ENERGI E2

EIA Report
Benthic Communities

Horns Rev 2
Offshore Wind Farm

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Horns Rev 2 Offshore Wind Farm

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Summary

As part of the Danish Governmental Plan for Renewable Energy, permission was given in 2005 to carry out an Environmental Impact Assessment for the establishment of a new offshore wind farm at Horns Rev.

Knowledge about potential impacts on the marine benthic communities from the establishment and operation of offshore wind farms is available due to the demonstration projects carried out at Horns Rev 1 Offshore Wind Farm. However, provision of supplementary information was found necessary regarding the existing habitats and benthic communities, which include benthic vegetation and invertebrate communities, in the designated wind farm area.

Two alternative sites are designated for the wind farm at Horns Rev 40 km west of Blåvands Huk. Both sites cover an area of approximately 35 km^2 and the water depths range from 5-15 m. The sediment in the wind farm areas display large variability and surface sediments consist of pure medium to coarse sand that is constantly reworked by waves and currents. Along the top of the reef and in shallower parts that are strongly exposed to waves, the sediment is more sorted compared to deeper parts where the sediment is coarser due to exposure to strong currents. Bedforms of small and large sand riffles caused by wave action and evidence of sand transport are found all over in the area. In the northern part of the designated sites, the sediment is generally finer closer to the reef. No unambiguous relationship between the depth regimes and the sediment structure is found at the different sampling sites in the wind farm area.

No vegetation, and no rare and endangered species, is found within the designated wind farm areas. The variations of the benthic infauna composition and community structure reflect the heterogeneous sediment in the area. In general, the benthic infaunal community in the Horns Rev area can be characterised as the *Goniadella-Spisula* or the shallow *Venus* community. These two communities are commonly found at sandbank where the seabed consists of relatively coarse sand and hydrographical conditions are turbulent. In the northern part of the designated wind farm area, the sediment generally shows a more uniform character with finer sand. In such areas, a more typical *Venus* community is found. Even within short distances, differences can be found in the community structure resulting in subdivisions of the main communities inside the designated wind farm areas, which reflects the character species' preferences for different sediment characteristics.

In the Horns Rev area and the wind farm areas, more epifaunal species can be found including the brown shrimp (*Crangon crangon*), which is object of commercial fishing. The benthic communities in the Horns Rev area are generally influenced by trawling and dredging activities. Dredging for the character clam species (*Spisula solida*) and trawling for sandeels are the main fishing activities in the area.

The wind turbines will be founded by use of either monopiles or gravitation foundations. The main impacts on benthic communities from the activities in the pre-construction, construction, operation and decommissioning phases are considered equal for the two foundation types. The sources of impact that are similar to both types of foundations include noise generated from piling activities. However, additional sources of impact

from dredging activities related to the establishment of gravitation foundations include increased smothering and suspended sediments.

In the pre-construction and construction phases, it is expected that noise and vibrations from pile driving activities may have a temporary and negligible local impact on the benthic communities and a very local and negligible destructive effect on infaunal species.

Smothering and increased suspended sediment from dredging activities is expected to have a temporary local negligible effect on benthic communities due to the general loss of fine sand. Benthic communities generally show a high tolerance to smothering with a presumed high recovery rate.

Loss of seabed with native benthic communities and change in substrate type during construction and operation is less than 0.2% of the total wind farm area. The change of habitat type and change from sandy infauna communities to epifouling communities are expected to be local and of minor significance. The deployed hard substrate will rapidly be colonised with algae and invertebrates, which is known to increase the biodiversity in the wind farm area. The succession will increase the diversity over a period of 5-6 years after deployment of the hard substrates, at which time the communities are expected to reach climax.

The physical presence of the wind turbine foundations will have a very local, minor, but permanent effect on the benthic community structure due to changes of the hydrodynamics near the turbines. During operation, significant effects from noise and vibration are not expected. Effects from electromagnetic fields are considered negligible, although migrating crabs, believed to be sensitive to the Earth’s magnetic fields, may be affected.

Effects during decommissioning are generally considered as the same during construction but in the reverse order.

In the operation phase, cumulative impacts are be expected as a consequence of reduced trawling activities inside the wind farm sites, which will be beneficial to benthic communities by enabling very sensitive species to establish and all species to mature more undisturbed. The introduction of more consolidated substrates from more offshore wind farms may generate a cumulative effect by introducing higher species richness and faster colonisation of specific and potentially vulnerable species to newly deployed foundations. No cumulative effects on benthic communities are expected from simultaneous sand and aggregation activities and construction activities.

No specific mitigation measures are necessary because rare or endangered species are not found and only minor impacts from construction, operation and decommissioning activities are expected on the benthic communities inside the designated wind farm areas.

Sammenfatning (in Danish)

Som del af den danske regerings plan for vedvarende energi, blev der i 2005 givet tilladelse til at udføre en VVM-undersøgelse (Vurdering af Virkningen på Miljøet) af etableringen af en ny havvindmøllepark på Horns Rev.

Viden om effekter på bunddyrsamfundene af etableringen af havvindmølleparker er tilgængelige fra demonstrationsprojekter gennemført i forbindelse med anlæggelsen af Horns Rev 1 Havvindmøllepark. Det var imidlertid nødvendigt at indhente supplerende information om de eksisterende habitater og bentiske samfund, omfattende vegetation og invertebrat-samfund, i det planlagte mølleparkområde.

Der er udpeget to alternative områder til placering af vindmølleparken. Begge de udvalgte områder dækker 35 km^2, og vanddybderne varierer mellem 4-15 m. Der er stor variation i sedimentets sammensætning, med overfladesedimenter bestående af rent mellemkornet til groft sand, som konstant omfordeles af bølger og strømme. Langs den øverste del af revet og i mere lavvandede områder, der er stærkt påvirkede af bølger, er sedimentet bedre sorteret end i dybere områder, hvor sedimentet er grovere som følge af stærke strømme. En bundstruktur med små og store sandribber, dannet af bølgebevægelser og som tegn på sandtransport, findes overalt i området. I den nordlige del af de planlagte mølleområder er sedimentet generelt finest tæt på revet. Der er ikke fundet nogen klar sammenhæng mellem dybdeforholdene og sedimentstrukturen i de forskellige prøvetagningsområder i mølleparkområdet.

Der findes ingen vegetation eller truede arter i de udpegede mølleområder. Variationerne inden for de bentiske faunasamfund reflekterer generelle forskelle i områdets sedimentforhold. Generelt kan det bentiske infaunasamfund karakteriseres som *Goniadella-Spisula* samfundet – eller *Venus* samfundet på lavt vand. Disse to samfund er almindelige på sandbanker, hvor havbunden består af relativt groft sand, og forholdene er turbulente. I den nordlige del af det udpegede mølleparkområde har sedimentet generelt en mere ensartet karakter med finere sand. I sådanne områder forekommer et mere typisk *Venus* samfund. Selv inden for korte afstande findes der forskelle i samfundsstrukturen, resulterende i underinddelinger af hovedsamfundene i de planlagte mølleparkområder, hvilket afspejler artsspecifikke præferencer for forskellige sedimentforhold.

Ved Horns Rev og i mølleparkområderne forekommer der flere arter tilhørende epifaunaen, herunder hesterejen (*Crangon crangon*), som fiskes kommercielt i området. De bentiske samfund i Horns Rev-området er generelt påvirkede af trawl- og skrabeaktiviteter. Skrab efter muslinger, især karakterarten (*Spisula solida*), og trawling efter tobis er de væsentligste fiskeri-aktiviteter i området.

Møllerne vil blive funderet på enten monopæle eller gravitationsfundamenter. De mest betydende påvirkninger af de bentiske samfund fra aktiviteter i præ-konstruktionsfasen, konstruktionsfasen, driftsfasen og nedbrydningsfasen forventes at være af samme omfang for begge typer af fundamenter. De påvirkninger, der er ens for de to fundamenttyper, inkluderer støj ved ramningsaktiviteter. Andre påvirkninger fra graveaktiviteter, herunder øget sedimentering af suspenderet sediment og suspenderet sediment, er i højere grad forbundet med etableringen af gravitationsfundamenter end med etableringen af monopæle.

I præ-konstruktionsfasen og konstruktionsfasen forventes det, at støj og vibrationer i forbindelse med ramningsaktiviteterne kan medføre forbigående og ubetydelige lokale påvirkninger af de bentiske samfund og en meget lokal og ubetydelig ødelæggende effekt på infauna-arterne.

Aflejring af suspenderet sediment og øget suspension af sediment pga. graveaktiviteter forventes at få forbigående, lokale og ubetydelige effekter på bunddyrssamfundene som følge af et generelt tab af fint sand. Bentiske samfund har normalt en høj tolerance over for aflejringer af sediment, og en hurtig normalisering af forholdene kan derfor forventes.

Tabet af havbund med naturligt forekommende bentiske samfund og forandringer i substrattype under konstruktionen og i driftsfasen udgør mindre end 0,2% af det samlede mølleparkområde. Ændringen af habitattypen og ændringen fra infaunasamfund på sandbund til påvækstsamfund på sten forventes at være lokal og af mindre betydning. Det udlagte hårde substrat vil hurtigt blive koloniseret med alger og invertebrater, hvilket generelt vil øge biodiversiteten i mølleparkområdet. Der forventes at succession i de introducerede påvækstsamfund vil øge diversiteten over en periode på 5-6 år efter, at det hårde substrat er blevet udlagt, hvorefter et klimakssamfund vil udvikles.

Den fysiske tilstedeværelse af vindmøllefundamenter vil have en meget lokal, ubetydelig, men permanent effekt på de hydrodynamiske forhold tæt på fundamenterne, hvilket vil påvirke den bentiske samfundsstruktur. I driftsfasen forventes ingen betydelige effekter af støj og vibrationer. Effekter af elektromagnetiske felter vurderes at være uden betydning for bunddyrsamfundene, selvom migrerende krabber, der menes at være følsomme over for Jordens magnetiske felter, potentielt kan blive påvirket.

Effekter i nedbrydningsfasen anses generelt for at være de samme som i konstruktions-fasen, men i omvendt rækkefølge.

I driftsfasen kan kumulative effekter muligvis forekomme som konsekvens af reduceret trawl-aktivitet i og mellem mølleparkerne på Horns Rev. Dette kan være til gavn for bunddyrsamfundene derved, at meget følsomme arter får mulighed for at etablere sig, og alle arter vil uforstyrret kunne opnå reproduktionsdygtig alder. Udlægning af faste substrater i flere havvindmølleparker kan muligvis forårsage kumulative effekter ved at medføre højere artsrigdom og hurtigere kolonisering af specielle og potentielt sårbare arter til nyanlagte fundamenter. Der forventes ingen kumulative effekter på bentiske samfund som følge af konstruktionsaktiviteterne og samtidige sand- og ralindvindings-aktiviteter i området.

Særlige afværgeforanstaltninger vil ikke være påkrævet, fordi sjældne eller truede arter ikke findes i området, og fordi der kun forventes mindre påvirkninger af bunddyrsamfundene i de udpegede mølleparkområder i forbindelse med konstruktion, drift og nedbrydningsaktiviteter.

1 Introduction

1.1 Background

In 1996, the Danish Government passed a new energy plan, ”Energy 21”, that states the need to reduce the emission of the greenhouse gas CO_2 by 20% in 2005 compared to the 1988 emissions. Energy 21 also sets the scene for further reductions after 2005 (Danish Environmental Agency, 1996). The means to achieve this goal is to increase the use of wind power and other renewable energy sources from 1% of the total energy consumption in 2005 to approximately 35% by 2030.Offshore wind farms are planned to generate up to 4,000 MW of energy by the year 2030. In comparison, the energy generated from offshore wind farms in January 2004 was 426 MW (www.offshorecenter.dk).

In 1998, an agreement was signed between the Danish Government and the energy companies to establish a large-scale demonstration programme. The development of Horns Rev and Nysted Offshore Wind Farms was the result of this action plan (Elsam Engineering and ENERGI E2, 2005). The aim of this programme was to investigate the effects on the environment before, during and after the completion of the wind farms. A series of studies on the environmental conditions and possible impacts from an offshore wind farm were undertaken for the purpose of ensuring that offshore wind power does not have damaging effects on the naturally occurring ecosystems. These environmental studies are of major importance for the establishment of new wind farms and extensions of existing offshore wind farms like Nysted and Horns Rev.

Prior to the construction of the demonstration wind farms at Nysted and Horns Rev, a number of baseline studies were carried out in order to describe the environment before the construction. The studies were followed by investigations during and after the construction of the wind farms and assessments were made of the eventual environmental impacts from the wind farms.

