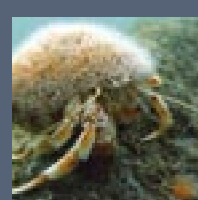
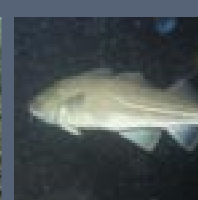
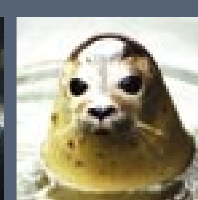
Offshore Wind Farms and the Environment

Danish Experiences from Horns Rev and Nysted

DANISH ENERGY AUTHORITY

PREFACE

The Power Source for the Future

Our future energy supply faces numerous challenges and has become subject to unstable international conditions. To meet these challenges offshore wind has a key role to play. Offshore windpower can contribute significantly to achieving the EU goals of a 21 per cent share of renewable electricity by 2010, halting global warming and reducing our dependence on coal, oil and gas.

We have come a long way since the 1980s, when most electricity production was based on coal and when the acidification of forests and lakes by acid rain was the predominant theme in the environmental debate. Today wind power provides 20% of Danish electricity consumption. Within a few years, the wind power industry has grown to become a significant industrial sector providing huge benefits for exports and employment. We are now talking about windpower generation plants rather than single turbines, and the Danish wind power industry is at the leading edge in an ever more competitive global market.

In the energy strategy for 2025 the Government expects to see a significant increase in the use of renewable energy in the years to come. The market-based expansion of this sector will be brought about through incentive schemes and investment in physical infrastructure as well as research-, development- and demonstration. With higher oil prices and high CO_2 allowance prices we expect that a significant proportion of the renewable energy expansion will be delivered by large, offshore wind farms. At sea, wind resources are better and suitable sites are more readily available to enable these large projects to operate in harmony with the surrounding environment.

We are therefore very pleased that the Danish environmental monitoring programme on large scale offshore wind power has received a positive evaluation by the International Advisory Panel of Experts on Marine Ecology.

To sustain public acceptance and provide continued protection to vulnerable coastal and marine habitats, it is important to build upon the positive experience gained so far with the use of marine spatial planning instruments.

Offshore Wind farms impact on their natural surroundings and it is essential to ensure that conditions in unique marine areas are not detrimentally affected. Spatial planning when identifying potential locations for offshore wind farms – taking into account grid connection routes and other areas of interests – must ensure that future offshore wind farms are established in suitable areas in such a way that substantial adverse environmental impacts can be avoided or diminished. One of the challenges we face is to assess the cumulative effects from multiple offshore wind farms to arrive at optimal site selection.

Thus a committee on future offshore wind farms is currently updating the Danish action plan from 1997 to use the experience and learning gained to date in order to identify appropriate locations and at the same time to minimise visual disturbances and the effects on animal species such as marine birds and mammals.

This publication describes the Danish experiences with offshore wind power and discusses the challenges of environmental issues that Denmark has had to address in relation to the two large-scale demonstration offshore wind farms Horns Rev and Nysted since 1999.

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Figure 1: The Horns Rev Offshore Wind Farm is located in the North Sea west of Jutland. The Nysted Offshore Wind Farm is located in the Baltic Sea south of Lolland.

PROTECTING NATURE WHILE UTILISING ITS POWER

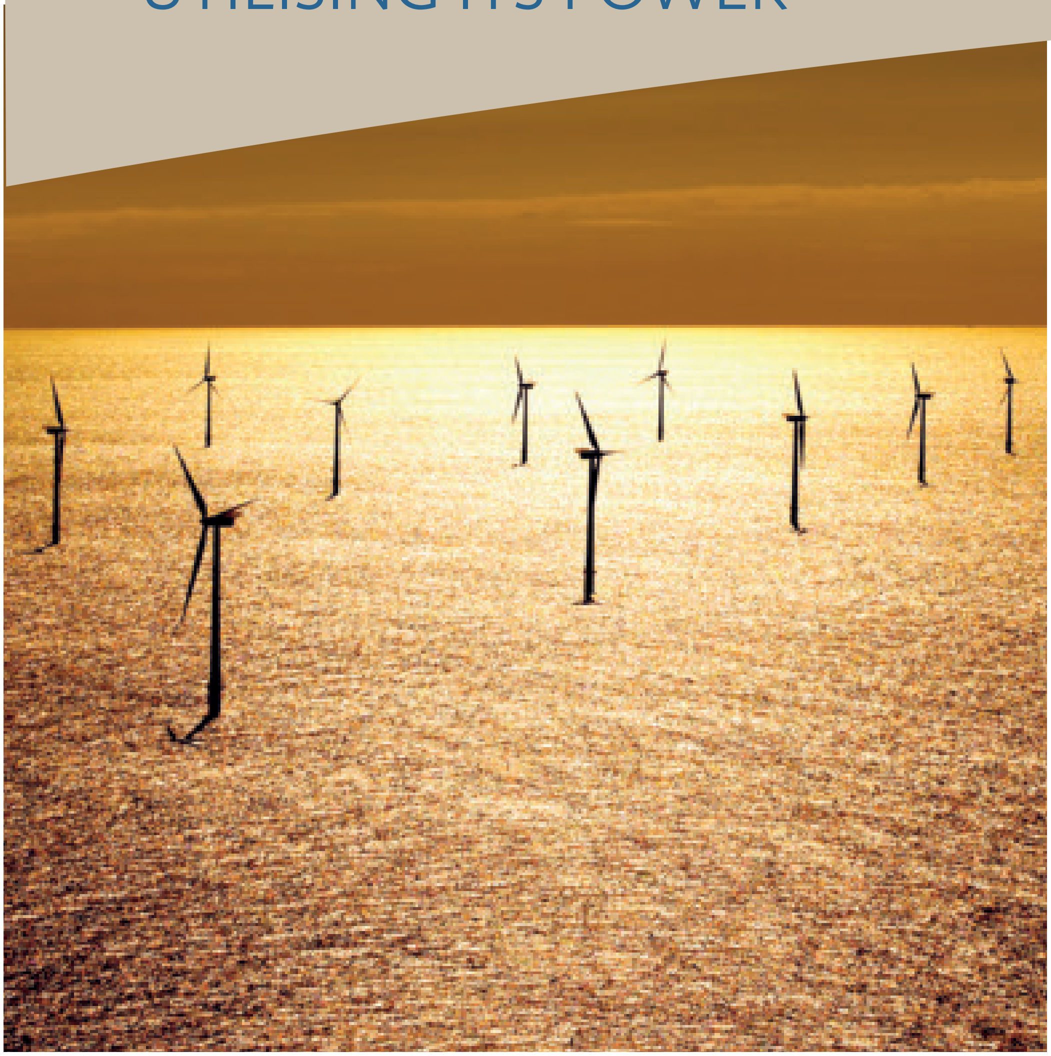


Photo: Vattenfall

Horns Rev Offshore Wind Farm.

Photo: Christian B. Hvidt

Catch of benthic fauna species from Horns Rev.

Photo: Daniel Bergmann

Common eider is one of the numerically important bird species at Nysted.

Experience from the environmental monitoring programme of the Horns Rev and Nysted wind farms

Wind power is one of the most important and promising forms of renewable energy being developed. It produces no emissions and is an excellent alternative in environmental terms to conventional electricity production based on fuels such as oil, coal or natural gas.

Danish experience from the past 15 years has shown that offshore wind farms are an attractive option. There are significant benefits to be had from offshore wind farms in the form of mitigating climate change, securing energy supply, decoupling economic growth from resource use and creating jobs. On the other hand they also have an impact on the surroundings in terms of visual intrusion, noise and impacts on nature.

During the period 1999–2006 a comprehensive environmental monitoring programme was carried out in order to evaluate the environmental impact of two of the biggest offshore wind farms in the world: the Horns Rev Offshore Wind Farm and the Nysted Offshore Wind Farm. This booklet discusses the results of this programme.

After an introduction to the Danish experience with offshore wind power, the wind power policy in Denmark and the EU, the authorisation process and the technical details of the wind farms, the booklet will address the main issues and the results of the environmental monitoring programme (Figure 2).

This booklet is based on the book "Danish Offshore Wind – Key Environmental Issues"

	HORNS REV OFFSHORE WIND FARM	NYSTED OFFSHORE WIND FARM
Fauna and vegetation	• The artificial reef effects from the wind turbine foundations and scour protections are changing the benthic communities to hard bottom communities with increased abundance of species and biomass.	• Monocultures of common mussels have developed at the turbine structures, due to low salinity and a lack of predators.
Fish	• Introduction of new artificial habitats with positive effects on fish communities after full development of artificial reef communities. • No linkage between the strength of the electromagnetic field and the migration of selected fish species.	
Marine mammals	• Seals were only affected by pile driving operations. No general change in the behaviour of seals at sea or on land could be linked to the construction or operation of the wind farm.	
	• The harbour porpoise population decreased slightly during construction, but increased again during operation.	• The harbour porpoise population decreased significantly during construction and only slight recovery was observed after two years of operation.
Birds	• Birds generally show avoidance responses to the wind farm. Some species are displaced from former feeding areas. • The collision risk with turbines is low. • Effects on overall bird populations are negligible.	
Attitudes	• More than 80% of the respondents from the local areas were "positive" or "very positive" towards the wind farms. • The prevailing perception is that the impact on birds and marine life is neutral. • Almost two thirds of the respondents stated that they found the wind farm effect on the landscape either "neutral" or even "positive". • More than 40% stated that they preferred future wind farms to be moved out of sight. • There's a significant willingness to pay to have wind farms located at distances where the visual intrusion is fairly small, ie up to 18 km from the shore. At Horns Rev there is no extra willingness to pay to have wind farms moved out of sight from 18 to 50 km from the shore.	

Figure 2: Main results of the environmental monitoring programme of the Horns Rev and Nysted offshore wind farms.

in which the results of the environmental monitoring programme are described and discussed in more detail.

Spatial planning important

Offshore wind farms are an attractive option in many ways; however, this type of infrastructure at sea must always respect the vulnerable marine environment. Appropriate siting of wind farms is an essential precondition for limiting negative impacts on nature and the environment, and in this context spatial planning is an important tool.

The general conclusion from the environmental programme of Horns Rev and Nysted is that offshore wind power is indeed possible to engineer in an environmentally sustainable manner that does not lead to significant damage to nature. In this respect, the prospects for future expansion of offshore wind farms look bright, provided that the environmental effects of new wind farm projects, including the cumulative effects of more wind farms, are still carefully assessed and taken into account in Environmental Impact Assessments (EIAs).

Photo: Christian B. Hvidt

Catch of cod outside Nysted Offshore Wind Farm.

GOOD EXPERIENCE WITH DANISH OFFSHORE WIND POWER

Middelgrunden with 20 wind turbines of 2 MW each, just outside Copenhagen, is an example of joint ownership between DONG Energy and a local cooperative.

