey data will demonstrate whether the seals' movements have changed after the erection of the turbines.

Nysted Offshore Wind farm
At Nysted offshore wind farm the seal study also included aerial surveys of seals and remote video registration. The purpose of these two studies is to investigate if the construction and operation of the wind farm has an effect on the number and behaviour of harbour seals and grey seals in the Rødsand seal sanctuary, which is located about 4 km from the wind farm.

Rødsand is historically one of the most important seal sanctuaries in Denmark with a population of a couple of hundred seals. The majority of these are harbour seals. The seals use the sanctuary in their breeding and moulting periods, in addition to during staging. The harbour seal breeds in June-July and moults in August, which is why the seals spend most of their time on land during these periods. Grey seals breed in February-March but seldom at Rødsand. However, one to two juveniles have been seen in the sanctuary both in 2003 and 2004. The grey seal moults in June/July. The sanctuary is closed to visitors between April and November.

The seals in the Rødsand seal sanctuary are recorded by two video cameras. The cameras were installed in March 2002 and have been sending the recordings to NERI. The cameras are about 200-300 m from the seals. Monthly aerial surveys are conducted of the seals at Rødsand and the closest haul-out areas. The investigations conducted before construction of the wind farm show that a population of about 200 harbour seals utilised Rødsand in August 2002 and that Rødsand is the most important sanctuary for seals in the summer in the southwest portion of the Baltic Sea (NERI, 2003b; NERI, 2003c)

The population of seals in the area increased by about 15% from 2002 to 2003, resulting in a population of 230 seals. The study during the construction period concluded that neither the number of sanctuary seals on land nor their behaviour, was affected by the construction work. It was, however, discovered that wind and weather have an influence on whether or not the seals are on land (NERI, 2004f; NERI 2004g). In 2004, during the first year of operation, the number of seals at Rødsand increased by 42%. So far there are no indications that the construction activities and operation of the wind farm have affected the local Rødsand population differently from the other populations in the western Baltic Sea. Actually, the Rødsand population appears to thrive relative to the other areas and it has increased substantially in size in 2004, at least during the month of August (NERI, 2005e; NERI, 2005f).

Birds

Denmark is centrally placed on the East Atlantic flyway and is annually passed by large numbers of migrating birds. Danish waters also hold very high concentrations of staging, moulting and wintering waterfowl. In total, at least 5-7 million birds of more than 30 species of waterfowl winter in Danish waters and even more individuals stage for shorter or longer periods during migration. As a consequence, Denmark has obligations under the Ramsar and Bonn Conventions, and the EU Bird Directive, to protect and maintain these populations. For this reason, it is pointed out in the principal approval of the planned wind farms that the environmental impact assessment and monitoring programmes should give special attention to bird life. With regard to birds, the potential impacts have been divided into two subjects of expected impact, namely disturbance effects and collision risk.

Horns Rev Offshore Wind farm
At Horns Rev detailed studies have been carried out on the birds on the reef with a view to clarify the response of the individual species to the wind farm. Bird counts are carried out by plane in order to provide information about the presence, numbers and geographical distribution of the birds at different times of the year. Both before and after the construction and commissioning of the wind turbines, aerial surveys were made of resting, foraging and migrating birds.

The preliminary findings from the post-construction studies have shown that most gull species seem to be attracted to the wind farm, whereas duck species have shown an increasing tendency towards avoiding the wind farm area. On a species level this means that divers, gannet, common scoter and guillemot/razorbill showed an increased avoidance of the wind farm area after the erection of the wind turbines. In contrast herring gull, little gull and arctic/common tern showed an increased preference for the wind farm area. The change in gull and tern preference for the wind farm area is likely to have been caused by the presence of the wind turbines and the associated boat activity in the area. The reason for the change in avoidance of the wind farm area for divers, gannet, common scoter and guillemot/razorbill is unknown. Disturbance effect from the wind turbines is one possible reason. Disturbance from increased human activity associated with maintenance of the wind turbines could be another. However, changes in the distribution of food resources in the study area could potentially play a role too (NERI, 2005b; NERI, 2005c).

Whether the latter is the case has been subject to investigations in 2005 where the stomach content of a number of common scoters have been analysed and compared with food resources found in sea bed samples. These studies are performed on the reef west of the wind farm where many common scooters have been spotted in the post-construction phase. The results of the data analysis of the studies await the final report in 2006.