On August 25, 2005, the Danish Energy Authorities gave permission to carry out an Environmental Impact Assessment (EIA) at Horns Rev with particular reference to constructing a new offshore wind farm at the site, Horns Rev 2 Offshore Wind Farm. The wind farm is planned to operate in 2009 and the installed capacity of this wind farm will be 200-215 MW, equivalent to 2% of the Danish consumption of electricity.

1.2 Introduction

During the demonstration programme at Horns Rev 1 Offshore Wind Farm, monitoring was performed on the impact to benthic communities from introducing artificial hard substrates into the pre-existing habitats of pure sand.

The present report comprises an assessment for the potential impacts from the establishment of Horns Rev 1 Offshore Wind Farm on benthic communities. The assessment will be carried out by describing the basic conditions of the area and experiences from the demonstration projects in Horns Rev 1 Offshore Wind Farm.

A provision of supplementary information on pre-existing habitats and benthic communities in the wind farm area was necessary in order to assess the impact from the establishment of the wind farm. For this report, benthic communities include benthic vegetation and benthic invertebrates. Therefore, samples providing information of benthic communities and sediment parameters were collected during a field survey in January 2006.

Impacts during the pre-construction phase, the construction phase, the operational phase, and the decommissioning phase of the turbines will be assessed, including the cumulative or the combined impacts from already established and further developed offshore wind farms at Horns Rev.

Only impacts from wind farm construction and establishment inside the wind farm area are considered. The effects from laying the cable in the cable trace are excluded from this assessment.

2 Horns Rev

Horns Rev is an extension of Blåvands Huk extending more than 40 km to the west into the North Sea. Horns Rev is considered to be a stable landform that has not changed position since it was formed (Danish Hydraulic Institute, 1999). The width of the reef varies between 1 km and 5 km.

Blåvands Huk, which is Denmark's most western point, forms the northern extremity of the European Wadden Sea, which covers the area within the Wadden Sea islands from Den Helder in Holland to Blåvands Huk.

2.1 Topography and sediment

2.1.1 Geology and geomorphology

Horns Rev was formed from deposits of sand and gravel on top of deposits created during the Eem geological period and glacio-fluvial sediment deposited during the Saale glaciation. The constituents of the reef are therefore not the typical mixed sediment of a moraine but rather well sorted sediments in the form of gravel, grit and sand. Huge accumulations of Holocene marine sand deposits, up to 20 m in depth, formed the Horns Rev area that is known today with continuous accumulations (Larsen, 2003). Horns Rev can be characterised as a huge natural blocking sand ridge, which blocks the sand volume transported along the Jutland coast. The yearly transport of sand is in a magnitude of 500,000 m^3 (Danish Hydraulic Institute, 1999).

Horns Rev is constantly subject to variations in hydrography and sea level changes but it is considered a quasi-stable formation that will continue to adjust to minor changes in the local conditions.

The seabed surface sediments at Horns Rev are constantly reworked by waves and currents. The sediments in the Horns Rev area consists generally of pure medium fine sand to coarse sand with no or very low organic content (<1%) (Leonhard & Pedersen, 2006). Coarser sediments can be found towards slopes facing greater depths where currents are stronger. Bedforms of small sand ripples can generally be found that are caused by the wave impact on the seabed. Great variability in the sediment grain size distribution can also be found within short distances,

2.2 Hydrography

The North Sea is a complex resonant tidal system caused by the rectangular form of the basin. The mean tidal range in the area is about 1.2 m (Danish Hydraulic Institute, 1999). Within the wind farm area, the water depths vary from about 4m to 14 m. The depth conditions in the area result in the waves breaking in the wind farm area. The average wave-height is about 0.6-1.8 m.

The hydrographic conditions in the Horns Rev area are mainly a result of the intrusion of Atlantic water into the southern part of the North Sea. The water moves erratically towards the Skagerak. The flow continues northwards as the Jutland coastal current and follows the Danish west coast towards the Skagerak under the effect of prevailing winds.

The tidal current is mainly in a north south direction. Current speeds above 0.7 m/s up to 1.5 m/s are not unusual at Horns Rev (Leonhard & Pedersen, 2006).

Due to the tidal currents, rough waves and mixing of water, stratification does not develop in the Horns Rev area and therefore oxygen deficiency is not likely to occur (Danish Hydraulic Institute, 1999).

The salinity in the area is 30-34 psu and is determined by the inflow of freshwater from the German rivers to the German Bight and the inflow of relatively high-saline water from the North Sea.

Low transparency due to high amounts of re-suspended material in the water column is characteristic for the Horns Rev area. High temporal variability is found in the water transparency due to the influence of tidal current, wind induced current, current speed and seasonal plankton dynamics. In general, the water transparency is low in spring, 1.8-6.0 in adjusted Secchi depth [Adjusted Secchi depth = estimated Secchi depth x (1+0.4) x wave height] and higher during autumn, 2.5-8.8. Pronounced diel variability in transparency is found within a few hours and can be associated with changes in the prevailing current directions (Leonhard & Pedersen, 2006).

3 The wind farm area

3.1 Description of the wind farm area

The Horns Rev 2 Offshore Wind Farm will be located approximately 30 km west of Blåvands Huk. The distance to the north-western point of Horns Rev 1 Offshore Wind Farm will be approximately 14 km, depending on the exact placement of the wind farm.

The area selected by the Danish Energy Authority for the preliminary study is shown in Figure 3.1. The establishment of the wind farm is expected to be in one of two different appointed sites. The exact position of the individual turbines has not yet been decided and there may be some minor adjustments regarding the positioning of both sites. However, the final placement will be inside the selected area of the preliminary studies referring to the two alternative sites, the northern or the southern site. The northern site extends northwards from the reef. The southern site extents east towards west and partly covers the reef. Both the selected areas cover 35 km^2, which is the maximum size of the Horns Rev 2 Offshore Wind Farm. The water depths at the two sites range from 4-14 m, Figure 3.1.

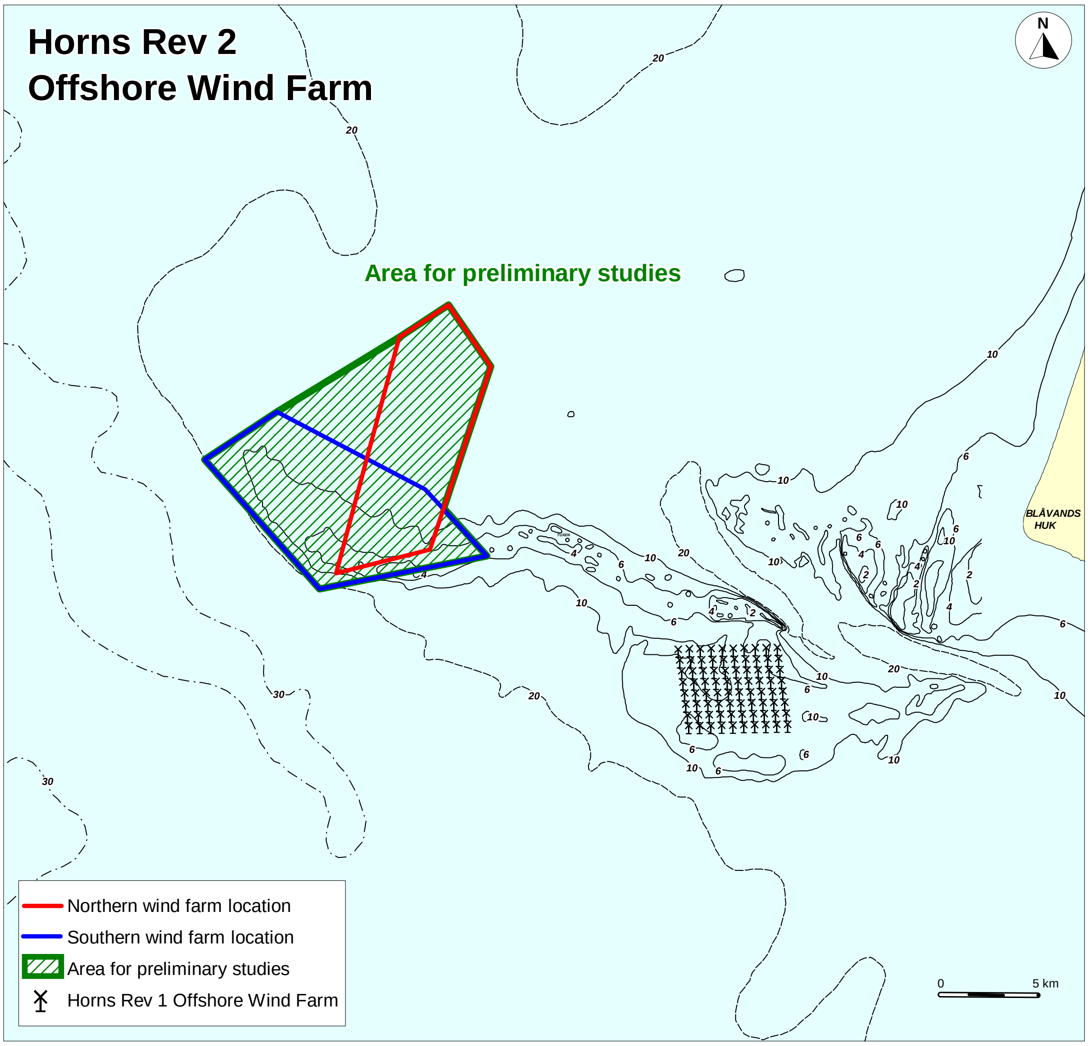

Figure 3.1. Sites selected for the Horns Rev 2 Offshore Wind Farm.

3.2 The turbines

The exact type of turbine and type of foundation has not yet been decided.

The wind turbine technology is undergoing rapid development with regard to the layout and efficiency of wind turbines as well as their size. In order to take advantage of this development, the final selection of the wind turbine type will take place later. The basis scenario for this EIA is a setup comprising 95 turbines plus possibly 1-3 experimental turbines. The expected distance between the turbines in this setup will be approximately 600 m. However, with an installed total capacity of 200-215 MW for the wind farm, the factual number of turbines may be reduced if larger units are selected.

The experimental turbines are included in this EIA although they will not be part of the wind farm established by ENERGI E2. The maximum total capacity of the experimental turbines will be 15 MW. The maximum height will be 200 metres and the type of foundation will be selected and decided by the developer, independently of what type of foundations will be decided for the wind farm.

The probable row patterns of the turbines at the two sites are shown in Figure 3.2. However, the position is subject for adjustment in the final park layout.

a) b)

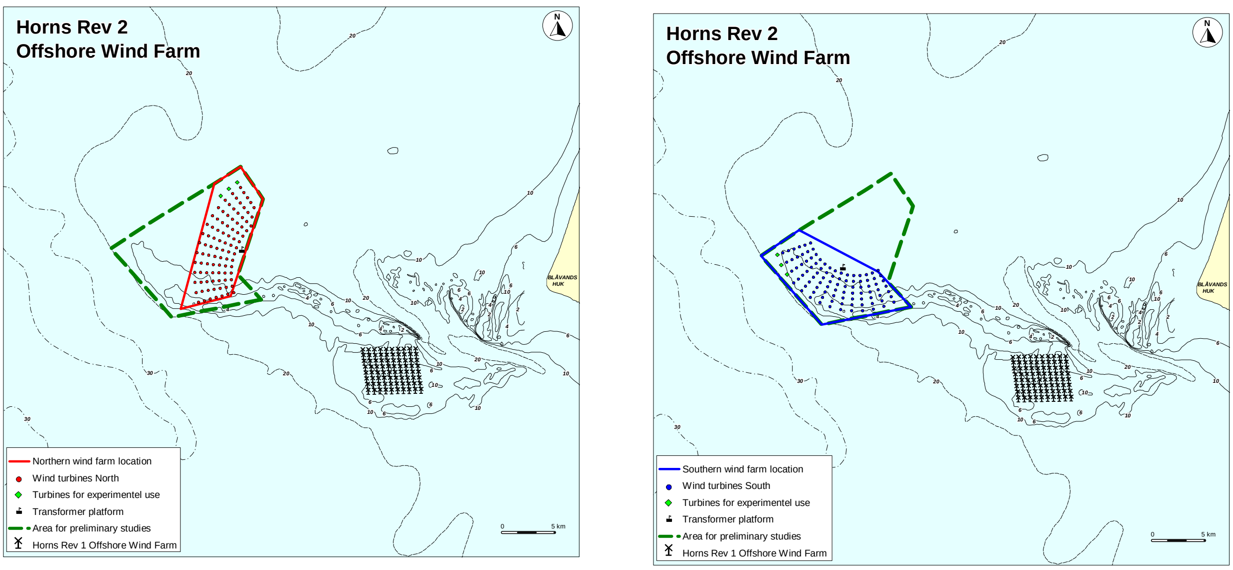

Figure 3.2. The proposed turbine positions at the northern site (a) and the southern site (b), the cable connecting the turbines and the transformer platform. Horns Rev 2 Offshore Wind Farm.