Eight Danish offshore wind farms established since 1991

Denmark is a small, densely populated country with a relatively long coastline. Far-reaching ambitions for expansion of wind power have therefore meant that it has become attractive to locate turbines offshore. This development has become possible because the higher installation and operating costs of offshore wind farms are, to a determining extent, offset by increased productivity.

Since 1991, eight wind farms have been established offshore (Figure 3). The first three offshore wind farms, at Vindeby (1991), Tunø Knob (1995) and Middelgrunden (2000), were pilot projects. These were followed by the large-scale demonstration wind farms Horns Rev (2002) and Nysted (2003). Furthermore, the Danish Energy Authority has approved three nearshore projects at Rønland (2003), Frederikshavn (2003) and Samsø (2003). The permits for all eight projects stipulated specific requirements for protection of the marine environment.

Large-scale demonstration programme

Several studies investigating the possibilities and regulatory conditions for offshore wind power installations have been undertaken. Besides selecting the sites for the small pilot projects, all interests of relevance to offshore wind power in Danish waters have been mapped most recently in 1995.

On the basis of the Danish Action Plan on Offshore Wind from 1997, the Government obliged the utilities to carry out a large-scale demonstration programme for offshore wind farms. The aim of the programme was

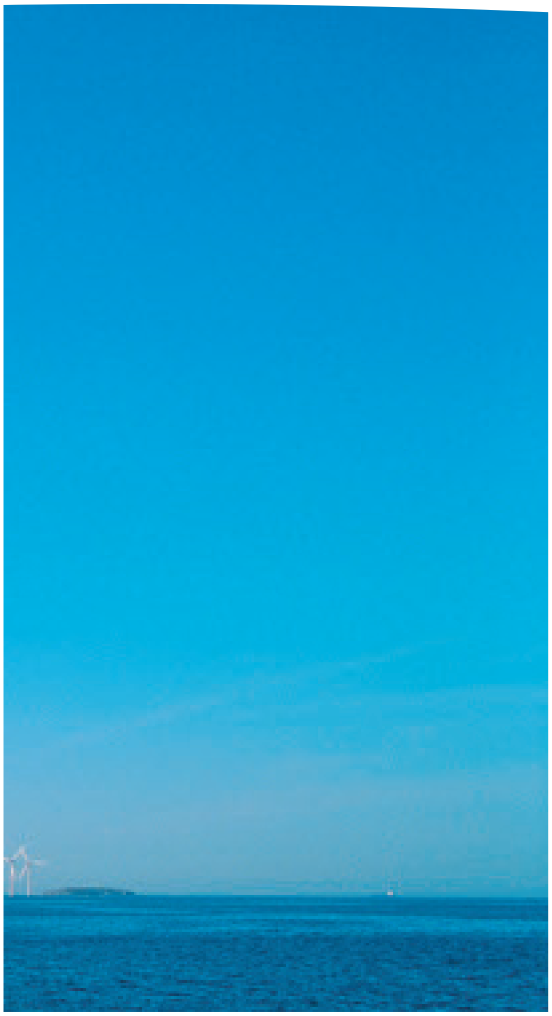


Photo: DONG Energy

Photo: Samsø Miljø- og Energikontor

Samsø offshore wind farm at Paludan Flak is a part of the island's ambitious project to supply all of its energy needs from sustainable sources.

Name Of Wind Farm	Year Of Commissioning	Turbine Capacity	Total Capacity	Estimated Annual Production
Vindeby, Falster	1991	11 450 kW units	5 MW	approx 10 GWh
Tunø Knob, Odder	1995	10 500 kW units	5 MW	approx 15 GWh
Middelgrunden, Copenhagen	2001	20 2 MW units	40 MW	approx 95 GWh
Horns Rev 1	2002	80 2 MW units	160 MW	approx 600 GWh
Samsø	2003	10 2.3 MW units	23 MW	approx 80 GWh
Rønland, Harboøre	2003	4 2 MW units 4 2.3 MW units	17 MW	approx 70 GWh
Frederikshavn	2003	2 2.3 MW units 1 3 MW units	8 MW	approx 20 GWh
Nysted Offshore Wind Farm	2003	72 2.3 MW units	165 MW	approx 600 GWh

Figure 3: Danish offshore wind farms in operation as of 2006

to establish the economic, technical and environmental issues required to accelerate offshore development and to open up selected areas for future wind farms. The programme involved government authorities as well as local authorities and this resulted in a framework for the subsequent formal approval procedure.

Horns Rev and Nysted – from plan to project

In 1999, the Danish Energy Authority gave the green light to undertake preliminary surveys of the sites at Horns Rev and Nysted.

In 2000, the Environmental Impact Assessment (EIAs) for both sites were submitted to the authorities, and in 2001 both wind farms were approved.

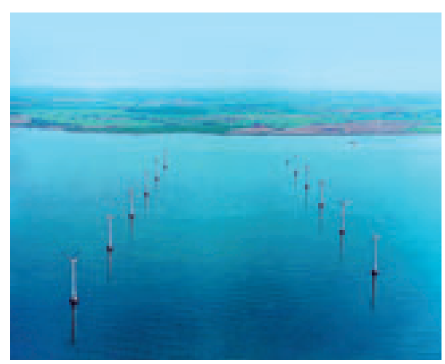


Photo: Jan Kofod Winther/SEAS

Vindeby, west of Lolland, was the world's first offshore wind farm. Its 11 wind turbines of 450 kW each provided Danish electricity utility companies with invaluable experience.

WIND POWER POLICY IN DENMARK AND THE EU

Continued expansion of offshore wind power

Denmark has a long tradition of implementing energy policies with broad political support and involving a broad range of stakeholders such as energy companies, industry, municipalities, research institutions, NGOs and consumers.

When the first energy crisis struck in the mid 1970s, exploitation of renewable energy as a replacement for fossil fuels to produce energy became very attractive. Ambitious wind power development programmes were therefore launched in several countries. Since then there has been a tremendous growth in technological development and turnover. Modern Danish wind turbines have been built higher and higher, and a new turbine can produce approximately 100 times as much electricity as a wind turbine from 1980.

Kick-starting Danish wind energy

Promotion of wind energy has been included in all Danish energy strategies with policy instruments, such as taxation, production subsidies, local ownership and agreements with utilities, as the most important tools. Technology-push instruments such as R&D programmes, test stations for wind turbines and certification schemes have also been used.

One of the most important incentives to promote wind turbines has been the obligation for the Danish Transmission System Operator (TSO) and the consumers to buy the total amount of renewable electricity produced in the country at a fixed price. The fixed feed-in tariff turned investment in wind farms into a very secure business for private investments.

In the spring of 1999, an electricity reform was introduced that unbundled the electricity sector, including the utilities, and laid down the principles for the future promotion of renewable energy. The current policy aims to strengthen the use of market-based instruments to increase competition in the energy sector and encourage cost efficiency in renewable energy development.

Strong international commitment

EU governments have agreed to aim at the target to reach a 21% share of renewable electricity by 2010. To achieve this objective there is an important role for wind power, and for several member states offshore wind power has a key part to play.

Although the prospects for offshore wind power are promising from a long-term perspective, the technology faces a number of challenges in terms of technological performance and competition for space with other marine users. Compatibility with the European power grid infrastructure and secure integration in the energy system as well as becomming fully competitive in the liberalised European electricity market are also important challenges.

All these issues have been dealt with in the Copenhagen Strategy 2005 on European Offshore Wind Power Deployment. In relation to the environment this strategy recommends as one of the key issues the establishment and use of marine spatial planning instruments to arrive at optimal site selection.

Photo: The European Commission

EU member states aim at 21% share of renewable electricity by 2010.

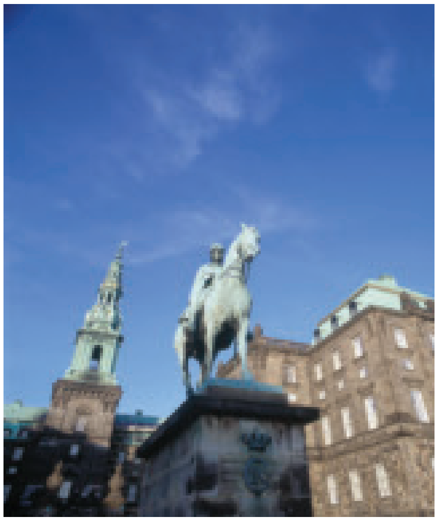


Photo: Folketinget

In 2004, a large majority in the Danish Parliament agreed on a new energy policy including expansion of offshore wind farms.

Also in other countries, there's a huge potential for increasing the size and number of offshore wind farms, especially in the North Sea and in the Baltic Sea where the UK, Sweden, Ireland, the Netherlands and Germany have installed or approved a capacity totalling in excess of 7,000 megawatt (MW). Among other European countries with specific offshore wind turbine projects are Spain, Belgium and France.

Policy agreements for future offshore wind farm initiatives

In 2004, the Danish Government closed energy policy agreements with a large parliamentary majority. One of the objectives was to promote the continued development of wind power technology and the future expansion of offshore wind farms. The agreement introduced a market oriented pricing system for wind power and secured the basis for installation of two new offshore wind farms at Horns Rev and Rødsand (see box).

If oil prices remain high and if ambitious international climate objectives result in higher CO_2 allowance prices, both wind energy and biomass will become so competitive that the amount of renewable energy produced will increase significantly. Under such conditions wind power may be able to cover more than 50% of the Danish electricity consumption in 2025 out of which most is envisaged to be placed offshore.

In 2005, the Danish Energy Authority began the work on a new plan for location of future offshore wind farms in the period from 2010 to 2025. The process builds on the Danish Action Plan on Offshore from 1997 as well as on experience from the Horns Rev and Nysted demonstration offshore wind farms and follows the principles of a Strategic Environmental Assessment.

HORNS REV 2 AND RØDSAND 2

The two new wind farms at Horns Rev and Rødsand, with a capacity of 200 MW each, will be capable of supplying 350,000-400,000 households with electricity, equivalent to 1,400-1,600 GWh or 4% of the total Danish electricity consumption.

In June 2005, DONG Energy was chosen as the winner of the tender for the wind farm at Horns Rev 2, and in April 2006 a consortium consisting of DONG Energy and E.ON Sweden won the tender for the Rødsand wind farm.

The next step for the winners will be to carry out preliminary studies and to prepare Environmental Impact Assessments (EIA) in order to clarify all impacts on nature and the environment. The EIAs will be subject to public consultation. The EIA for Horns Rev was published for consultation in October 2006. The two wind farms are expected to be commissioned 2009/2010.

Photo: DONG Energy

Coal and wind.