Attempts have been made to assess the risk of collision between birds and rotor blades both visually and by means of radar observations in both daylight/good weather conditions and at night/poor weather conditions. As the observations could not, for obvious reasons, commence until the wind turbines had been commissioned, relatively few data are currently available on the subject. However, so far, no actual collisions between birds and rotor blades have been observed, and generally, very few birds were recorded inside the wind farm. Gulls and terns were the most frequently occurring species recorded in between turbines, but mainly observed at the edge of the wind farm and far less in the central parts of the wind farm. Thousands of common scoters have been observed in the area close to the wind farm, and flocks of this species have occasionally been seen flying inside the wind farm. The low number of seabirds and waterfowl recorded inside the wind farm and the general tendency of deflection around the wind farm by migrating birds recorded by radar indicate that most bird species generally exhibit an avoidance reaction to the wind turbines, which reduces the probability of collision. The birds generally respond to the presence of the wind farm at distances between 300 and up to 6000 m before the wind farm and change direction to navigate around the wind farm (NERI, 2005b; NERI, 2005c). Most of the birds that actually entered the wind farm seemed to adjust flight orientation to pass directly through the wind farm in parallel with turbine rows and not to cross several rows.

Nysted Offshore Wind farm

At the Nysted offshore wind farm aerial surveys are conducted of staging, moulting and wintering birds in the area and the routes of the migratory birds (figure 4) are charted from the observation tower at Rødsand, both by means of radar and telescope. Radar is used both day and night and the telescope is used exclusively during the day for species identification. An infrared camera is also used to monitor the birds' behaviour close to the wind turbines. The purpose of this project is to develop a system for quantifying the birds that might collide with the wind turbines. The system is called "Thermal Animal Detection System" (TADS) and consists of an infrared camera mounted on a wind turbine, which registers birds flying close to the wind turbine and its blades. Any collisions which may occur would be recorded (NERI, 2003d).

These four projects investigate whether or not migratory and non-migratory birds in the area are affected by the wind turbines. The main impacts addressed are: changes in migratory routes near the wind farm, changes in utilisation of the habitat in the wind farm area and risk of collision with the wind turbines. In 2005 a project has been be initiated for the purpose of collecting data on birds' flight altitudes near the wind farm. This data will be used in calculating the risk of bird collisions. Information about the birds' altitude can help to ascertain whether or not they fly at the wind turbines' height. The measurements are undertaken with horizontal radar from a ship. Visual observations are also made of the birds' flight behaviour close to the wind farm.

Concerning migrating birds, the study showed that waterfowl (mainly eiders), which approached the wind farm would adjust their orientation at some distance of the wind farm, regardless whether they would fly in between the turbines or pass north or south of the wind farm. Minor adjustments of the orientation already started at 3,000 m. However, the most marked change in the orientation occurred at a distance of approximately 1,000 m.

It also appeared that the majority of the waterfowl deviated laterally from their original orientation as they approached the wind farm, and to the extent that they would finally avoid the wind farm area. During the base-line study before the construction between 24% and 48% of the flocks passed the eastern edge of the wind farm. During the autumn operation period, the percentage was reduced to 9% in both 2003 and 2004. It could also be shown that the lateral avoidance response was associated with less migration activity in the wind farm area. It would be expected that the observed lateral displacement from the regular migration pattern is associated with a lower risk of collision for the birds. Hence, the results from the present study suggested that the nature of the avoidance response amongst waterfowl is very important to incorporate in models, which are developed to predict collision risk. The consistency of the results describing the eider-dominated migration at Rødsand suggested that eiders can be expected to avoid crossing offshore wind farms. Avoidance occurred both during day- and night time. However, the extent to which eiders may show this avoidance response, their relative use of different migration routes around the wind farm is likely to be site-specific (NERI, 2005g).