3.2.1 Foundation

The foundations of the turbines will either be monopiles or gravitation foundations. For both types, a scour protection is necessary to minimize erosion due to strong currents at the site. The foundations including protection will occupy an area less than 0..3% of the entire wind farm area.

3.2.1.1 Gravitation principle

The gravitation foundation consists of a flat base to support the basis of the turbine tower. The size of the base is determined by the size of the turbine with the weight of the basal disc being typically >1000 tones. The gravitation foundation is made of concrete or a steel case filed with heavy weight material such as boulders and rocks. This type of foundation is typically used at water depths in the range of 4-10 metres.

The establishment of a gravitation foundation requires preparation of the seabed. This preparation includes removal of the top layer of sediment and construction of a horizontal layer of gravel. Additionally, the gravitation foundation requires scour protection to prevent wave erosion.

3.2.1.2 The monopile principle

The foundations of the existing wind turbines at Horns Rev 1 Offshore Wind Farm are so-called monopile foundations. The monopile foundation is a steel pile driven into the seabed. The pile is normally driven 10–20 m into the seafloor and has a diameter in the range of 4-7 metres. The pile diameter and the depth of penetration are determined by the size of the turbine and the sediment characteristics. Contrary to the gravitation foundation, no preparation of the seafloor is needed.

On the seabed, establishment of scour protection might be necessary around the foundation to minimise erosion due to strong currents at the site.

3.2.2 The scour protection

The scour protection has a diameter of approximately 25-35 m in total, varying between sites and depending on the type of wind turbine chosen. The scour protection is approximately 1-2 m in height above the original seabed and consists of a protective stone mattress of large stones with a subjacent layer of smaller stones.

3.2.3 Subsea cables

The wind turbines will be interconnected by 36 kV cables sluiced down to a depth of one metre into the seabed. The cables will connect the turbines to a transformer platform with each string consisting of up to 14 turbines. From the transformer station, the power is transmitted via a subsea 150 kV cable to shore. Assessment of impact attributable to this cable is not included in this EIA.

The power cables are expected to be tri-phased, PEX-composite cables carrying 50 Hz alternating current. The cables have a steel armament and contain optical fibres for communication.

3.2.3.1 Electromagnetic fields

An electric current passing through a cable creates an electromagnetic field around the cable. The strength of the field is proportional to the size of the electric current.

Magnetic fields are measured in microtesla (µT). One µT = 10 mG (milligauss) = 0.8 A/m. The Earth's magnetic field is about 50 µT (www.electricity.org.uk). The maximum intensity of a magnetic field immediately below an 11 kV overhead power line at ground level is approximately 7 µT (www.electricity.org.uk).

From German wind farms, magnetic fields have been measured around the power cable connecting the wind farm with the mainland. The magnetic field around a tri-phased composite power cable covered by a steel armament was less than 10 µT (microtesla). The magnetic field is reduced to less than 3 µT one metre from the power cable. The natural magnetic field in the ground in Germany is approximately 45 µT. (ABB Power Technologies, 2003).

Eltra (2000) has calculated the size of the magnetic field from the power cable connecting the wind farm at Nysted to the mainland when the wind farm is at maximum production. The magnetic field is approximately 5 µT on the sea bottom one metre above the power cable when the wind farm produces up to 600 ampere (Eltra, 2000). The corresponding induced electrical field generated is greater than 1000 µV/m at a distance of 4 metres from the cable. Additionally, the electrical field extends approximately 100 m before dissipating.

4 Methods

4.1 Assessment methodology

The main effects from the establishment of Horns Rev 2 Offshore Wind Farm on the benthic communities are identified and assessed according to certain criteria shown in Table 1.

The impact significance on marine benthos ecology has been evaluated by ranking the status and level of importance of marine benthos target species and communities or issues and the magnitude of any potential impacts.

Magnitude is determined on the basis of species vulnerability, spatial and temporal incidence of impacts and the ability of a species or community to recover.

In determining the significance of an impact, 'magnitude' is assessed against 'importance' to provide a range of significance from 'negligible' to 'major' as shown in Table 2.

Table 1. Criteria for the assessment of impacts (after DONG, 2006).

Criteria	Factor	Note
Importance of the issue	International interests National interest Regional interest Local areas and areas immediately outside the condition Only to the local area Negligible to no importance	In physical and biological environment local area is defined as wind farm area
Magnitude of the impact or change	Major Moderate Minor Negligible or no change	The levels of magnitude may apply to both beneficial/positive and adverse/negative impacts
Persistence	Permanent –for the lifetime of the project or longer Temporary – long term – more than 5 years Temporary –medium-term- 1-5 years Temporary –short term- less than 1 year	
Likelihood of occurring	High (>75%) Medium (25-75%) Low (<25%)	
Other	Direct/indirect impact – caused directly by the activity or indirectly by affecting other issues as an effect of the direct impact; Cumulative –combined impacts of more than one source of impact	

Table 2. Ranking of significance of environmental impacts (after DONG, 2006).

Significance	*Description*
Major impact	*Impacts of sufficient importance to call for serious consideration of change to the project*
Moderate impact	*Impacts of sufficient importance to call for consideration of mitigating measures*
Minor impact	*Impacts that are unlikely to be sufficiently important to call for mitigation measures*
Negligible – No impact	*Impacts that are assessed to be of such low significance that are not considered relevant to the decision making process*

Residual impacts will be presented using the outlined criteria in table format shown in Table 3.

Table 3. Residual impact assessment table after DONG, 2006.

Issue	Importance	Magnitude	Persistence	Likelihood	Other	Significance
Xxx	Local	Minor	Temporary	High		Minor

4.2 Screening survey

A screening survey, including benthic vegetation, was conducted in January 2006. Samples were collected from 24 stations in the designated two wind farm areas (Figure 4.1), Appendix 1.

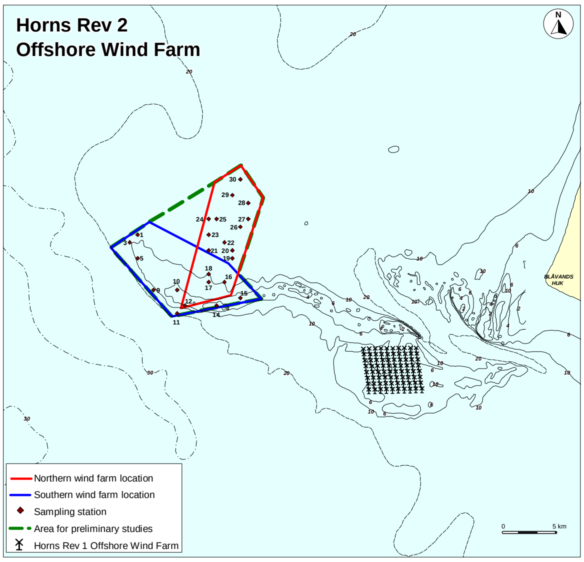

Figure 4.1. Location of sampling sites.

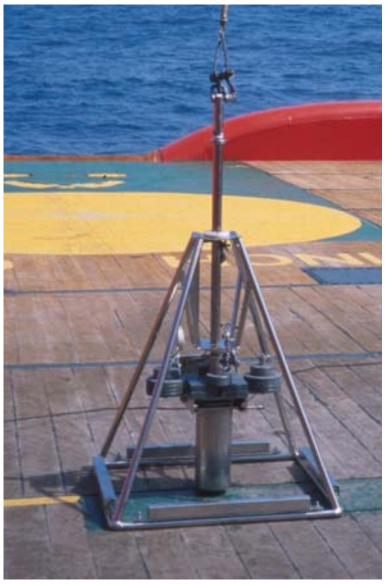

Photo 1. HAPS core sampler

At each station, two quantitative HAPS-samples with a surface area of 0.0123 m^2 were taken by SCUBA divers using polycarbonate tube samplers or by a HAPS core sampler, Photo 1, operated from the sea surface. The sediment core sample depths were approximately 15 cm. One sample was collected for analysing infauna and one sample was collected for analysis of sediment characteristics.

The SCUBA divers made notes on seabed characteristics and observations of epibenthic species.

Samples for identification of species composition, abundance and biomass were carefully sieved through a 1.0 mm laboratory test sieve. The residual was preserved in 96% ethanol, which is equivalent to approximately 80% ethanol when taking the water content of the sample into consideration.

4.2.1 Sample handling

4.2.1.1 Sediment

Sediment was characterised by analyses for grain size distribution, dry matter content and the amount of organic material measured by combustion loss. Dry matter content was measured as a percentage of the wet weight. The combustion loss was measured as a percentage of the dry weight. The samples were treated according to DS 405.11 and DS 204. The sediment was washed in distilled water to remove any remaining salts and dried at 105°C until constant weight was obtained. The sediment was pre-treated with hydrogen peroxide to remove organic material.

Grain size distribution was determined using a combination of sieve analysis and sedigraph technique. Sieve analysis was used for the sand fraction, i.e. all the material retained by a 63 µ sieve, according to a modified standard DS 405.9 using a total of 15 sieves.

A sedigraph 5100 was used for analysis of the silt/clay fraction, i.e. all the material passing through a 63 µ sieve. The sediment was pre-treated with a 0.005 molar solution of sodium pyro phosphate and treated with an ultrasound vibrator for 5 minutes.

Cumulative percentage curves of the sieve and the sedigraph analysis data were prepared with their characteristics described by means of median particle diameter and measured as the point at which the 50% abscissa intersects the cumulative percentage curve.

On the basis of sediment statistics, a sorting index was calculated. Sediments with a sorting index less than 0.5 were characterised as well-sorted. A sorting index of 0.5–1 characterises sediments as medium-sorted, while a sorting index of >1 characterises sediments as poorly sorted (modified after Folk & Ward [GEUS, 2002]).

Data are presented in the data report (Bech, 2006).

4.2.1.2 Benthos

In the laboratory, samples for identification of species composition, abundance and biomass were carefully sieved through a 0.5 mm test sieve.

The fauna samples were sorted under a microscope and the animals were identified to the lowest possible taxon. The number of individuals and the ethanol wet weight of each taxon were determined. Abundance (ind. m^{-2}) and biomass (g wet weight [ww] m^{-2}/g; dry weight [dw] m^{-2}) were calculated for the total fauna.

The shell length of the mussels, i.e. the longest distance between anterior end and posterior end, was measured by means of electronic slide gauge.

4.2.2 Data analyses

Infauna datasets were analysed on the basis of the combined data of sediment characteristics and species composition in terms of abundance and biomass.

Data has been compared to previous campaigns in adjacent areas including Horns Rev 1 Offshore Wind Farm area. Previous campaign data available for analysis are presented in Table 4.1. Survey areas are presented in Figures 4.2-4.3.

Table 4.1. Campaign data available for comparative community analysis.