ENVIRONMENTAL ASSESSMENT AND PUBLIC CONSULTATION

The approval of offshore wind farm projects is based on Environmental Impact Assessments (EIA) and consultation of all interested parties

The right to exploit wind energy within the Danish waters belongs to the State and permission to conduct preliminary studies and to exploit wind energy at sea is granted by the Danish Energy Authority.

The procedure for establishing offshore wind farms has been gradually developed as experience has been gained with the first eight Danish offshore wind power projects. The Danish Energy Authority functions as a one stop shop in relationship to the many, often opposing, interests connected to the establishment of offshore wind power projects.

Permissions for preliminary studies and for exploitation of wind energy at sea may only be given either after applications have been requested in connection with a call for tenders, or in an open door procedure after an application has been made public and other interested parties have been given the opportunity to apply.

Environmental reporting and consulting

An assessment of the environmental consequences (an EIA report) followed by a consultation of the public, the authorities and any organisations concerned is given their size and numbers a requirement to all offshore wind farm projects.

Besides studying the wind, current and seabed conditions that must be known in order to plan an offshore wind power installation, an applicant must also show how the installation will affect the marine environment.

The description of the environmental consequences must cover fauna and flora, seabed conditions, water, air, climate conditions, archaeological remains, impact on the landscape and coastal safety. The EIA report must also demonstrate how any damaging environmental impacts can be reduced or compensated and indicate possible alternative locations for the installations.

Important involvement of the public

The establishment of offshore wind farms requires permission for preliminary surveys as well as a final approval of the project – a building permit. Both of these permissions depend on a process of public consultation. When, on the basis of preliminary studies, an application (including an EIA report) has been submitted, the Danish Energy Authority submits this material for public consultation with a deadline of at least eight weeks.

Experience gained during the first EIA procedures for offshore wind farms shows that the authorities concerned, interest groups and citizens all utilise the public consultation of EIA reports in order to make comments that contribute to the final decision regarding the projects.

Approval and appeal

Once the EIA procedure has been completed, the Danish Energy Authority makes a decision on the final approval. The approval is made public and any party with justified and individual interests in the decision has the right to register a complaint with the Energy Appeal Board regarding the decision.

Once authorised to carry out a project, the developer must provide the Danish Energy Authority with documentation proving how the conditions in the permit will be fulfilled. This must be done in the form of a detailed project description for the installation works. The developer may not begin to install the offshore wind farm until after the Danish Energy Authority has reviewed that the documentation submitted is sufficient.

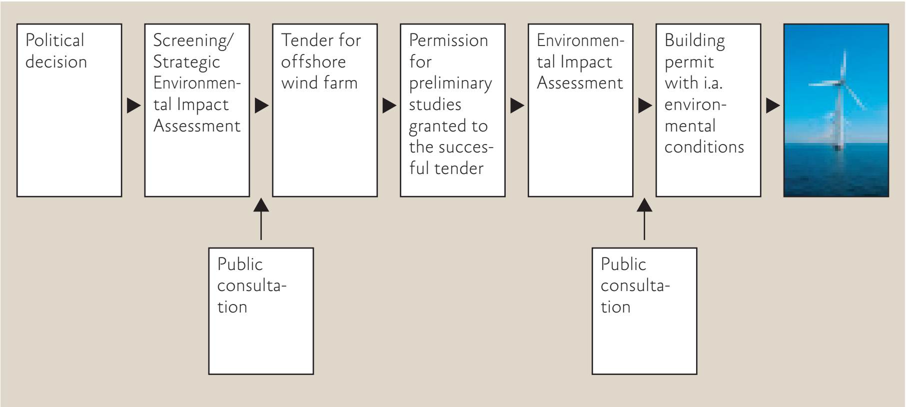


Figure 4: The authorisation procedure for establishing offshore wind farms in Denmark following a tender procedure.

Photo: Vattenfall

Figure 5: Horns Rev visualised and photographed. The EIA report for Horns Rev showed a number of visualisations of the wind farm appearance from various positions onshore. Here is the visualisation of the wind farm seen from Blåvands Huk (top) and a photo taken after the construction (bottom).

EIA REPORT

The rules regarding EIA reports are described in Executive Order no. 815 of 28 August 2000 on assessment of the environmental impact of offshore electricity producing installations.

Any party applying to establish an offshore wind farm must prepare an environmental report in order to ensure

- that the environmental conditions within the defined installation, impact and reference areas are studied and described,
- that all known environmental impacts in connection with the construction and operation of the wind turbine installations have been previously considered and assessed, and
- that the authorities and the general public have a basis for assessing and deciding on the project.

HORNS REV AND NYSTED OFFSHORE WIND FARMS

Two large-scale wind farms at sea with 152 turbines and 325 MW capacity

In 1999, the Danish Energy Authority gave the green light to preliminary surveys at Horns Rev and Nysted. In the summer of 2000, the Environmental Impact Assessment (EIA) for both sites was submitted to the authorities, and in 2001 the application to build both wind farms was approved.

Horns Rev Offshore Wind Farm

The Horns Rev Offshore Wind Farm was constructed by Elsam in the summer months of 2002. In July 2006, Vattenfall took over 60% of the wind farm and in the process assumed the responsibility for all operation and maintenance of the facility.

The wind farm comprises 80 wind turbines erected in a matrix pattern. Each turbine has a capacity of 2 megawatt (MW) which gives a total installed capacity of 160 MW. The production from the wind farm is estimated to be equivalent to the electricity consumption of just over 150,000 Danish households.

The Horns Rev Offshore Wind Farm is located south of the actual reef, Horns Rev in the southwestern part of Denmark (Figure 6). The distance to Blåvands Huk is approximately 14 km. The wind farm covers an area of approximately 24 km². The wind farm itself is located outside nature protected areas although the transmission cable from the wind farm runs through an EU special protection area (Natura 2000 area).

Nysted Offshore Wind Farm

The Nysted Offshore Wind Farm was constructed by a joint venture of DONG Energy and E.ON Sweden. DONG Energy operates the wind farm and SEAS Transmission is the owner of the grid connection, ie the substation at sea and the cabling from the substation to the shore.

Photo: Christian B. Hvidt

Horns Rev Offshore Wind Farm.

THE CONFIGURATION OF AN OFFSHORE WIND FARM

A wind turbine consists of a turbine tower, which carries the nacelle, and the turbine rotor, consisting of the rotor blades and the hub. Currently the size range of offshore wind turbines in Denmark is approximately 2–2.3 MW, with a top height of approximately 110 m. The development is undoubtedly towards bigger turbines (Figure 8).

Current offshore wind power technologies are based on foundation types most suitable for shallow water. These foundations are either concrete gravity caisson foundations (Nysted) or steel monopiles driven into the seabed (Horns Rev). In waters with greater depths, tripod and quadropod foundations, of the kind used for small offshore oil and gas installations, could presumably be used in future turbine foundation solutions.

The power generated by the wind farm is collected in submarine cables buried in the seabed. The cables between the turbines are connected to a substation, from where a export cable leads the power to shore. Here the power cable is connected to the public power transmission system.

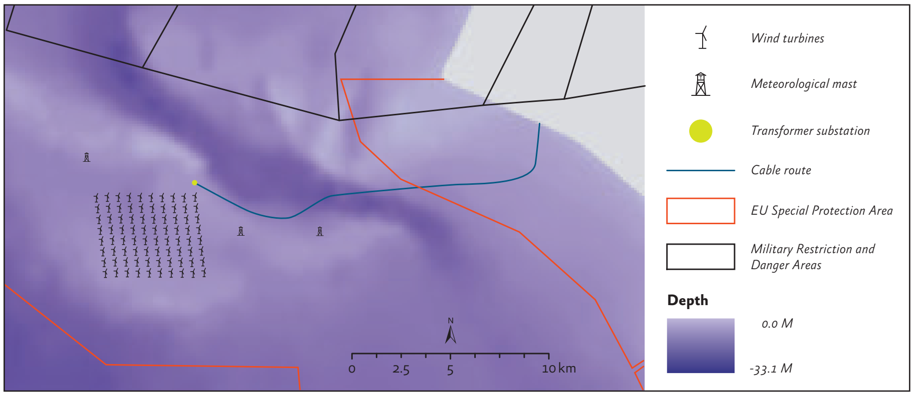


Figure 6: Map of the Horns Rev Offshore Wind Farm area

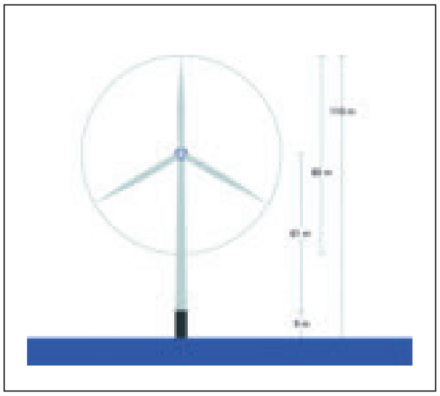


Figure 8: Wind turbine dimensions

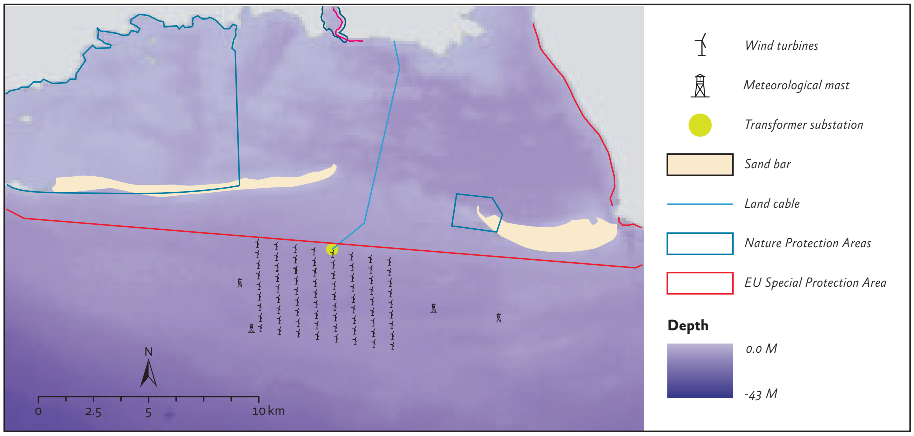


Figure 7: Map of the Nysted Offshore Wind Farm area

The wind farm consists of 72 turbines placed in eight north-south oriented rows. Each turbine has a capacity of 2.3 MW which gives a total installed capacity of 165.6 MW. The production from the wind farm is estimated to a supply equivalent of 145,000 households with renewable electricity.

The Nysted Offshore Wind Farm is located approximately 10 km south of the town of Nysted in the southeastern part of Denmark. Close to and north of the wind farm is the Rødsand formation consisting of two barrier spit systems bordering the shallow Rødsand lagoon (Figure 7). The wind farm covers an area of approximately 28 km². Close by lies Rødsand seal sanctuary and Hyllekrog game reserve. The entire area north of the wind farm has been designated a Ramsar Site and an EU Bird Protection Area (SPA) to protect the requirements of specified wild birds and regularly occurring migratory birds and as a EU Habitat Area (SAC) to maintain and restore the marine habitats and wild fauna and flora.