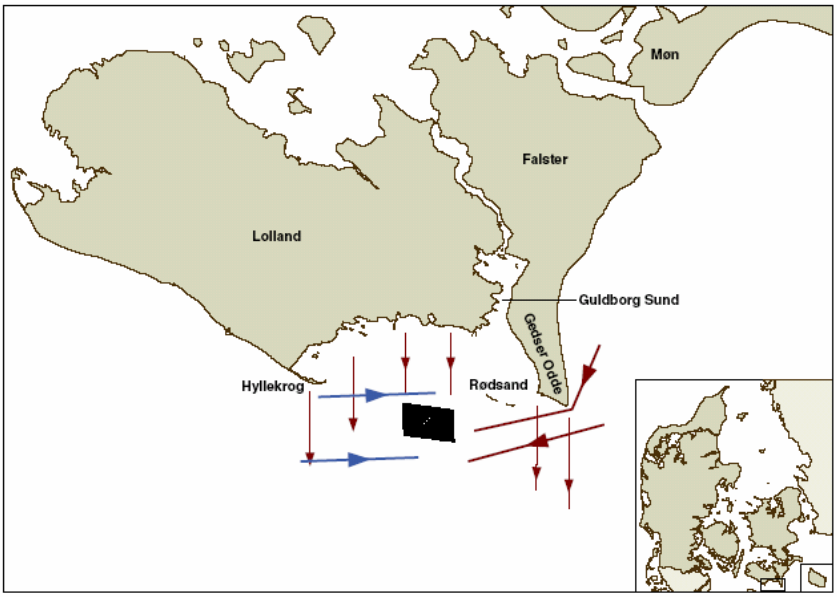

Figure 4. *The wind farm and the study area south of Lolland and Falster. The thin arrows show the direction of the land birds migration route, and the thick arrows show the direction of the waterfowl migration route. The blue arrows show the spring migration route, and the red arrows show the autumn migration route.*

The results of the investigations of staging and wintering birds may suggest that long-tailed duck was displaced from the wind farm area during construction and the first operation period, although this interpretation should be considered with caution, given a limited data set. Furthermore, cormorants seemed to be attracted by the meteorological masts and the turbine foundations, which they used as roost sites. Finally, there were some indications that gulls occurred in higher abundance during operation in 2004 compared to the base-line study. However, there was no evidence to suggest that they were specifically attracted to the wind farm area (NERI, 2005g).

As previously mentioned, an IR camera was also used in order to estimate collisions between birds and wind turbines. In the autumn of 2003, the IR camera was installed on a wind turbine. Unfortunately the proper functioning of the camera was delayed and the migration had already passed by the time the equipment was in working order. The equipment was, however, tested in various weather and wind conditions and it was concluded that it could withstand the harsh conditions of an offshore wind farm. In spring and autumn 2004 the migration was observed and recorded (NERI, 2005h), and the survey will continue in the autumn of 2005.

Surveillance of birds passing the wind turbines was conducted through a camera pointing up the wind turbine blades or at a 45-degree angle towards the sky. In this position, bird migratory movements close to the wind turbine can be recorded. In the vertical camera position no birds were recorded passing the sweep area of the rotating turbine blades nor colliding with any part of the turbine during approx. 11,000 hours of monitoring. But in three cases seagulls were recorded close to the wind turbine.

In general, based on studies to date, it can be concluded from both the camera surveillance and radar observations that migrating flocks of waterfowls, to a large degree, avoid flying into the wind farm area. The birds that did fly in between the wind turbines were able to avoid the individual wind turbines. Based on a probability calculation, it is estimated that about one flock of eider will pass a single wind turbine's sweep area per season (spring and autumn) (NERI, 2005g; NERI, 2005h).

It should be stressed that the survey continues in 2005, and when the results inform the survey in 2005 are analysed more firm conclusions can be drawn about the birds' behaviour near both wind farms.

Concluding remarks

The installation of wind turbines was finished in the autumn of 2002 (Horns Rev) and the summer of 2003 (Nysted). Hence, the annual status reports for 2004 represent data from just over a year after the initial commissioning of the wind farms. Thus, natural variation between years, seasons, species and sites and the possible habituation effects during the operational phase cannot be fully considered. The results are to be considered as preliminary and must await the final compilation of data in the spring of 2006 before firm conclusions can be drawn with respect to impact on the biological environment.

No other marine areas have been subjected to such an extensive and multi-disciplined monitoring programme, which makes the studies in the two Danish offshore wind farms unique and provides a solid base for an inter-comparison between individual groups of species and areas.

Several of the environmental monitoring programmes have been optimised through constant evaluation and monitoring of the outcome since the original programme designs were implemented alongside the EIA surveys. The experiences from this iterative process have led to either modified and even more valuable programme designs or to the abandonment of less rewarding programmes.

It is expected that the experiences gained though the extensive surveys at Horns Rev and Nysted can provide a valuable basis for future environmental monitoring at other offshore wind farm sites and form a solid basis in the governmental decision making process.

With the termination of the monitoring programmes in 2006, all possible conclusions and lessons from the studies will be disseminated. In order to avoid duplication of existing knowledge and research in relation to future offshore programmes, the final dissemination process is extremely important. Emphasis should be given to answering the questions that can be answered and thereby securing that future monitoring brings understanding beyond the present day knowledge.

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