Horns Rev Offshore Wind Farm I		Wind farm area		Reference area	
Campaign	**Year**	**Spring**	**Autumn**	**Spring**	**Autumn**
EIA screening	1999	x		x	
Baseline	2001	x	x		
Monitoring	2003		x		x
Monitoring	2004		x		x
Monitoring/extended survey area	2005	x		x	

a) b)

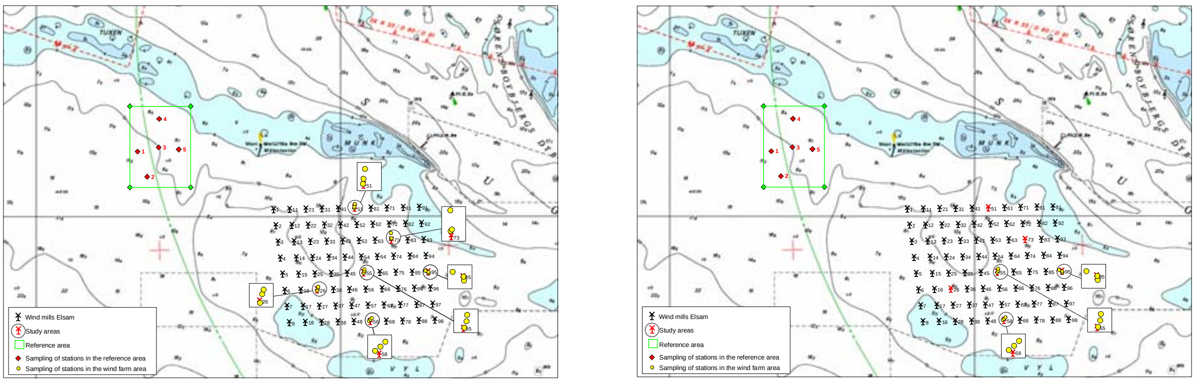

Figure 4.2. Map of locations sampled during the baseline surveys in 2001. a) June 2001, b) September 2001.

a) b)

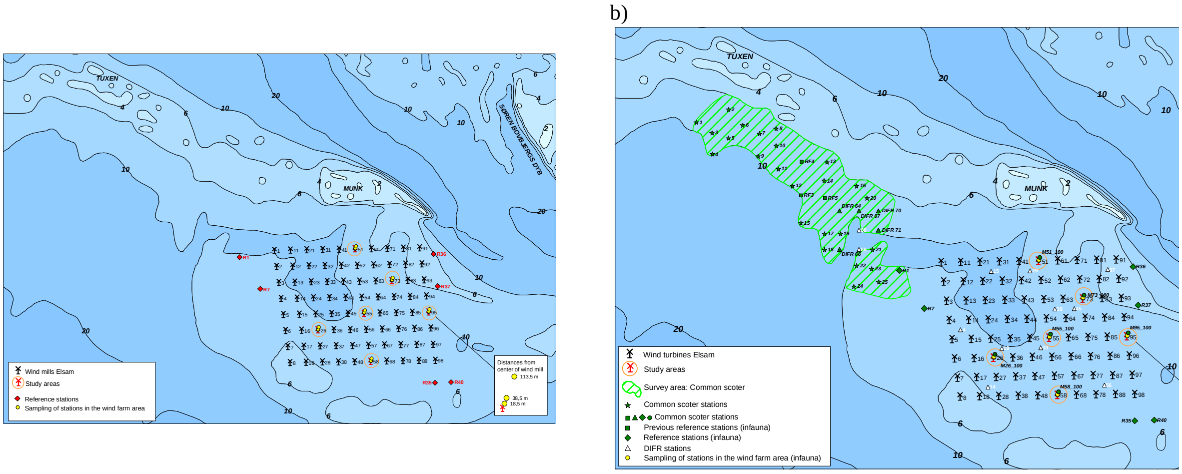

Figure 4.3. Map of locations sampled in September 2003-2004 (a) and in spring 2005 (b).

4.2.2.1 Sediment characteristics

The sediment characteristics were investigated geo-statistically before interpolating the sampled data into coverage showing different aspects of grain size:

1. Proportion of silt and clay (< 0.063 mm)
2. Proportion of fine sand (0.063 – 0.2 mm)
3. Proportion of coarse sand (0.6-2 mm)
4. Proportion of gravel (> 2 mm)
5. Median grain size (mm).

Experimental variograms were fitted to the empirical data using spherical models with a nugget-scale ratio typically below 1:5 and length parameters varying between 2500 m and 3500 m. Interpolations were made using Surfer Version 8 by applying the experimental variograms with the radius of the search ellipse set by the length parameter. Due to the relatively large constraints on the extrapolation distance imposed by the length parameters, the interpolated sediment data only covered parts of the Horns Rev area. As a result, the coverage of all other habitat variables had to be masked by the missing-value areas.

The surface current velocities were averaged for the month overlapping each survey and the average long-shore and cross-shore current speeds were exported to GIS.

Correlations between characteristics were quantified using Pearson's correlation coefficient, also called *linear* or *product-moment* correlation. For further explanation, see http://www.statsoft.com/textbook/stbasic.html#Correlations. Sediment parameters are used in analysis of species preferences to sediment characteristics.

4.2.2.2 Species composition

Differences between the faunal communities at the individual sampling sites (Horns Rev 2 Offshore Wind Farm, Horns Rev 1 Offshore Wind Farm and reference areas) were analysed on the basis of the combined species composition data in terms of abundance and biomass.

Within each subset, differences in the species compositions between areas and between survey campaigns or between the sampling sites were quantified using the Bray-Curtis dissimilarity index based on root-root transformed data. Root-root transformation reduces the importance of dominating species, which gives a better reflection of the species composition based on presence/absence compared with non-transformed data.

The Bray-Curtis index is calculated as:

$$BC = \frac{\sum_k |x_{ik} - x_{jk}|}{\sum_k x_{ik} + \sum_k x_{jk}}$$

where i and j are sub-samples and k is the number of species in the sub-samples. Similarity was expressed as 1 - BC. At maximum similarity, BC = 0 and at maximum dissimilarity, BC = 1.

The BC values are used for presenting data in 2-dimensional plots using a non-metric Multidimensional Scaling (MDS) ordination. For further description of the MDS technique, see http://www.statsoft.com/textbook/stmulsca.html. In MDS plots, usually a *stress* factor (0-0.5) is displayed as the distortion between the similarity rankings and the corresponding distance rankings in the ordination plot. Low stress 0.1-0.2 corresponds to a good agreement between the calculated similarity rankings and the ordination shown.

A formal test for differences between areas and campaigns was made for each subset using a non-parametric permutation procedure applied to the similarity matrix underlying the ordination. To evaluate the relative importance of the different species, the average contribution to the overall similarity within groups and the average contribution to the overall dissimilarity between groups were calculated for each species.

To link sediment characteristics to species composition, two different approaches were used. First, a dissimilarity matrix was calculated between samples based on all sediment characteristics using the Euclidean distance as the dissimilarity measure. This matrix was tested for agreement with the dissimilarity matrix based on species composition using the weighted Spearman rank correlation, see:
http://www.statsoft.com/textbook/stnonpar.html#correlations for further information.

Second, the same test for agreement was performed on combinations of sediment characteristics at steadily increasing levels of complexity to find the combination with the highest rank correlation.

The software package PRIMER 6 was used for statistical analysis (Clarke & Warwick, 1994). A formal test for differences between sites was made for each subset using a non-parametric permutation procedure applied to the similarity matrix underlying the ordination. To evaluate the relative importance of the different species, the average contribution to the overall similarity within groups and the average contribution to the overall dissimilarity between groups were calculated for each species.

4.3 Assessment of cumulative impacts

The cumulative impacts assessment in connection with the establishment of Horns Rev 2 Offshore Wind Farm are, by definition, impacts that may result from the combined or incremental effects of past, present or future developments in the Horns Rev area on the benthic communities.

Past, present and future developments were identified from existing published information and potential impacts to benthic communities were described and evaluated. Special focus was made to the existing offshore wind farm (Horns Rev 1 Offshore Wind Farm) and to existing marine sand and aggregate extraction sites.

4.4 Designation of reference sites and areas

Possible reference sites might be appointed according to similarities in community structure with the appointed wind farm area.

5 Existing benthic communities

5.1 Sediment characteristics

In general, the seabed in the planned wind farm sites consist of almost pure sand with no or very low organic content (<1%). High variation was found in the particle fractions characterizing the seabed as medium to coarse sanded with a mean median particle size of approximately 498 µm, Figure 5.1. Closely corresponding seabed sediment characteristics were found in other areas at Horns Rev including the existing wind farm (Leonhard & Pedersen, 2006).

Bedforms of small sand ripples and mega ripples are seen all over the area caused by the wave impact on the seabed, Appendix 1. Tidal currents create dunes and ripples, showing evidence of sand transport directions both to the north and to the south.

No correlation between median grain size and depth was found, Figure 5.1, except at some stations situated in the deepest area toward slopes facing greater depths where coarser sand was found. Similar results were found in previous studies at Horns Rev (Leonhard & Pedersen, 2006). This was especially pronounced at the southern part of the reef, which might be a result of strong currents from the south facing the sand barrier being forced towards NW along the border of the sand accumulation, Figures 5.2 and 5.3.

Although great variations exist, the sorting index shows a statistically significant relationship ($P<0.01$) with depth, Figure 5.1. The sediment is medium to poorly sorted in deeper waters, whereas in shallower areas, the sediment is generally better sorted although highly variable over even quite short distances. This might be a result of highly variable current regimes and more exposure to waves on top of the reef.

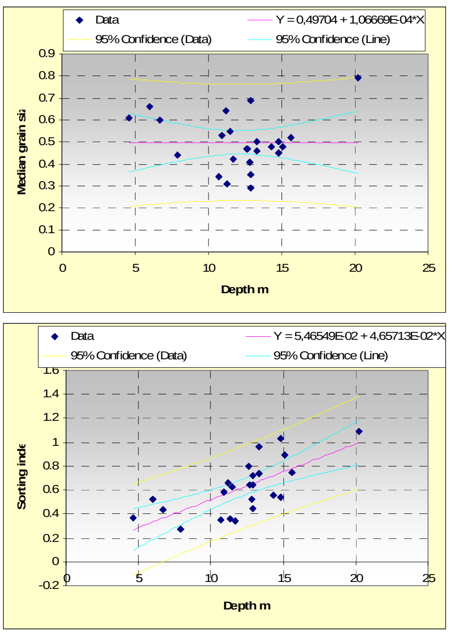

Figure 5.1. Sediment characteristics (a) grain size (b) sorting index and depth regimes at the sample locations at Horns Rev 2006.

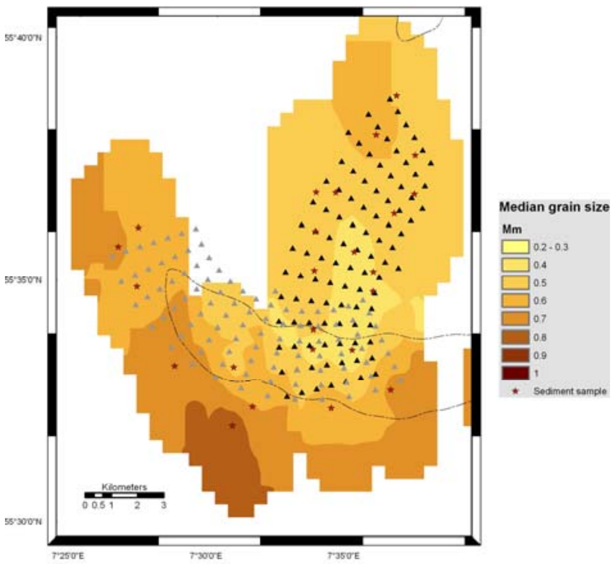

Figure 5.2. Modelled grain size distribution patterns at the planned sites for Horns Rev 2 Offshore Wind Farm.

North of the reef, the seabed is sandier and a more uniform grain size distribution is found. This might reflect a more stable hydrodynamic environment that is different from the more moderate southern current regimes.

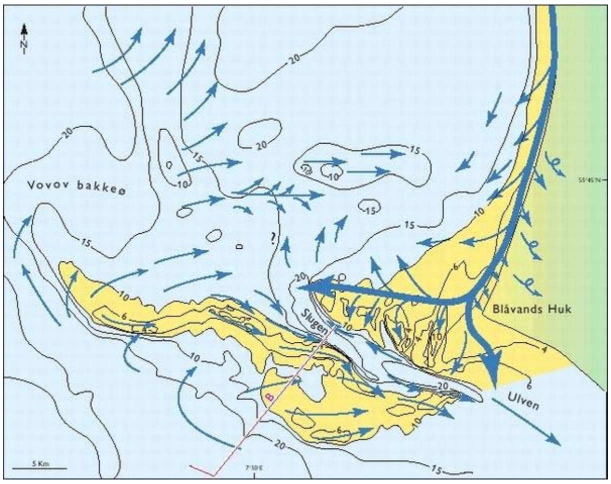

Figure 5.3. Possible sediment fluxes in the Horns Rev area. Accumulation takes place both on the plane seabed as well as on the slopes of spits and banks. (After Larsen, 2003).

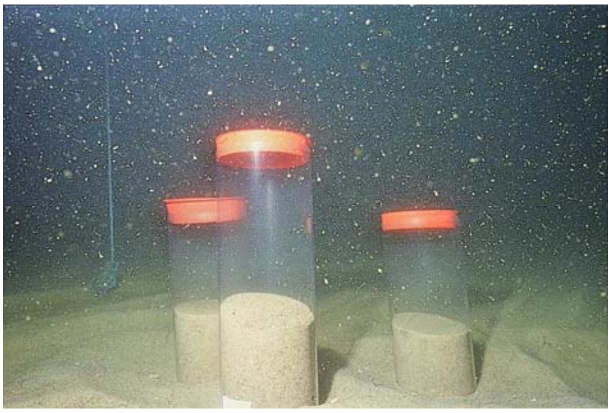

Photo 2. Sediment core samples. Horns Rev 2001© Elsam Engineering/Bio/consult.