MEGAWATT CAPACITY

Electrical power is usually measured in watt (W), kilowatt (kW) megawatt (MW), etc where 1 MW is equal to 1,000 kW or 1 million W.

If a wind turbine has a capacity of 2 MW, it means that the turbine will produce 2 MW of energy per hour of operation, when running at its maximum performance.

At sea, in the best areas in terms of wind, such as in the North Sea at Horns Rev, the production corresponds to full production 40–50% of the year.

ENVIRONMENTAL ISSUES DURING CONSTRUCTION

Focus on protection of marine mammals like harbour porpoises and seals

The overall environmental conditions of the Horns Rev and Nysted wind farms were assessed and described in the respective Environmental Impact Assessment reports (EIA reports). This constituted the basis for the environmental requirements laid down in the Danish Energy Authority's final approval of the projects – the building permits.

Environmental management systems

Environmental management systems were established for both wind farms during construction to ensure that the regulatory environmental requirements and terms were efficiently anchored in the projects. These management systems included procedures and instructions for all persons on the site in relation to the handling of environmental issues, such as waste, noise measurement, procedures for scaring off marine mammals, contingency plan in case of environmental accidents such as oil spill, etc. The environmental requirements were also incorporated into the requirement specifications to suppliers (see textbox).

After the construction phase, amongst other issues, the total amount of sediment spill and removed amounts of sediment have been recorded, and it was concluded that the regulatory requirements were respected. Also the amount and types of waste generated during the construction period were registered and the locations of interesting marine archaeological objects found during the construction period were recorded.

Special attention was paid to conditions for driving of sheet piles and monopiles and

Photo: DONG Energy

Mounting of turbine tower at Horns Rev.

ENVIRONMENTAL REQUIREMENTS

The regulatory requirements for the construction phase at Horns Rev and Nysted respectively, differed considerably since the two areas differ to a great extent and feature different sensitivity issues. In general, the following points were addressed during the construction phase at both wind farms but in varying orders of priority:

- Sediment spill monitoring
- Incidents, accidents and oil spill
- Waste handling
- Precautions regarding pile driving/ vibration of sheet piles/monopiles
- Sediment depositing
- Marine archaeology
- Registration of navigation in the area

Photo: Nysted Offshore Wind Farm

The ship Ocean Ady in front of the first wind turbine at Nysted. Turbines no. 2, 3 and 4 lie ready on deck.

registration of navigation in the areas, as these two conditions influence for instance disturbance of marine mammals during the construction period.

Measures to protect marine mammals

Requests were made for both wind farms momentarily to scare off marine mammals in the close vicinity which otherwise might be harmed by the high noise levels. Pile driving was used for the establishment of the monopiles at Horns Rev, piling of sheet piles at one foundation and for meterology masts at Nysted Offshore Wind Farm. All of these activities caused momentary noise.

The requirement for measures warning marine mammals before piling was met by using soft start/ramp up procedures and by the application of so-called pingers and seal scarers. The application of these devices was registered and monitored.

Limitation and control of navigation

The Nysted Offshore Wind Farm is situated approximately 2 km from a nature reserve and 4 km from the Rødsand seal sanctuary. This has called for special consideration in connection with the construction work, including limitation and control of navigation in the area.

It was made clear to all involved parties at the construction site that all transport to and from the wind farm was to take place in a special transportation corridor only, and that access to the nature reserve was forbidden without prior approval.

To ensure compliance with the demands and for safety reasons, all navigation to and from the wind farm was registered and reported. Thus the navigation to and from the wind farm was controlled, and the impact of navigation on the sensitive areas, the nature reserve and the seal sanctuary, has been limited as much as possible.

Photo: Svend Tougaard

During the construction phase special attention was paid to protecting marine mammals like grey seals.

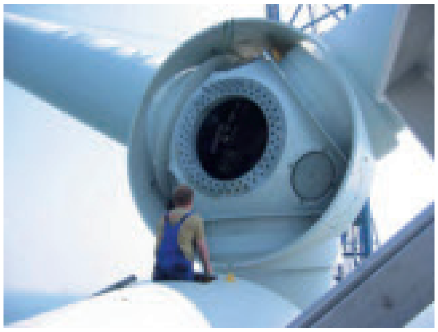


Photo: Nysted Offshore Wind Farm

Mounting of turbine rotor at Nysted.

THE ENVIRONMENTAL MONITORING PROGRAMME

Measuring environmental conditions before, during and after construction of the wind farms

The building permits for Horns Rev and Nysted included an obligation to carry out comprehensive environmental monitoring programmes that should include detailed measurement of the environmental conditions before, during and after the two wind farms were established.

Between 1999 and 2001, as part of the Environmental Impact Assessments (EIAs) and as the basis for the Horns Rev and Nysted environmental monitoring programme, baseline studies were undertaken in order to establish a reference for later analysis to be able to compare the existing environmental conditions to the introduction of a wind farm. The environmental monitoring programme was initiated following the completion of the EIAs and the baseline studies.

Administration and dialogue

In the period 2001–2006, the programme had a budget of DKK 84 million (approximately EUR 11 million) financed as a public service obligation by electricity consumers. The work has been co-ordinated by the Environmental Group consisting of the Danish Forest and Nature Agency, the Danish Energy Authority, Vattenfall and DONG Energy.

The results of the studies have been evaluated by the International Advisory Panel of Experts on Marine Ecology (IAPEME), consisting of experts with unique competence within the individual branches of the entire monitoring programme. These experts have evaluated the progress of the programme

Photo: Maks Klaustrup

Diver taking fauna samples at the Horns Rev Offshore Wind Farm.

	1999	2000	2001	2002	2003	2004	2005	2006
Visualisation and socio-economic investigations	●○	●○			●○	●○		
Hydrography	●							
Hydrography and coastal morphology	○	○		○	○	○		
Benthic fauna and flora along 132 kV cable	○	○	○	○	○	○		
Benthic fauna and flora in the farm area	●○	●	●○		●	●	●○	
Fish in the farm area	●○	○		●				
Fish, sand eel				●		●		
Electromagnetic fields and possible effect on fish			○	○	○	○		
Monitoring of harbour porpoises	●	●	●○	●○	●○	●○	●○	●
Monitoring of seals	●○			●○	●○	●○	●○	
Monitoring of birds	●○	●○	●○	●○	●○	●○	●○	○
Development of new habitats					●○	●○	●○	

Figure 9: Environmental studies carried out at Horns Rev Offshore Wind Farm (●) and Nysted Offshore Wind Farm (○).

and made recommendations for future monitoring approximately once a year.

The decision-making process relating to the programme has been characterised by openness and constant dialogue between all parties involved. For instance the Environmental Group has been in constant dialogue with a "Green Group" consisting of representatives from the World Wide Fund for Nature (WWF), the Danish Society for Nature Conservation, the Danish Outdoor Council, Greenpeace, the Danish Ornithological Society and the Danish Organisation for Renewable Energy.

Focus of the environmental studies

The studies and analyses in the environmental monitoring programme have dealt with:

- Benthic fauna and vegetation: Studies of bottom fauna and vegetation, including the food basis for fish, with particular focus on the introduction of a hard bottom habitats, eg the turbine foundation and scour protection.
- Fish: Studies of the distribution of fish around the wind turbines and the scour protection and the impact of electromagnetic fields on fish.
- Marine mammals: Studies of the behaviour of harbour porpoises and seals in and near the wind farm areas.
- Birds: Studies of resting, foraging and moulting birds, including modelling of collision risks and monitoring of bird collisions with wind turbines.
- Attitudes: Sociological and environmental economic studies of people's attitudes towards the wind farms.

The BACI method

Where possible, all studies apply the BACI approach (Before After Control Impact), which is a schematic method used to route environmental effects from substantial man-made changes. Accordingly studies were divided into three stages consisting of three years of baseline monitoring (before), monitoring during the construction and three years of monitoring during the operation phase (after).

Some studies had to await the actual construction of the wind farm. This included the assessment of bird collision risk with turbines and artificial reef effects due to the introduction of hard bottom substrates.

AIMS OF THE ENVIRONMENTAL MONITORING PROGRAMME

The monitoring programme was set up to chart the environmental conditions before, during and after the two farms were constructed. The aim was to clarify:

- The risk of experiencing essential negative effects on the environment.
- The ecological fragility of the specific areas.
- The usefulness of the areas to investigate specific effects.
- The relevance of the effects to decision-making regarding further development within the specific areas and the overall development of future offshore wind farms.
- The importance of the different effects in relation to the demand for action and the economic framework for the programme.

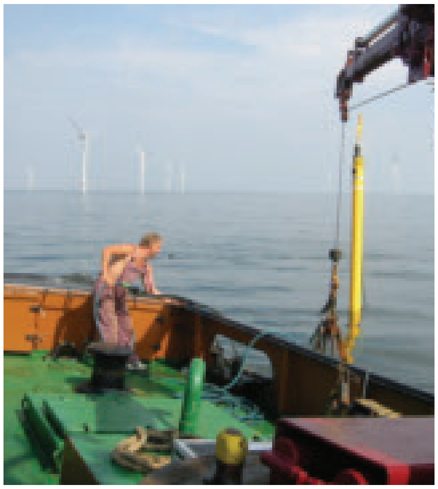


Photo: Vattenfall

Deployment of acoustic datalogger (T-pod) outside the Horns Rev Offshore Wind Farm. T-pods record the echolocation sounds made by harbour porpoises.

BENTHIC COMMUNITIES: CHANGE IN BOTTOM FLORA AND FAUNA

Wind turbine foundations and scour protections act as sanctuaries for vulnerable species

The main effect of the establishment of the Horns Rev and Nysted wind farms was the introduction of the turbine foundations and the scour protections onto seabeds that previously consisted of relatively uniform sand. These hard bottom structures, covering 0.2% of the total wind farm area, have increased habitat heterogeneity and locally changed the benthic communities from typical fauna communities with most aquatic animals living in the seabed to hard bottom communities with increased abundance and biomass.

The habitats introduced by the wind farms will be suitable for colonisation by a variety of marine animals and algae, and the hard bottom structures may act, both individually and collectively, as an artificial reef and as sanctuary areas for threatened or vulnerable species. Furthermore, it is expected that the introduction of hard bottom communities will increase the availability of food to fish, which again will lead to an increase in the available food to marine mammals and birds.

Different native fauna

The baseline studies of Horns Rev found no vegetation and the native fauna composition was found to be closely associated with the sandy environment. The fauna was very variable and heterogeneous with the bristle worms *Goniadella bobretzkii* and *Ophelia borealis* and the thick trough shell amongst the most predominant and characteristic species. Mobile fauna was often found on the seabed in the area. The brown shrimp, which often was observed, is an important prey species for both sea birds and fish.

At Nysted, the native fauna community was characterised as a shallow water Macoma community, named after the Baltic tellin. The bottom fauna was very homogeneous and some species found were typical indicators of brackish water. Common mussels were locally found in large numbers constituting more than 35% of the total biomass.

Massive colonisation by common mussels

After the establishment of the wind turbines at Horns Rev the hard substrates were colonised mainly by species not previously recorded in the sandy seabed community, thereby increasing the species richness in the area.

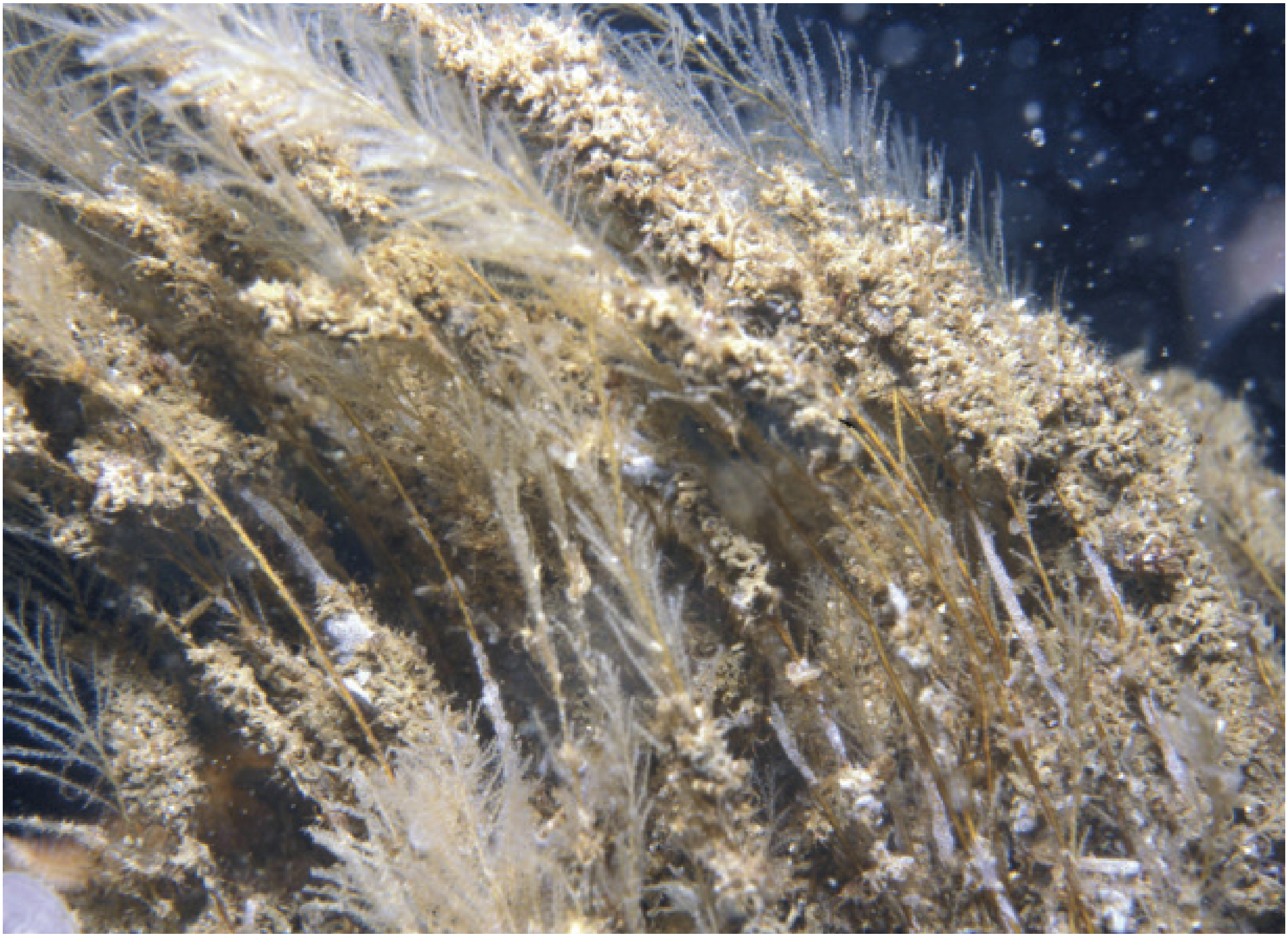
At Nysted, the colonising communities were mainly composed of species previously recorded in the benthic mussel bed and algae communities. Almost monocultures of common mussels had developed at the turbine structures.

At both wind farm sites, the initial colonisation of the common mussel was massive. In 2003, densities from 90,000 to 200,000 individuals/m² could be found at the upper-

Photo: Maks Klaustrup

Scour protection with common mussels at Nysted.

Common starfish at the scour protections of Horns Rev. Starfish is a key predator in the area.
Photo: Maks Klaustrup



The whiteweed, a threatened species in the Wadden Sea, overgrown by Jassa marmorata.
Photo: Jens Christensen.

most parts of the turbine foundations. Due to a lack of efficient predators at Nysted, the common mussel *(Mytilus edulis)* was the predominant species controlling the community. Higher salinity and the presence of more efficient predators like the common starfish *(Asterias rubens)* are interpreted as the main reason for the reduced predominance of common mussel at Horns Rev.

Development of algae communities

A succession in the development and distribution of attached algae was found on the new hard bottom structures. In the upper part of the foundations of the Horns Rev wind turbines, a cover of algae was found shifting from an initial colonisation of filamentous green algae to a more diverse and permanent vegetation of green, brown and red algae. Similar species were also found colonising the foundations at Nysted.

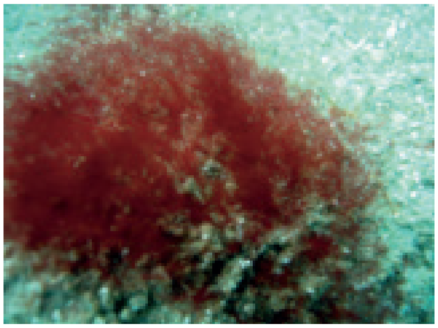


Photo: Maks Klaustrup

The red algae, Polysiphonia fibrillosa, found at foundations at Horns Rev and Nysted.

Photo: Maks Klaustrup

Common mussels with growth of hydrozoans at Nysted.

METHODS

A total of six infauna and vegetation community surveys were performed at Horns Rev and Nysted during the pre-construction and post-construction phases.

At Horns Rev, quantitative samples of infauna and sediment were taken by scuba divers and analysed.

At Nysted, common mussels were sampled at mussel bed sites by scuba divers, and the seabed character and coverage of benthic communities were mapped and assessed using a photo-sampler methodology.

Sampling of benthic communities of turbine foundations was performed at six turbine sites at Horns Rev and at eight turbine sites at Nysted. The sampling sites were selected according to differences in depth regimes and turbine locations.

FISH: FEW EFFECTS ON THE FISH COMMUNITIES SO FAR

Turbine foundations may have positive effects after full development of reef communities

The environmental monitoring programme carried out at Horns Rev and Nysted wind farms indicates that the construction itself only has short-term effects on fish. The effect of noise and vibrations from the wind farms is believed to be of minor importance.

Two elements may have long-term effects on fish fauna and fish communities: the establishment of turbine foundations introducing hard substrates into the natural habitat and the electromagnetic fields induced by the power cables transporting the electric power to the shore.

New artificial habitats

Establishment of an offshore wind farm means loss of natural habitats because of the foundations and scour protections but at the same time it introduces new artificial habitats. At Horns Rev and Nysted, the natural sandy habitats around the turbines were replaced by stones and rocks.

Full development of the reef community typically takes several years since not all species colonise the new habitats simultaneously and some species continue their growth. The full effect of the scour protections as artificial reef structures can therefore only be observed after several years.

In addition to the direct effect of establishing the artificial structures, the turbine foundations also cause indirect reef effects on the flow patterns and the sediment composition around the foundations. These may influence benthic fish species through changes in food sources, burying ability and predator densities.

Differences between areas

The natural occurrence of fish was found to differ between Horns Rev and Nysted, to a large extent due to a number of physical and biological factors. Overall, the fish communities at the two wind farms differed primarily due to differences in water salinity. Due to the position in the Baltic Sea, Nysted is more brackish (lower salinity) than Horns Rev.

At least 42 fish species are known to inhabit the area around Horns Rev. The most abundant group of fish is sandeel. This group was represented by three species, ie lesser sandeel, small sandeel and greater sandeel.

The fish fauna at Nysted along the cable route has been recorded to comprise a total of 43 species. The most abundant species caught were Baltic herring, Atlantic cod, short-spined sea scorpion, flounder, common eel and eelpout.