5.2 Benthic communities

An extensive amount of general literature exists on benthos surveys covering the North Sea (Kröncke & Bergfeld, 2001). The data sets from the DANA cruises 1932–1955 (Ursin, 1960; Kirkegaard, 1969; Petersen 1977) and the results of Birkett's (Birkett, 1953) survey are valuable historical baselines of the community structure of North Sea benthos but generally very little data is available from more regional shallow sandbank areas such as Horns Rev. From 1999 to 2005, comprehensible datasets on the benthos communities at Horns Rev are provided through the PSO programmes in connection with the monitoring of impacts from the establishment of Horns Rev 1 Offshore Wind Farm (Leonhard & Pedersen, 2006).

5.2.1 Population ecology and distribution at Horns Rev

The native fauna composition at Horns Rev is like the fauna found on other sublittoral sandbanks in the North Sea. The fauna at Horns Rev is very variable, heterogeneous and difficult to compare with other sandbanks and adjoining deeper areas (Vanosmael et al. 1982; Salzwedel et al. 1985; Degraer et al. 1999) and shows high variability in spatial and temporal distribution patterns. The benthos community at Horns Rev has a great similarity with the benthos communities described in other shallow coastal waters of the North Sea where the sediment consists of pure medium–coarse sand. The community in such areas can be described as the *Ophelia borealis* community (Dewarumez et al. 1992) or, more commonly accepted, as the *Goniadella-Spisula* community (Kingston & Rachor 1982; Salzwedel at al. 1985).

In the *Goniadella-Spisula* community, some characteristic species are found including bristle worms (*Gooniadella bobretzkii* and *Ophelia borealis*) and the thick trough shell (*Spisula solida*). The two last mentioned species are important for the biomass in the community mainly due to their relatively large size.

The above-mentioned species together with some other species, bristle worms (*Pisione remota* and *Orbinia sertulata*) and the small mussel (*Goodallia triangularis*), were found relatively uniform in abundance and biomass dominance relations. These species were used as indicator organisms for environmental changes in the established wind farm area at Horns Rev 1 Offshore Wind Farm (Leonhard & Pedersen, 2006).

As at other sandbanks, Horns Rev has similar turbulent sea bottom conditions and low organic content in the sediment. The benthic community at Horns Rev is generally characterised by lower diversity, abundance and biomass compared to adjacent areas where the bottom conditions are less unstable and the sediment has a higher content of fine sand and organic material (Leonhard, 2000). In comparison, the number of mussels that are important food items for diving ducks, such as the common scoter (*Melanitta nigra*), are far lower in the Horns Rev area than in nearby areas of the North Sea where higher abundances of *Angulus tenuis*, *Fabulina fabula* and *Spisula subtruncata* have been found (Degraer et. al., 1999). The American razor shell (*Ensis americanus*), an alien species introduced in Danish waters in the mid 1980's (Jensen & Knudsen, 2005) and an important food item for the common scoter, was found with a scattered distribution pattern in the reef area in 2005, Figure 5.4 (Leonhard & Pedersen, 2005).

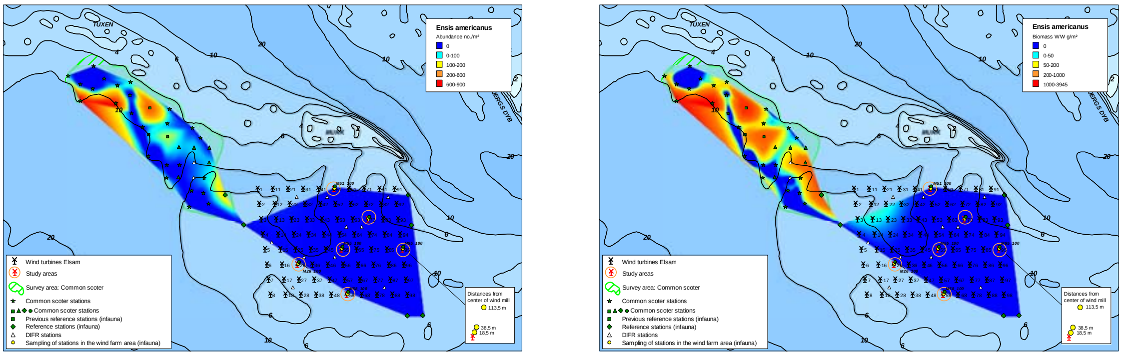

Figure 5.4. Abundance (left) and biomass (right) of the American razor shell (Ensis americanus) *in the Horns Rev area in spring 2005.*

On the more stable and plane seabed outside the reef, a *Fabulina fabula* or *Venus* community can normally be found. This community is characterised by the *Venus* clam (*Chamelea gallina*), the sea potato (*Echinocardium cordatum*), the bristle worm (*Magelona mirabilis*) and the brittle star (*Ophiura texturata*). This community is found at sites monitored by the Danish counties under the NOVANA programme (Leonhard, 2000).

The bivalves (*Spisula solida*, *Spisula subtruncata* and *Angulus tenuis*) are included in the Red List of Wadden Sea species. In areas outside of Denmark, they are either sensitive or vulnerable (Petersen et al. 1996). There is no mention of the status in Denmark for these species.

Mobile epifauna can often be found on the seabed in the Horns Rev area. The hermit crab (*Pagurus bernhardus*), the common shore crab (*Carcinus maenas*), swimming crabs (*Liocarcinus pusillus*, *L. holsatus* and *L. depurator*), the common whelk (*Buccinum undatum*), brown shrimp (*Crangon crangon*), the common starfish (*Asterias rubens*), the

Alder's necklace shell (*Polinices polianus*) and occasionally the edible crab (*Cancer pagurus*) are registered in the area (Leonhard & Pedersen, 2006). The brown shrimp is an important prey species for both sea birds and fish (Hoffmann et al., 2000).

Photo 3. Hermit crab Pagurus bernhardus. *(© Elsam Engineering/Bio/consult).*

Photo 4. Brown shrimp Crangon crangon. *(© Elsam Engineering/Bio/consult).*

5.2.2 Species distribution pattern in the wind farm area

No vegetation is found within the planned wind farm area.

A rather low diversity in the benthic infauna community is found within the planned wind farm area. A total of 34 species besides the chordate *Branciostoma lanceolatus* are found, Appendix 2. The most abundant species are shown in Table 5.1.

Table 5.1. Abundance and biomass of dominant and character species in the wind farm area compared to the abundance and biomass in the reef area in 2005.

Dominants	Horns Rev 2						Extended reference area spring 2005					
	Abundance		Biomass				Abundance		Biomass			
Species	no./m²	Kol Sum %	gWW/m²	Kol Sum %	gDW/m²	Kol Sum %	no./m²	Kol Sum %	gWW/m²	Kol Sum %	gDW/m²	Kol Sum %
Aonides paucibranchiata	163	13.3	0.618	0.4	0.279	0.6	29	4	0.046	0	0.008	0
Goodallia triangularis	149	12.2	0.348	0.2	0.252	0.5	191	26.4	0.457	0.1	0.343	0.1
Pisione remota	136	11.0	0.071	0.0	0.012	0.0	165	22.8	0.142	0	0.008	0
Ensis americanus	115	9.4	89.333	51.4	29.642	63.1	105	14.5	565.29	97.8	422.498	99.1
Goniadella bobretzkii	108	8.8	0.282	0.2	0.116	0.2	50	6.9	0.039	0	0.004	0
Travisia forbesii	102	8.3	7.076	4.1	2.778	5.9	10	1.3	0.533	0.1	0.256	0.1
Total		63.0		56.2		70.4		75.9		98.0		99.3

High spatial variations are found in the total abundance and biomass distribution, which mostly reflected the differences in the distributional pattern of the most abundant species and the larger species, Figures 5.5 and 5.6.

In general, the dominant or character species contribute to the majority of the total abundance and biomass at each sample site. Exceptions from this general pattern can be found at sites low in abundance where other species can be found more numerous or when single larger specimens are found at the sites.

More subgroups of benthic communities can be found within the wind farm area, which is more or less attributable to the differences in seabed sediment character, Figure 5.7. In general, differences in the benthic communities at slopes north and south of the reef are found attributable to differences in grain size where at the south slopes the seabed is of a more coarse nature, Figure 5.8. At the reef, the seabed is also of a more coarse nature differentiating the benthic community there from the benthic community in the northern area where the seabed generally consists of finer sand. The benthic community in very coarse sanded areas (station 11) dominated by the bristle worm (*Protodorvillea kefersteini*) is not comparable with the communities found in other sub areas. Site 10 had very low abundance.

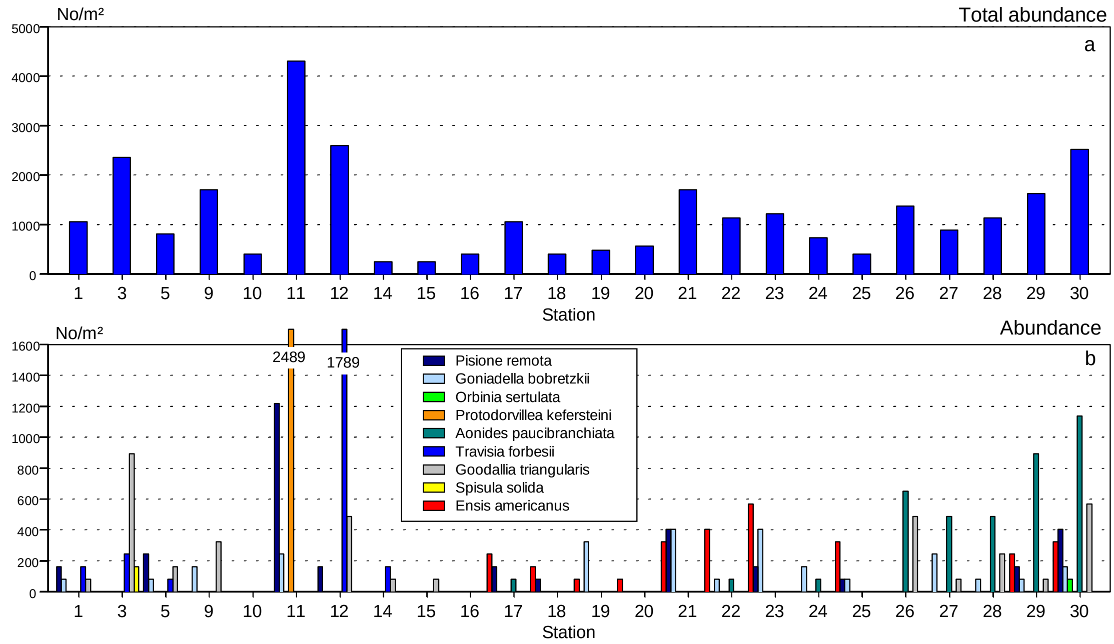

Figure 5.5. Total abundance (a) and abundance of dominant or character species (b) at each sample site in the planned wind farm sites. Refer to Figure 4.1.