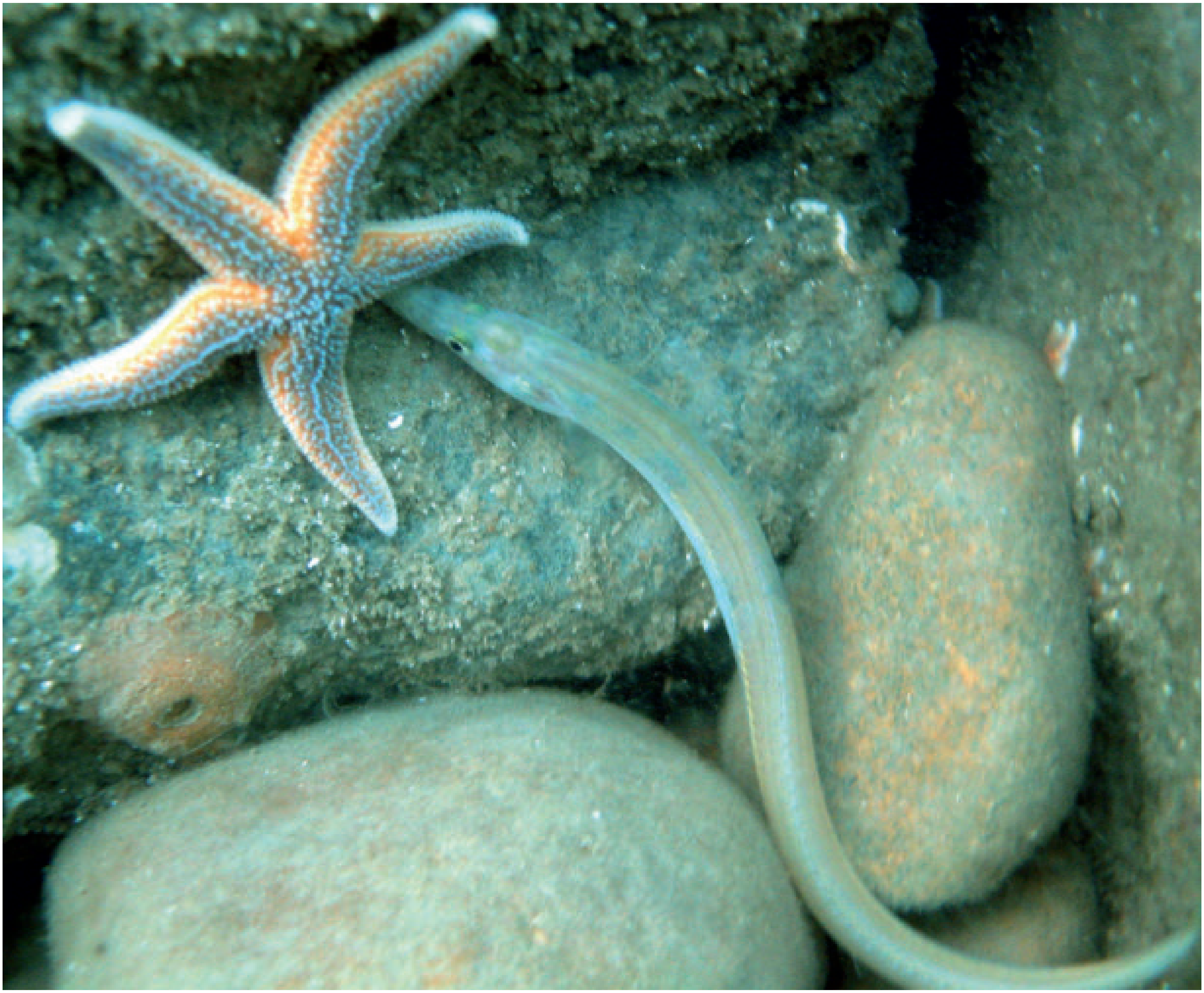
Insignificant reef effects

A total of 12,099 and 18,388 fish were registered during the hydroacoustic surveys at Horns Rev and Nysted, respectively. At both sites, supplementary fishing indicated that the species compositions were similar inside and outside the wind farm areas.

The hydroacoustic surveys did not prove the expected reef effect but tendencies of local and regional effects were observed. The reef effect may become more clearly expressed over the coming years as colonisation and development of the biological communities progress.

Photo: Jens Christensen.

Cod at Horns Rev.



Sandeel and starfish at the scour protection of Horns Rev.
Photo: Maks Klaustrup

Photo: Naturfocus

Figure 10: Illustration of the setup for the hydroacoustic surveys.

At Nysted, local variations in the spatial distribution pattern were observed inside the wind farm although no significant statistical differences were found.

At Horns Rev the density of sandeel increased by approximately 300% from 2002 to 2004 within the wind farm area and it decreased by 20% in the control area outside the wind farm during the same period. It is therefore unlikely that the wind farm has a negative effect on the sandeel.

Limited effects of power cables

The investigations carried out at Nysted to detect effects of the electromagnetic fields on fish were characterised by a high complexity and many difficulties, both in the sampling phase and in the analysing phase. The investigations show some impact from the cable route on fish behaviour, but the data analysis did not prove any correlation between the observed phenomena across and along the cable route and the strength of the electromagnetic fields.

One alternative explanation to the impacts observed could also be that fish reacted to the physical conditions along the cable route if the seabed was not fully re-established. Current knowledge is still too inadequate to make clear conclusions on the level of disturbance.

Catch at the Nysted Offshore Wind Farm.

Photo: Christian B. Hvidt

METHODS

The spatial and temporal distribution patterns of fish at Horns Rev and Nysted have been monitored by the use of advanced hydroacoustic equipment with the intention of detecting possible effects of the artificial reefs on the number of individuals and biomass. As a supplement to the hydroacoustic measurements, fishing with conventional survey equipment (nets etc) was carried out to supply information on species composition.

At Horns Rev, sandeel is one of the most abundant groups of fish. Due to a known strong correlation between the distribution of sandeel and the composition of the sediments, the distribution of both sandeel and sediment composition was surveyed.

Surveys and assessment of the effect on fish from electromagnetic fields were concentrated at Nysted with a specially designed setup and fishing gear applied to the area along the cable route. As part of the survey programme at Nysted, the migration direction for common eel was investigated through a mark and recapture programme.

MARINE MAMMALS: SEALS AND PORPOISES REACT DIFFERENTLY

Seals on land were almost unaffected by the wind farms, while the activity of harbour porpoises decreased in the wind farm areas during construction and at Nysted also during operation

Offshore wind farms can potentially affect marine mammals in several ways. The physical presence of the turbines and the construction activities can cause animals to avoid the areas, partly or completely. The most important factor is likely to be underwater noise.

Construction activities are generally noisy and especially pile driving operations generate very high sound pressures that may injure the animals at close range. The operation of wind turbines also generates noise, but at considerably lower levels which are only audible in the vicinity of the wind farm.

Construction of an offshore wind farm also creates permanent alterations to the local environment where turbine foundations and scour protection will be colonised by algae and animals new to the area. This will cause subsequent changes in the fish fauna that are likely to be neutral or even positive to seals and porpoises.

Main results

Both Horns Rev and Nysted wind farms were found to be part of much larger foraging areas for seals, but no general change in the behaviour of seals at sea or on land could be linked to the construction or operation of the wind farms. The only effect detected on land was a reduction in the number of seals on land during pile driving operations at Nysted.

A slight decrease in harbour porpoise abundance was found at Horns Rev during construction but no effect was seen during operation. At Nysted, a clear decrease in the abundance of porpoises was found during construction as well as operation of the wind farm. The effect has persisted after two years of operation of the wind farm, with indications of slow recovery. Clear effects of pile driving operations were observed at both wind farms.

Seals stay at Horns Rev

The Horns Rev wind farm area is placed in the middle of an important harbour seal foraging area. Seals were seen inside the wind farm area before, during and after construction, with the exception that no seals were observed inside the wind farm during pile driving operations. No effects of the wind farm were observed after the wind farm was put into operation.

Seals around Nysted only affected by pile drivings

An important additional question at Nysted was whether construction and operation of the wind farm influenced the behaviour of harbour and grey seals on the neighbouring Rødsand seal sanctuary. The construction of the wind farm only 4 km away from the seal sanctuary had no overall measurable effect on the presence of seals on land.

The only clear link to the construction activities was seen during pile driving operations. During these periods fewer seals hauled out in the seal sanctuary.

Photo: Jacob Tougaard

Harbour seal tagged with satellite transmitter.

Photo: Svend Tougaard

Harbour seals at Langli Sand near Horns Rev, with the town of Hjerting in the background.

Photo: DMU

Harbour seal.

Photo: Jonas Teilmann

The activity of harbour porpoises decreased in the wind farm areas during construction. At Horns Rev the distribution returned to normal during operation.

Photo: Jonas Teilmann

The activity of porpoises decreased significantly in the Nysted wind farm area during construction and the first two years of operation.

Small effect on porpoises during construction of Horns Rev

Prior to the environmental monitoring programme it was known that the eastern part of the North Sea, and thus also Horns Rev, was home to a large number of porpoises and that Horns Rev plays an important role as a foraging area for porpoises in the area. Visual observations from ship surveys showed that there was a general but small effect during the construction of the wind farm on the distribution of porpoises away from the area, but the distribution returned to the baseline situation during operation. During pile driving operations porpoises in the entire Horns Rev area were affected.

Slow recovery of porpoises at Nysted

Porpoise densities in the western part of the Baltic Sea, including the area around Nysted, have generally been lower than around Horns Rev. The presence of porpoises decreased significantly in the wind farm area during construction and the first two years of operation.

Whereas the disturbance during construction was anticipated, the slow recovery at Nysted was unexpected. The reason for the slow recovery is unknown, but one possible explanation could be that the general area is of lesser importance to the porpoises and that porpoises are less motivated to remain in the area when disturbed.

Figure 11: Rødsand seal sanctuary with seals resting on land. The observation tower and camera tower are seen. To the right a close up of the camera setup.

METHODS

Marine mammals are difficult to study at sea and the traditional visual surveys from ships and aircrafts were therefore supplemented or replaced by other methods such as acoustic monitoring by stationary dataloggers, remotely controlled video monitoring and tagging of animals with satellite transmitters.

MONITORING OF SEALS

Seals are rarely observed at sea and therefore seals were tagged with satellite transmitters to follow their movements. At the Rødsand seal sanctuary, five harbour seals and six grey seals were tagged before the construction of the Nysted Offshore Wind Farm started, and at Rømø, 50 km from Horns Rev, 21 harbour seals were tagged, before, during and after construction. To monitor the behaviour of seals at Rødsand visual observations were made from a bird observation tower during the baseline study period and by a remotely controlled camera system during construction and operation. This was supplemented by monthly surveys from aircraft at Rødsand and the other land sites in the area.

MONITORING OF HARBOUR PORPOISES

Acoustic monitoring systems were used to investigate the presence of porpoises at the Horns Rev and Nysted wind farms relative to one or more reference areas. To orientate and catch fish porpoises produce high frequency echolocation sounds almost continuously. These sounds were recorded by dataloggers (T-PODs) moored using anchors and buoys both inside and in reference areas outside the wind farm areas. Six T-PODS were deployed in and around each wind farm. At Horns Rev, the changes in spatial distribution of porpoises were also studied with traditional visual surveys from ship.

BIRDS: AVOIDANCE RESPONSES AND LOW COLLISION RISK

The majority of bird species generally avoid both wind farms. Effects on overall bird populations are negligible

Offshore wind farms is likely to become the single most extensive industrial infrastructure development in the marine environment, and the construction of wind turbines presents three types of hazards to birds at sea.

Firstly, they can present a barrier to the movement of migrating or feeding birds. Many bird species avoid unfamiliar man-made objects, especially large moving objects. Birds might therefore deflect prior migration routes or feeding movements, although some may also be attracted to the turbines. Displacement of feeding birds on a more frequent basis may ultimately affect survival or breeding success.

Secondly, there may be a physical habitat loss, as a food resource is buried under the turbine foundations, or lost below anti-scour protection. These features may, however, also create novel feeding opportunities, for instance where hard concrete substrates or anti-scour protection are introduced to a formerly exclusive sandy seabed.

Finally, if birds do not show avoidance behaviour, there is a potential risk of collision with the turbines. This has until now been considered to be the most important hazard because of its direct effect on the death rate.

Considering the first two large offshore wind farms of Horns Rev and Nysted, the overall effect of these hazards is likely to be small at population level as the area affected compared to the extent of similar shallow waters is miniscule and the collision risk is small. But the cumulative impact of many more such installations could have an impact on the survival and reproduction of birds in the future. It is important that the cumulative impacts of this, and other man-made installations, on populations of birds are addressed for future exploitation of offshore wind.

Different characteristics

Horns Rev and Nysted differ markedly in physical characteristics and bird species present. With its North Sea location, Horns Rev is exposed to the prevailing southwesterly winds, experiences lunar tides and is far more characterised by genuine marine conditions than the more protected and enclosed brackish Baltic Sea location of the Nysted site.

Numerically important bird species at Horns Rev include divers (mostly red-throated divers), gannet, common scoter, herring gull, little gull, kittiwake, arctic/common tern and auks.

At Nysted the numerically important species include cormorant, mute swan, goldeneye, long-tailed duck, common eider, red-breasted merganser, herring gull and great black-backed gull. Nysted also lies on the main migration route for many thousands of waterbirds, dominated by eiders and dark-bellied brent geese.

Avoidance and displacement

Radar studies showed that birds generally avoided the Horns Rev and Nysted wind farms. Between 71 and 86% of all bird flocks heading for the Horns Rev Offshore Wind Farm ultimately avoided entering the

Photo: Ib Krag Petersen

Counting birds from aircraft.

Photo: Nysted Offshore Wind Farm

Cormorants on the foundations of Nysted Offshore Wind Farm.

wind farm between the turbine rows. Patterns at Nysted confirmed similar large-scale avoidance patterns. There was considerable movement of birds along the periphery of both wind farms, as birds preferentially flew around rather than in between the turbines.

At both Horns Rev and Nysted, changes in flight direction tended to occur closer to the wind farm at night (at a distance of 0.5 km) than by day (a distance of 1.5 km or more). For some species like eiders it is not possible to exclude that birds react already at a distance of 10–15 km by modifying their flight orientation.

Comparison of pre- and post-construction aerial surveys of waterbird distributions showed that many species avoided the wind farms. Divers at Horns Rev showed almost complete avoidance of the wind farm post construction, where also very few common scoters were encountered despite up to 381,000 in the general area. Long-tailed ducks showed statistically significant reductions in density in the Nysted Offshore Wind Farm where they had shown higher than average densities prior to construction. This suggests major displacement of this species from former feeding areas. No bird species convincingly demonstrated enhanced use of the waters within the two wind farms.

Although bird displacement represents effective habitat loss, it is important to assess the relative loss in terms of the proportion of potential feeding habitat affected relative to the areas outside the wind farm. For

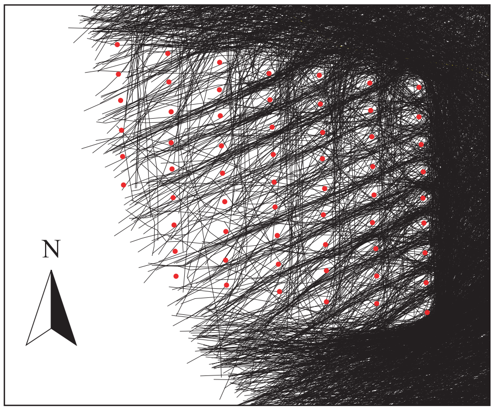


Figure 12: Flight trajectories of birds at Nysted. The westerly orientated flight trajectories of birds tracked by radar at the Nysted Offshore Wind Farm during initial operation of the wind turbines. Black lines indicate migrating waterbird flocks, red dots the wind turbines and the scale bar equals 1000 m. Reproduced with permission from the Royal Society of London.

most species considered here, that proportion is relatively small and therefore likely to be of little biological importance. However, the additional costs of many other such wind farms may constitute a more significant effect.

Limited physical effects on habitats

The physical loss and gain of habitats associated with wind farm construction were considered to be trivial in proportional terms. Even accounting for the anti-scour structures, these features equated to 0,2% of the total area of the marine substrate within the whole wind farm. Their effects would therefore be small and difficult to distinguish from other distributional effects.

Photo: Daniel Bergmann

Common scoter is one of the numerically important bird species at Horns Rev.

Low collision risk

The risk of colliding with the wind turbines proved to be very low. Of 235,000 common eiders passing Nysted each autumn, predicted collision rates were 0.02% (45 birds). The low figure was confirmed by the fact that no collisions were observed by infra-red monitoring. Radar studies showed that approximately 80% of the birds heading for the wind farm avoided passing it and that many birds entering the wind farm re-orientated to fly down between the turbine rows.

Infra-red video surveillance of a single wind turbine at Nysted confirmed that waterbirds (mostly eider) reduced their flight altitude within the wind farm, flying more often below rotor height than they did outside the wind farm. More than 2,400 hours of monitoring resulted in a mere 11 bird detections well away from the sweep area of the turbine blades and only one collision of a small bird/bat.

Major consequences unlikely

The general conclusion of the bird studies at Horns Rev and Nysted is that most of the more numerous bird species show avoidance responses to both wind farms. However, neither site is so close to a nesting area of any of the species that they affect reproduction and the slight extension to flight distances is also unlikely to have any major consequences for the populations.

In general, avoidance also extended, not just to flying between the turbines, but also to not resting or foraging between them. This implies that construction of wind farms in favoured feeding areas for certain bird species may cause habitat loss at least up to three years after construction, even if the habitat and feeding resources remain intact. This should be considered in future EIAs for areas where high bird concentrations are present.

METHODS

From the start it was impossible to address the hazards with respect to all bird species found in the vicinity of the wind farms. The study therefore focused on:

- species subject to special protection measures, eg under EU or domestic legislation,
- species for which the two study areas have some significance at some stage in the annual life cycle,
- species that for some reason are especially susceptible to habitat loss or collision, and
- species that are susceptible to even small increases in adult mortality.

For these reasons, the emphasis was primarily on studies of long-lived large-bodied birds, essentially marine water birds.

The study of bird flight trajectories was carried out with conventional ship navigation radar as the most important tool for recording the patterns of all bird movements in the vicinity of the wind farms.

Aerial surveys were designed to map the numbers and distribution of the different species before and after construction of the wind farms. The bird counts were carried out from aircraft by trained observers that logged bird species, numbers and behaviour with the precise time of the observation on a dictaphone. Positioned observations were then entered into a computerised Geographical Information System (GIS) for subsequent analysis.

Collision risks were studied after construction by mounting remote controlled infra-red video surveillance equipment on one of the Nysted turbines. Combined with radar observations this system monitored 30% of a sweep area of the turbine and provided data on both the specific nature, eg the flight altitude, and frequency of bird avoidance and a direct sampled measure of the number of collisions per unit time monitored.

SOCIOECONOMIC EFFECTS: POSITIVE ATTITUDES

Both local and national populations are generally positive towards wind farms. On the other hand there is also a significant willingness to pay to locate future wind farms at distances where the visual effects on the coastal landscape are reduced

In Denmark, the number of onshore wind turbines has increased significantly in the last couple of decades. At the same time the effects on the surroundings in terms of noise, reflections and visual intrusions have been the focus of much debate.

Wind power offshore has been expected to affect some of these effects, and the environmental monitoring programme therefore included an investigation of people's attitudes and perceptions of the scenic and environmental effects of offshore wind farms.

A sociological and environmental economic study showed that both local and national populations are generally positive towards offshore wind farms. At the same time there are clear differences in the attitude and preferences between the local areas and nationally.

Different local areas

The Horns Rev Offshore Wind Farm is placed 14–20 km west of Blåvands Huk. This area is predominated by recreational homes and around 3,300 people are permanent residents in the municipality. Only a few homes have a location with a view of the wind farm.

The wind farm at Nysted is placed 10 km from the coastline and, contrary to Blåvands Huk, some of the approximately 4,300 citizens can see the wind farm from their houses. The wind farm can also be seen from the town of Nysted and from the town harbour, which is a meeting place for both locals and tourists.

More than 80% are positive towards existing wind farms

In the environmental economic study it was found that more than 80% of the respondents from the Horns Rev and Nysted areas were "positive" or "very positive" towards existing wind farms. In addition, people in the Horns Rev area are generally more positive towards existing offshore wind farms than respondents in the Nysted area. This is expressed by more respondents stating that they are "very positive" towards existing wind farms. At the same time a predominant part of the "negative" responses are from Nysted (Figure 14).

These results are consistent with the findings of the in-depth interviews where a number of underlying reasons for the respondents' positive or negative attitudes were registered.

Positive attitudes were generally motivated by environmental concerns in relation to energy production, reliability of energy supply, exports and employment benefits. Among the respondents with negative attitudes, two things were in focus. Firstly, people expressed concern with the visual impact

Photo: Maks Klaustrup

Only 12 to 19% of the respondents answered that wind farms will have a negative effect on underwater marine wildlife.

Figure 13: Visualisation from the survey questionnaires of 100 wind turbines at a distance of 8 km with a cost per household of 70€ (top) and 144 turbines at a distance of 18 km with a cost per household of 140€ (bottom).

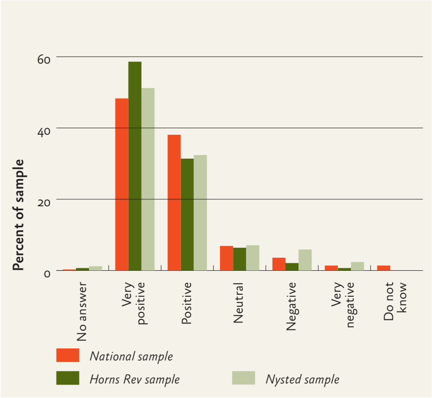


Figure 14: The attitude towards existing wind farms divided onto each of the three samples

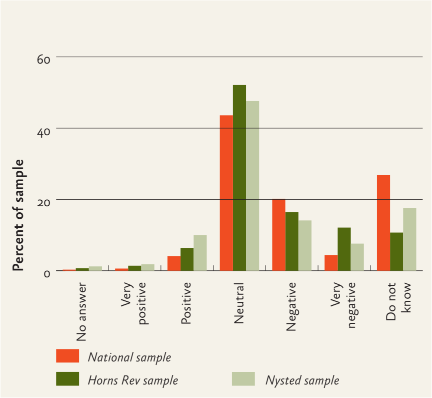


Figure 15: Respondents' perception of wind farms' effect on bird life

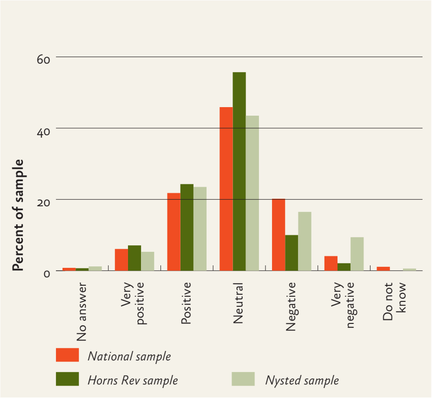


Figure 16: Respondents' perception of offshore wind farms' effect on the coastal landscape

on the coastal landscape, and secondly, there was a concern that the wind farms would have a negative impact on the marine environment.

Prevailing perception of limited effects on marine life

The prevailing attitude among both local and national respondents is that the impact on birds and marine life is neutral. However, between 22 and 29% of the respondents stated that they believed wind farms would have a negative or very negative effect on birdlife.