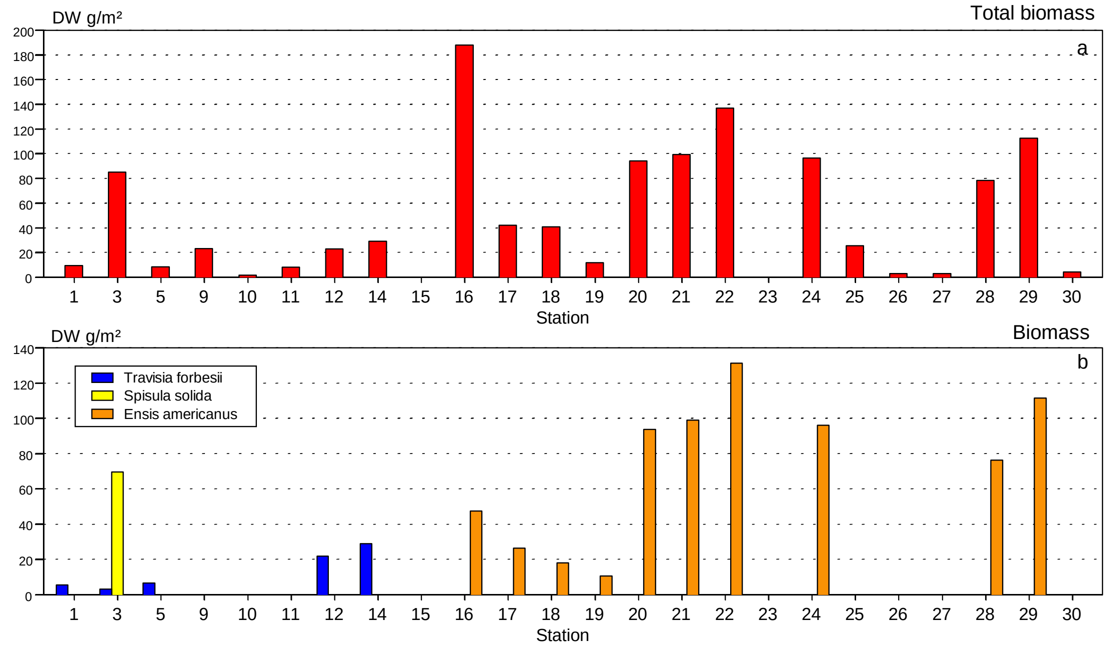

Figure 5.6. Total biomass (a) and biomass of dominant or character species (b) at each sample site in the planned wind farm sites. Refer to Figure 4.1.

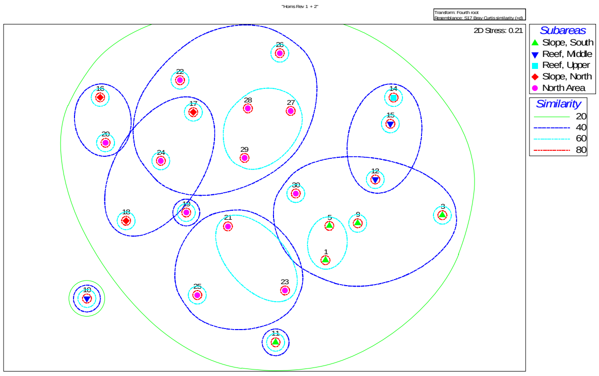

Figure 5.7. MDS plot for benthic communities in predefined sub areas.

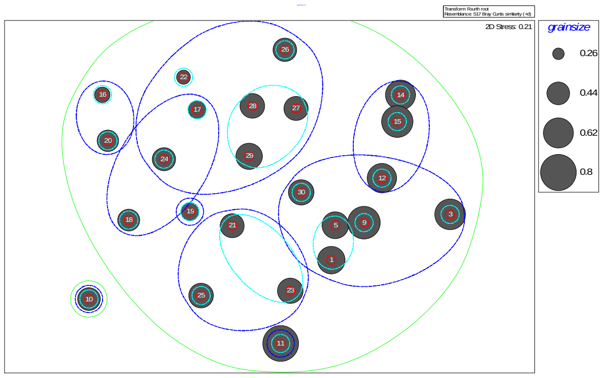

Figure 5.8. MDS plot of grain size distribution in predefined sub areas

Each sub area is more or less characterized by abundance distributional patterns of the dominant or character species, Figures 5.9-5.14 and Table 5.2. But even within sub areas, differences in benthic community structures can be found, Figure 5.7.

Table 5.2. Dominant or character species distribution pattern in different sub areas.

Mean abundance No./m²	**Sub area**				
Species	**Slope south**	**Middel reef**	**Upper reef**	**Slope north**	**North area**
Aonides paucibranchiata	0	0	0	27	318
Goodallia triangularis	293	190	81	0	122
Pisione remota	325	54	0	81	102
Ensis americanus	0	0	0	163	190
Goniadella bobretzkii	114	0	0	0	169
Travisia forbesii	98	596	163	0	0

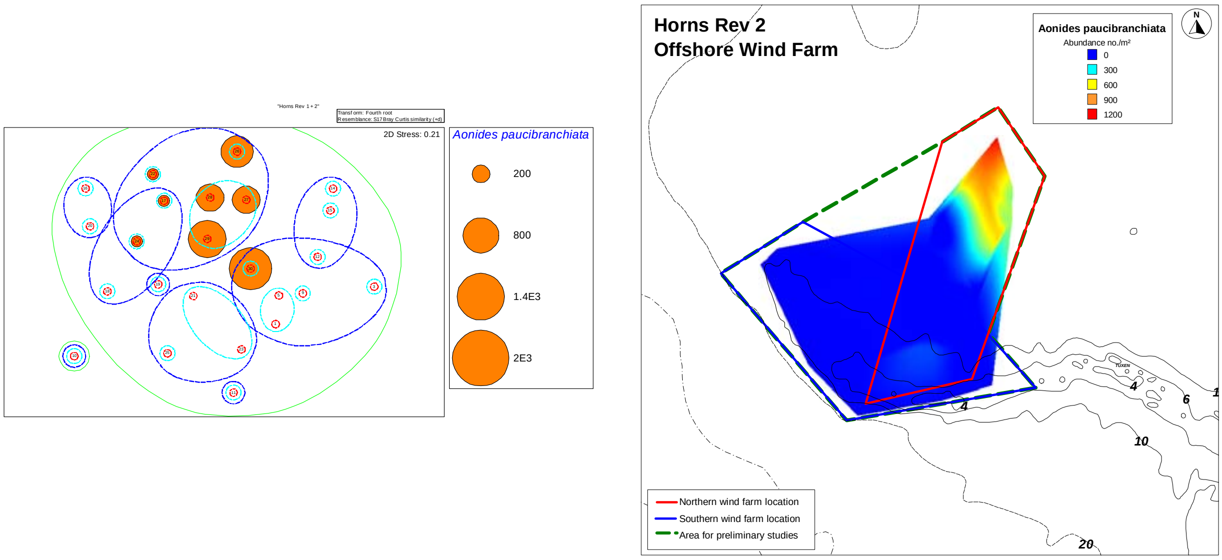

Figure 5.9. *MDS plot and distribution map for* Aonides paucibranchiata.

The bristle worms (*Aonides paucibranchiata* and *Goniadella bobretzkii*) and the American razor shell (*Ensis americanus*) dominate the northern part of the wind farm area. The northern slope areas can also be characterized by a dominance of *Ensis americanus*.

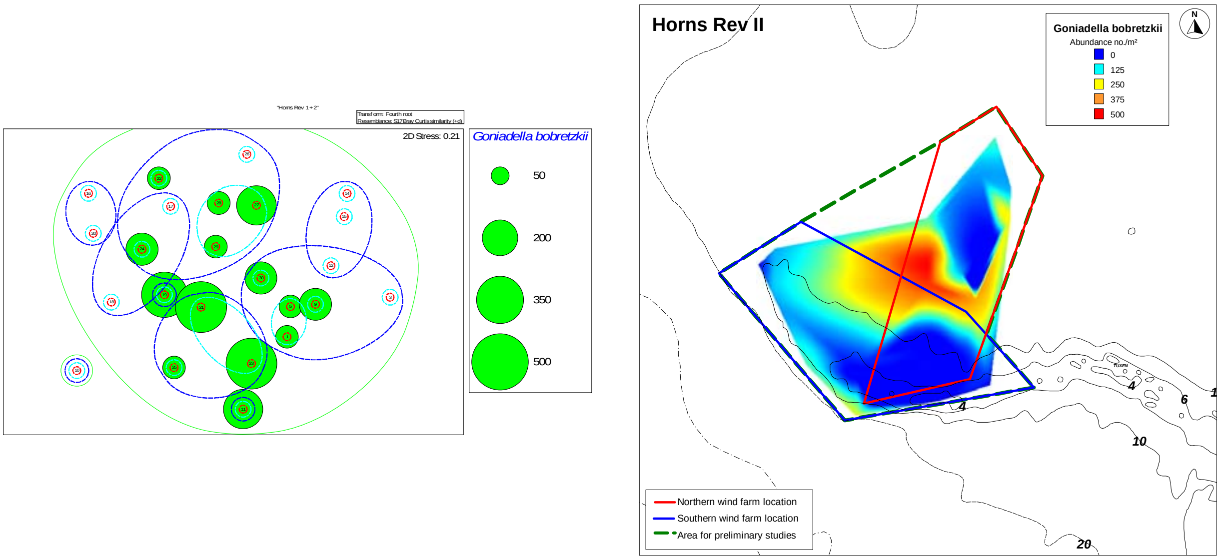

Figure 5.10. MDS plot and distribution map for Goniadella bobretzskii.

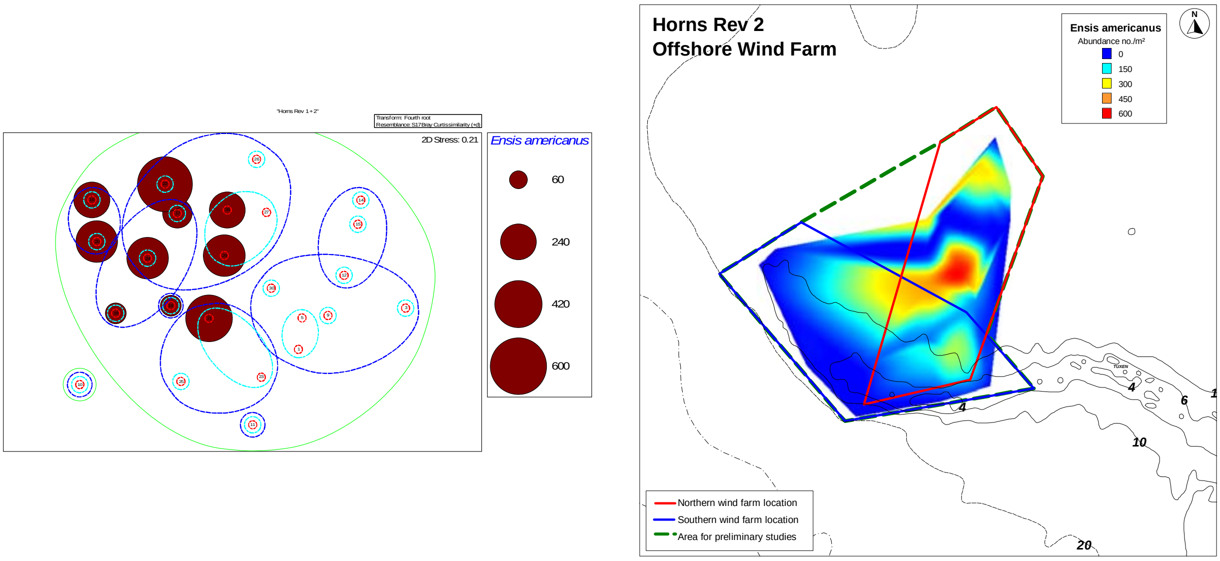

Figure 5.11. MDS plot and distribution map for Ensis americanus.

The upper reef area has low diversity and abundance. This area can be characterized by a dominance of the bristle worm (*Travesia forbesii*) and the presence of the small mussel (*Goodalia triangularis*), which is generally more common in the middle reef area and in the southern slope area. The middle reef area is strongly dominated by *Travesia forbesii*. Other mussels that are found in this include the banded wedge shell (*Donax vittatus*) and *Thracia phaseolina*.

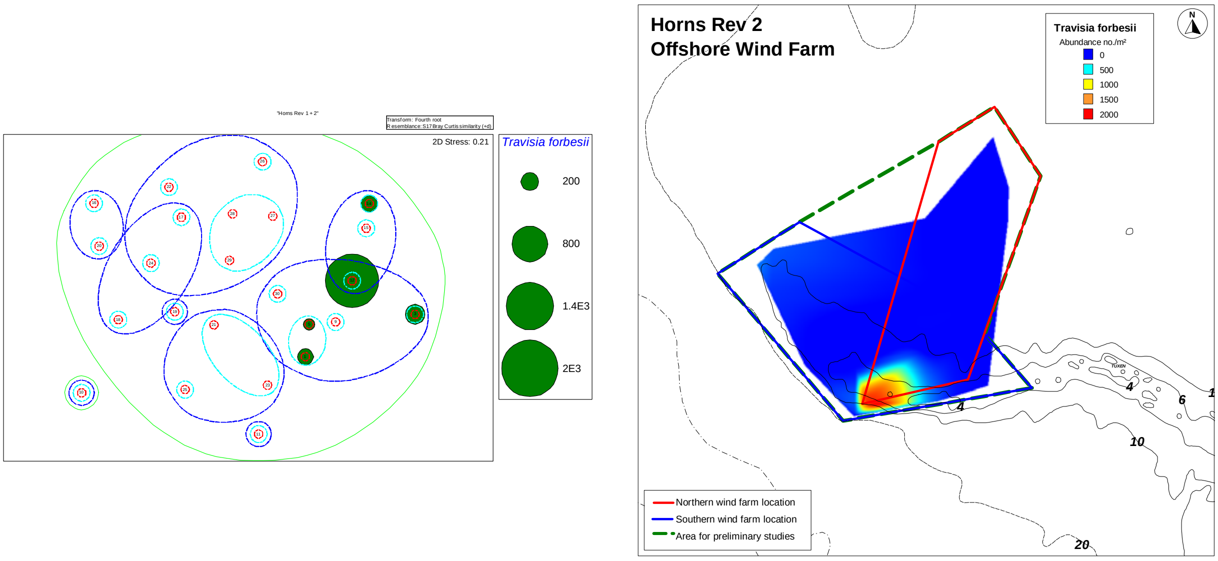

Figure 5.12. MDS plot and distribution map for Travisia forbesii.