A rather large proportion of the respondents answered "don't know" when asked about their opinion of wind farms' effects on birds and animals living in the sea (Figure 15). It is interesting to note that respondents in the two local samples have a significantly lower percentage of "don't knows". This indicates that the local populations are better informed and have a higher level of knowledge of the effects of wind farms than the Danish population as a whole.

Opposition stronger prior to the construction

The sociological study showed that the opposition against the wind farm at Horns Rev was the largest by far prior to construction. This negative attitude gradually became less pronounced, and in 2004 the general opinion could be described as neutral or even slightly positive towards the offshore wind farm.

Two major concerns caused the initial opposition. Firstly, all the respondents pointed to the decision-making process which was seen as somewhat centralised, and secondly, there was a major concern that the wind farm would cause extensive visual disturbance. The sociological study did not find a similar change in the Nysted area where negative attitudes towards the local offshore wind farm were more persistent.

Preferred distance and willingness to pay for it

Almost two thirds of the respondents stated that they found wind farms' effect on the landscape either "neutral" or even "positive" (Figure 16), but the case was slightly different when they were asked about the placement of future wind farms.

When asked about their preference to the generic scenario of placing 720 wind turbines of 5 MW each offshore, more than 40% of the respondents in both the Horns Rev and Nysted samples stated that

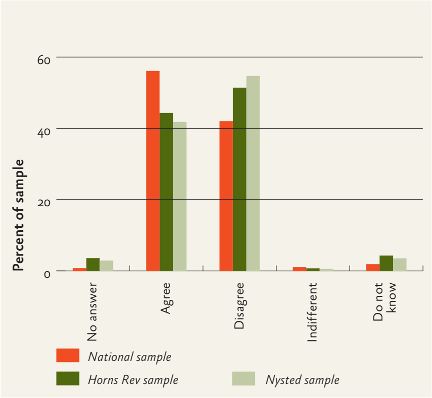


Figure 17: Respondents' answer when asked if they would prefer offshore wind farms located so that they are not visible from the coast.

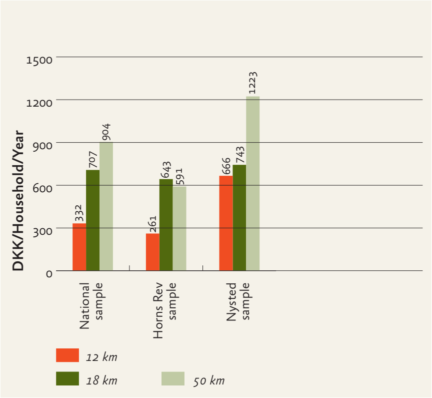


Figure 18: Willingness to pay to locate wind farms more than 8 km from the shore

they would prefer future wind farms to be moved out of sight. In the national sample more than half of the respondents stated that they would prefer wind farms to be moved out of sight (Figure 17).

When it came to the question of building future wind farms in several small groups or fewer but larger groups, more than 70% of local and national respondents stated that they would prefer larger and fewer farms.

Even though a majority of respondents found that wind farms had a neutral or positive effect on the landscape, the survey showed a substantial willingness to pay to place wind farms at a distance of more than 8 km from the shore.

In the national sample there was a significant willingness to pay to have wind farms located at distances where the visual intrusions are fairly small, ie up to 18 km from the shore. There are not equally strong preferences to have wind farms moved further out to a distance of 50 km where they are virtually invisible from the shore.

In the Horns Rev sample, respondents were willing to pay 261 DKK/household/year to have the distance extended from 8 to 12 km and 643 DKK/household/year to have the distance extended from 12 to 18 km. There was no extra willingness to pay to have wind farms moved from 18 to 50 km from the shore (Figure 18).

In the Nysted area, respondents were willing to pay nearly twice as much as in the Horns Rev sample to have the distance of wind farms extended to 50 km from the shore.

METHODS

A sociological study examined the local attitude towards the existing offshore wind farms and an environmental economic study investigated people's preferences and willingness to pay for future locations of offshore wind farms.

The sociological study consisted of in-depth interviews to expose the attitudes towards the two local wind farms at Horns Rev and Nysted. In total 46 persons were interviewed for 1–2 hours and the interviews were supplemented with analyses of the local media coverage of the wind farm projects.

The environmental economic study used a quantitative questionnaire based on the Choice Experiment approach to reveal the preferences for different location strategies. The study was conducted as a mail survey in May 2004 with 1,400 randomly selected individuals divided into three samples: a national sample of 700 respondents and two samples of 350 respondents, each representing the populations living close to the wind farms at Nysted and Horns Rev. The questionnaire also comprised a series of attitudinal questions on wind farms in general.

GENERAL IAPEME VIEWPOINTS

General viewpoints on the environmental monitoring programme from the International Advisory Panel of Experts on Marine Ecology (IAPEME)

The huge increase in the number of wind farm projects has required an enormous research effort to produce Environmental Impact Assessments (EIAs) for individual projects. Consequently, there is a substantial amount of "grey" literature, of a highly variable quality, about the environmental impacts of wind farms; unfortunately, however, only little has been published in peer reviewed scientific journals or in books, and developers have tended to retain data as commercially confidential material.

We congratulate the Danish authorities on the open and transparent manner in which the monitoring activities have been carried out at Nysted and Horns Rev, and the presentation of detailed results of this work in highly accessible forms. Not only are there numerous detailed, data-rich 'Final Reports' that can be downloaded from the internet, but the book "Danish Offshore Wind – Key Environmental Issues" and this booklet also summarize the key research findings on topics from hydrography to top predators.

Generally, the research carried out at Nysted and Horns Rev has followed the ideal design for such work (a BACI approach – Before After Control Impact) but it has also required that several novel technologies should be developed. Such work is expensive, long-term and requires skilled and dedicated researchers. Denmark has invested heavily in this research, and as a consequence the work is very much at the forefront of research into the environmental effects of offshore wind farms and will provide important information for those many countries where offshore wind farms are now being developed following the Danish example.

Highlights

The studies have shown that the Nysted and Horns Rev wind farms have had very little impact on the environment, neither during their construction nor during the operational phases.

There have been local effects on the benthic communities, particularly increases in faunal biomass and diversity associated with the introduction of hard substrates onto a naturally sandy seabed (towers, foundations and scour protection). These structures and increases in food may well over time attract higher numbers and a wider range of fish species, although monitoring has not yet demonstrated any strong effect on fish communities at these two sites. Indeed, one conclusion from the work must be that demonstrating changes in fish populations at these local scales is very difficult when fluctuations in many fish stocks occur at much larger spatial scales.

The development of the T-POD system (deployed data loggers recording porpoise sound production underwater) to measure porpoise ultrasonic activity within the wind farm and in control areas has been one of the major achievements of this programme. During the construction phase, the number of porpoises at the farms decreased immediately when noisy activities commenced, alleviating fears that marine mammals would remain in the area and so might be hurt by the intense pressures generated by pile driving. At Horns Rev, the porpoise numbers very quickly returned to "normal" once construction was completed, although data on porpoises at Nysted are different and more difficult to interpret. Seals also showed little response to the wind farms, except during the construction phase.

The development of a technology to measure collisions of birds, the TADS system (Thermal Animal Detection System) has been another of the major achievements of this programme. The TADS provides empirical evidence that waterbird collisions are rare events. Collision risk modelling and bird tracking by radar as well as visual observations show that many species of waterbirds tend to avoid the wind farm, changing flight direction some kilometres away to deflect their paths around the site. Birds flying through the wind farm tend to alter altitude to avoid the risk of collision. Under adverse weather conditions, which were thought to be likely to increase collision risk, results show that waterbirds tend to avoid flying. The strong avoidance behaviour results in very low estimates of collision risk, but of course increases habitat loss and increases costs of travel. The bird studies demonstrate strong differences between bird species in their responses to the marine wind farms, with some species of conservation concern, such as divers and scoters, showing particularly high aversion to these structures.

Applications of findings at Nysted and Horns Rev to other marine wind farms

The technological tools developed in the Nysted and Horns Rev studies, especially for the study of behavioural responses of marine mammals and birds, will be very useful for researchers working on new offshore wind farms in other locations. These technologies can readily be transferred to estuarine or open sea sites and applied for the study of a wide range of focal species.

The broad results from Nysted and Horns Rev also seem likely to be more generally applicable to other offshore wind farms, although it is important to appreciate that some differences have been found between Nysted and Horns Rev, and that responses are likely to vary among species and in relation to other environmental factors. It would not be sensible to generalise about impacts from a baseline study of the only two studies we have available so far.

Further research needs

There is clearly a need to study a number of other offshore wind farms to compare results with those reported in this monitoring programme. A larger number of studies will be required if broad generalisations are to be made with confidence.

There are also a number of questions that arise from the results obtained at Nysted and Horns Rev:

- Does the opportunities that hard structures introduced on the seabed present for species, such as crab and cod, result in these predators increasing in numbers and impacting on the communities of the surrounding sandy substrate over a number of years through predation?
- Do fish numbers increase at offshore wind farms over a longer time scale than the studies reported here, or do their communities and numbers respond more to large-scale processes than to local changes at the scale of individual wind farms?
- Can experiments be designed to test more critically the question of whether fish movements are affected by the electromagnetic fields generated by cables carrying the electricity ashore?
- What characterizes important habitats for marine mammals and how tolerant are they to disturbance in such areas?
- Do some species of waterbirds accommodate to marine wind farms and learn not to show such strong avoidance behaviour?
- Do marine mammals and waterbirds learn to forage within offshore wind farms if food abundance in these sites increases above normal levels?
- Even if the impact of a single wind farm on birds is apparently trivial at population level, can a paradigm be developed to assess cumulative impacts on bird populations of numerous offshore wind farms along their flight lines?

Current plans to extend the wind farms at Horns Rev and Nysted provide an ideal opportunity to determine the long-term impact of habitat loss thus testing rigorously the aversion to these structures shown by some species of marine birds as documented in the original studies.

IAPEME

In 2000 the Danish Energy Authority appointed five international experts to the International Advisory Panel of Experts on Marine Ecology (IAPEME). The task of the panel has been to comment on the environmental monitoring programme before, during and after the establishment of the wind farms and assess the methods used in the programme. The panel have also commented on the observed impacts of the wind farms on birds, mammals, fish and benthos ecosystems.

The panel members are:

Professor Robert W. Furness, (chairman),
University of Glasgow,
United Kingdom

Professor Rudi H. Drent,
University of Groningen,
The Netherlands

Professor Klaus Lucke /
Professor Ursula Siebert,
University of Kiel,
Germany

Professor Antony Jensen,
University of Southampton,
United Kingdom

Assistant Professor Peter Grønkjær,
University of Aarhus,
Denmark

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www.hornsrev.dk

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