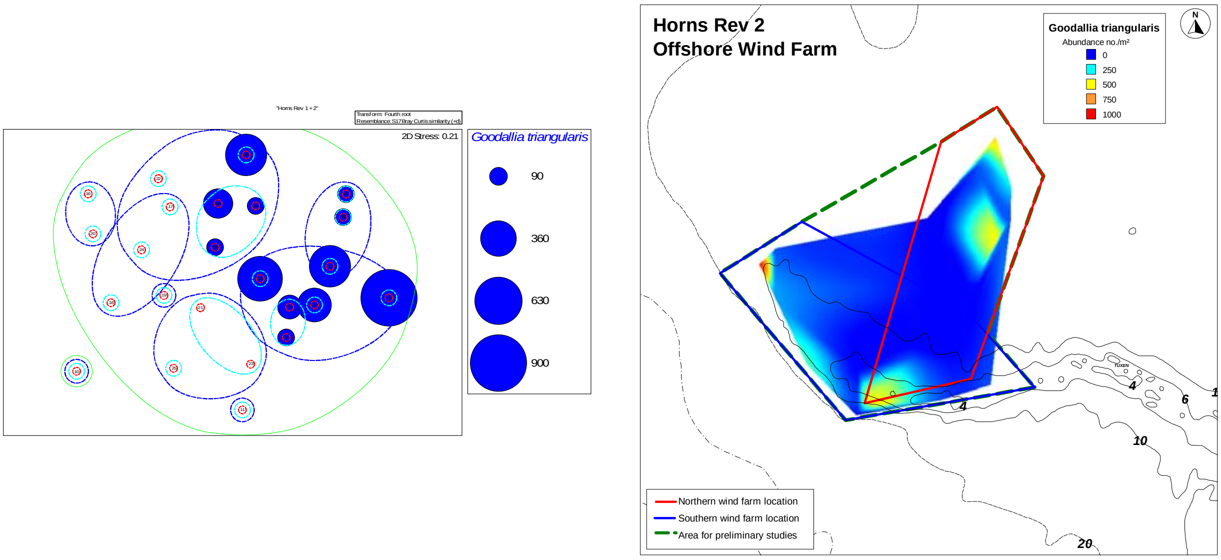

Figure 5.13. MDS plot and distribution map for Goodallia triangularis.

The southern slope area can generally be characterized by a dominance of the small bristle worms (*Pisione remota* and *Goniadella bobretzskii*), although *Goniadella bobretzskii* is more common north of the reef. The thick trough shell (*Spisula solida*) is also found in the southern slope area.

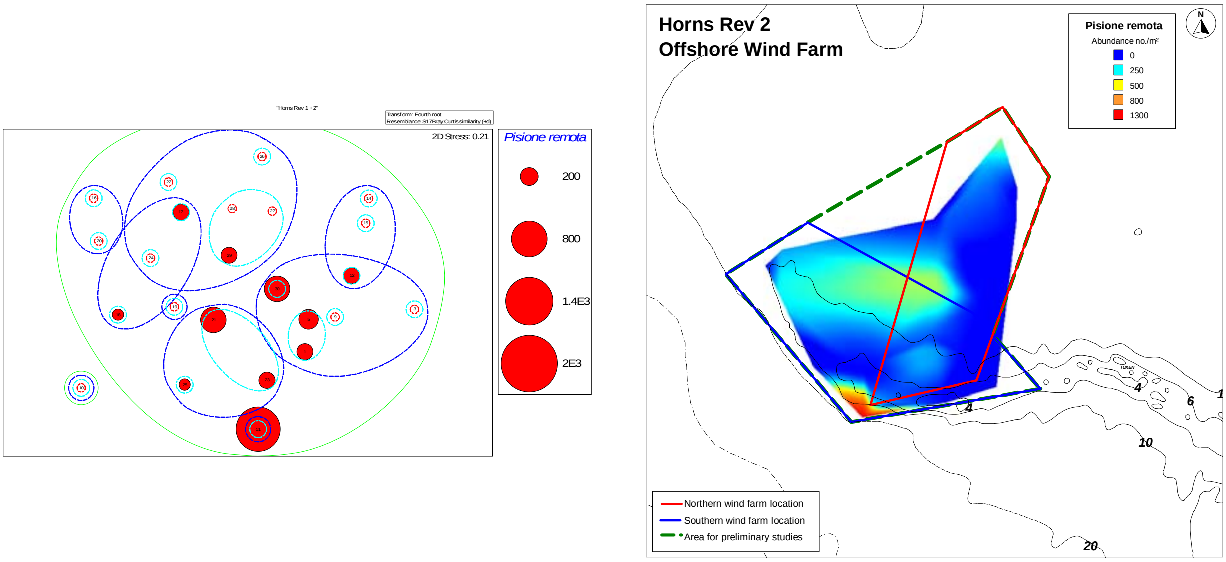

Figure 5.14. MDS plot and distribution map for Pisione remota.

Some similarities exist between the community structure inside the wind farm area and the community structure found at other sites including the existing offshore wind farm area at Horns Rev, Figure 5.15. But no unambiguous tendencies can be found or generalisations be made, which demonstrates the high variability in infaunal community structure in the reef area.

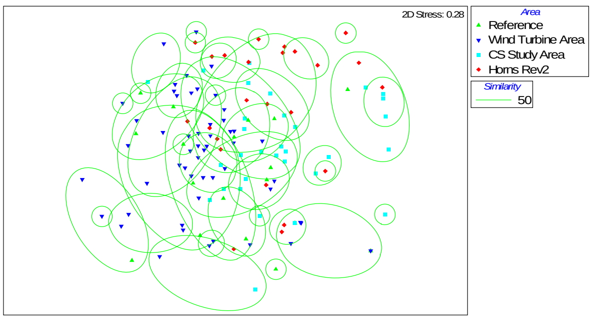

Figure 5.15. MDS plot of all available datasets from Horns Rev showing similarities in community structure between the Horns Rev 2 Offshore Wind Farm sites and other surveyed areas.

The communities in the farm area can more or less be generalised as the *Venus* community in the northern part and the *Goniadella-Spisula* community within the reef itself and in the southern part. Great variability exists in the community with the different dominant species generally showing different affinities to specific sediment parameters, Figure 5.16. Unlike other dominant species, *Ensis americanus* shows a general correlation towards organic content in the sediment. *Pisione remota*, *Travisia forbesii* and *Goodallia triangularis* show a correlation towards a coarser sediment nature.

In general, the *Venus* community is associated to more stable compacted fine sand habitats, whereas the *Goniadella-Spisula* community is associated to coarser and loose sands subject to moderately strong water movement. The *Goniadella-Spisula* community is less stable in its species composition than the *Venus* community to which it is closely allied and collectively considered to be the 'Shallow *Venus* Community' (MNCR, 2006). Although adapted to an energetic environment, the communities are rather sensitive to changes in wave and current regimes resulting in communities changing from one to another, Table 5.3.

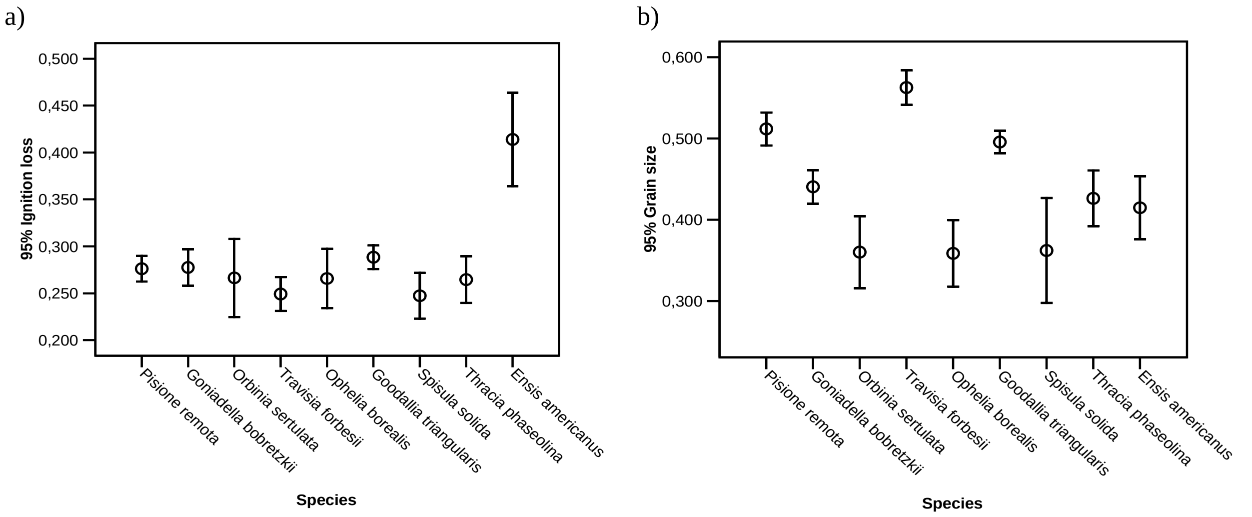

Figure 5.16. Correlation between sediment parameters and distribution of dominant and character species at Horns Rev. (All available data from PSO project included).

Table 5.3. Sensitivity matrix of the Venus *community in compacted fine sand as identical for the* Goniadella-Spisula *community (after Rayment, 2001).*

Biotope sensitivity assessment. MarLin (www.marlin.ac.uk)				
Physical Factors	**Intolerance**	**Recoverability**	**Sensitivity**	**Species Richness**
Substratum Loss	High	High	Moderate	Major Decline
Smothering	Low	Very high	Very Low	No Change
Increase in suspended sediment	Low	Very high	Very Low	No Change
Increase in water flow rate	High	High	Moderate	Decline
Decrease in water flow rate	Intermediate	High	Low	Minor Decline
Increase in turbidity	Low	Very high	Very Low	No Change
Increase in wave exposure	High	High	Moderate	Major Decline
Decrease in wave exposure	Intermediate	High	Low	Minor Decline
Noise	Tolerant	Not Relevant	Tolerant	No Change
Displacement	Intermediate	High	Low	No Change
Chemical Factors				
Heavy metal contamination	High	High	Moderate	Decline
Hydrocarbon contamination	Intermediate	High	Low	No Change
Biological Factors				
Introduction of non-native species	Tolerant	Not Relevant	Tolerant	No Change
Extraction	Intermediate	High	Low	Minor Decline

5.3 Influence of fishing activity

Seabed and benthic communities in the Horns Rev area are influenced by trawling and dredge-fishing activities. Bottom trawling for sandeels and brown shrimp (*Crangon crangon*) and dredging for clams (*Spisula solida*) currently takes place in the area proposed for the wind farm. Besides the reduction in target species populations, repeated and frequent disturbance by fishing gear over an extended period results in alteration of the benthic community. This is characterised by a general reduction in the abundance of long-lived benthic species and an increase in small opportunistic species (Bergman et al., 1996; Kröncke & Bergfeld, 2001; Piersma & Camphuysen, 2001; Chícharo et al., 2002).

A combined effect of direct mortality and indirect mortality due to scavenging after trawling and dredging activities are found on benthic communities. Due to the passage of a beam trawl and due to dredging activities, benthic fauna may be damaged, dislodged, or become available to scavengers. All carnivorous animals that are present in a recently trawled or dredged area can be considered as potential scavengers or predators. These include different species of fish and predatory benthic invertebrates like the common starfish, crabs and common whelk.

Species show specific vulnerability to fishing impact. Mortality varies depending on the type of gear used to fish, sediment type, density, vertical position in the bottom, sex and age of species. Studies have found that the most vulnerable species to trawling activities were those that are physically most fragile (e.g. the sea potato (*Echinocardium cordatum*), which can be found in the Horns Rev area) or live in the uppermost layer of sediment where they were within reach of the trawl (e.g. *Spisula* spp.) (Bergman & Santbrink, 2002). Apparently more robust species were the striped venus clam (*Chamelea galina*) and species that burrow deep into the sediment (e.g. *Ensis* sp.).

No actual studies exist on the impact from trawling or dredging activities on benthic community structure in the Horns Rev area. Other studies shows however, that additional disturbance caused by fishing may have few long-term effects on communities adapted to frequent natural disturbance (Kaiser et al., 1996) like the sandbank and *Venus* communities at Horns Rev.

6 Sources of impacts

The life cycle of an offshore wind farm typically comprises four phases: 1) the pre-construction phase, 2) the construction phase, 3) the operation phase and 4) the decommissioning phase.

Each of these 4 phases are associated with various impacts to the wind farm site and the associated fauna, resulting in a number of effects that will be reviewed and assessed in Section 7.

6.1 Main impacts

The four phases in the life cycle of a wind farm are associated with the following main categories of impacts and effects on marine benthic communities, Table 6.1:

Table 6.1. Overview of the main sources of impacts associated with the different phases or life stages of an offshore wind farm.

Source of impact	**Phase**			
	Pre-construction	Construction	Operation	Decommissioning
Noise and vibrations	X	X	X	X
Suspension and redistribution of sediments	X	X	X	X
Physical disturbance of sea-bed		X		
Loss of seabed area		X	X	
Introduction of hard substrate			X	
Electromagnetic fields			X	

6.1.1 Noise and vibrations

Underwater sound is a composite phenomenon, consisting of a sound pressure level component (SPL) and a frequency component. Sound pressure level in this report is given in dB re: 1μ Pa – 1m, the unit normally used in underwater sound measurements. Sound frequencies are given in Hertz (Hz).

The background noise levels in the sea are produced by different oceanic noise sources both natural and man-made. The natural noise originates from mainly physical and biologic processes. Physically generated noise in the Horns Rev area includes wind, wave, and rain generated noise. The biological noise includes vocalization by marine mammals and communication among individuals of various fish species, e.g. Atlantic cod. Noise generated by the wind is primarily related to wave action and is a product of speed, duration, water depth and proximity to the nearest coast. Wind introduced noise typically lies within the frequency band 0.001 - >30 KHz while wave-generated noise is typically located within the infrasonic spectra from 1 – 20 Hz.

Anthropogenic noise is generated during all four phases. Differences in sound pressure level (dB) and frequencies are likely to exist between the phases with sound produced during the construction and decommission phase expected to be more intense than the sound created during both the pre-construction and the operation phases. However, in terms of duration, all but the operation phase is short.

The main source of noise during the pre-construction phase is likely to be the seismic surveys, but also vessel activity contributes to the overall noise in this phase. The sounds created in the construction phase originate from various sources. The most intense and thus most significant noise is generated during the piling activity of the foundations (Table 6.2). The piling is expected to continue for several months and may exceed all other noise sources during that period.

*Table 6.2. Noise generated construction activities associated with establishment of an offshore wind farm. For comparison, the list contains a number of other common sources of noise at sea. * (Centre for Marine Ecology and Coastal Studies, 2002;)** (Simmons et al., 2004).*

Anthropogenic sound source	**Peak sound level at source (dB re 1µ Pa)**	**Dominant frequency(ies) (Hz)**
5m RIB with an outboard motor*	152	6300
Tug/barge travelling at 18 km/hr*	162	630
Large tanker*	177	100 & 125
Fishing boat**	151	250-1000
Fishing trawler**	158	100
Tug puling empty barge**	166	37
Cargo ship typical used at wind farms**	192	100-1000
Supply ship (*Kigoriak*)*	174	100
Trenching**	178	-
Seismic air gun survey*	210 (Average array) 259 (Average array)	10-1000
Pile driving*	135-145 225-236	50-200 130-150

Most invertebrates can only perceive a sound wave as a physical force. They typically do not have delicate organs or tissues whose acoustic impedance is significantly different from water.

Among invertebrates, only cephalopods (octopus and squid) and decapods (lobster, shrimp, and crab) are known to sense low frequency sound (Offutt, 1970; Budelmann and Young, 1994). Based on Budelmann's measurements, the cephalopod threshold for hearing far-field sound waves is estimated to be 146 dB. The hearing threshold for the American lobster has been determined to be approximately 150 dB in the low frequency range (Offutt, 1970).

7 Assessments of effects

Of the different types of impacts listed above, the possible and expected impacts on benthic communities are described below.

7.1 Phases 1 & 2 – pre-construction and construction

Sources of potential impact to the benthos during the pre-construction and construction phases are described below followed by an assessment of impact to the benthic communities.

Establishment of a marine wind farm is associated with a number of pre-construction and construction activities primarily including: vessel traffic, seismic surveys, pile driving, preparation of the seabed, sediment removal, sediment deposition and cable laying. These activities result in different impacts on the biological communities in the area outlined in Figure 7.1.

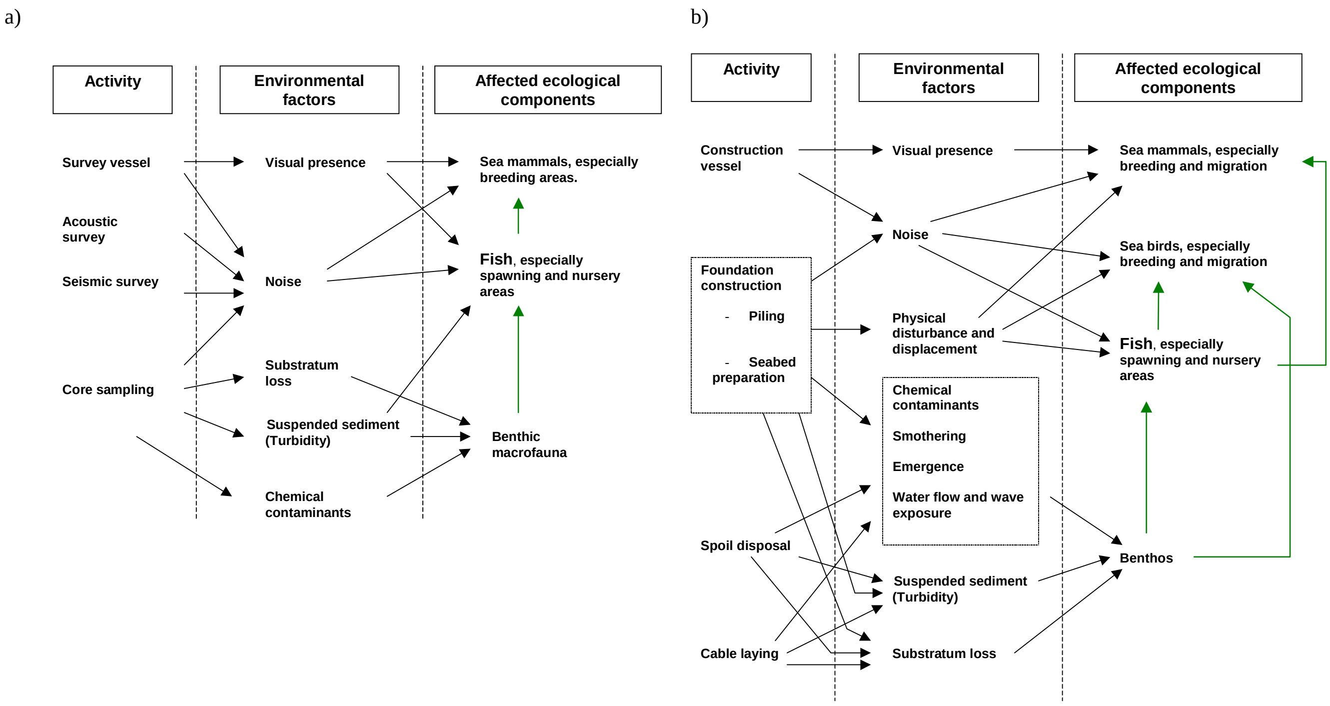

Figure 7.1 Main effects and impacts during the pre-construction (a) and construction phases (b) (adapted from Elliot, 2002; Hiscock et al., 2002). Blue colour indicates changes in the biological interactions.

7.1.1 Noise and vibrations

Apart from seismic surveys during the pre-construction phase, pile driving activities connected to the monopole design will be the largest and most prominent source of noise and vibration and will be persistent for the most of the construction period.

The biotope present is considered tolerant to noise and none of the species present in the area are likely to be particular sensitive to the noise generated.

The siphons of bivalves and palps of bristle worms are likely to detect vibrations and are probably withdrawn as a predator avoidance mechanism. Very localised destructive effects from pile driving might be expected on bivalves and other benthic organisms. Shortly after the establishment of the Horns Rev 1 Offshore Wind Farm huge accumulations of dead razor shells were found close to the turbine foundation, Photo 6.

*Photo 6. Common shore crab (*Carcinus maenas*) on dead razor shells. .© Elsam Engineering and Bio/consult.*

*Photo 7. Edible crab (*Cancer pagurus*) on seabed.© Elsam Engineering and Bio/consult.*

Temporary displacement of crabs, Photo 7, might occur due to the generation of pile driving noise as the detection level for crabs is close to the level of noise generated.

Table 7.1. Assessment of impact from pile driving activities.

Issue	Importance	Magnitude	Persistence	Likelihood	Other	Significance
Noise and vibrations	Local	Minor	Temporary	High	Direct	Negligible

7.1.2 Suspension and redistribution of sediments

The construction of gravitation foundations and the cable laying activities might increase levels of suspended sediment and might cause a temporary displacement of sediment and temporary changes in sediment types.

No fine sediments are present in the wind farm area. Although due to the current and wave regimes, the sandy sediments in the reef area are constantly being redistributed.

Spillage from dredging activities will be transported by current mainly close to the bottom and only a small part will be distributed into shallower areas (GEUS et al., 2000). Given the generally coarse sandy nature of the seabed inside the wind farm area, most of the sediment spill will settle within a short distance from the dredging vessels. A worst-case spill scenario for gravitation foundations at the Horns Rev 1 Offshore Wind Farm showed only very local and short-term impact of increased turbidity, more than 2 mg/l, and a total accumulation of spilled sediment not exceeding 2 kg/m^2. This was much lower than the natural variation in the reorganisation and accumulation of re-suspended sediment in the area (Elsam, 2000). Temporary changes in sediment types might be caused by sedimentation from spillages of dredging activities close to the turbine sites.

In general, the benthic communities are adapted to and tolerant of sediment redistribution and are very insensitive to smothering. Smothering with sediment would temporarily halt feeding and respiration, which requires the infauna to relocate to their preferred depth.

Most species within the registered communities are active burrowers and would be unlikely to suffer mortality. Feeding and respiration would be likely to return to normal soon after relocation and so recoverability is presumed very high.

The epifauna species such as *Asteria rubens* are mobile and flexible enough to relocate to surface following smothering. Species richness is likely to remain unchanged.

Table 7.2. Assessment of impact from suspension and redistribution of sediment.

Issue	Importance	Magnitude	Persistence	Likelihood	Other	Significance
Suspension and redistribution of sediment	Local	Minor	Temporary	Low –High (Dependent of construction methodology)	Direct	Negligible

7.1.3 Loss of seabed area and change in substrate type

The footprint of the wind farm on the seabed will depend upon the type and diameter of the foundations used for the turbines and substation. Monopiles would induce less impact compared to gravitational foundations to the benthos in terms of loss of habitat area, although the benthic community generally shows a high intolerance to habitat loss. No endangered or rare species are found within the wind farm area and only less than 0.2% of the *Venus* or *Goniadella-Spisula* communities within the total wind farm area with will be affected.

Changes in seabed substrate type is most likely to be introduced at the turbine sites by the presence of the monopiles or gravity foundations including pure sand to hard structures and scour protections. The introduction of hard bottom substrates will create an additional seabed habitat permitting the establishment of new species in the area. The coverage area of hard bottom structures will be limited while the impact is considered as minor.

The installation of cable connections within the wind farm area will also cause temporary loss of seabed. The impact caused by permanent and temporary loss of substrate is considered as minor.

Table 7.3. Assessment of impact from loss of seabed and change in substrate type.

Issue	Importance	Magnitude	Persistence	Likelihood	Other	Significance
Loss of seabed	Local	Minor	Permanent	High	Direct	Minor
Change in substrate type	Local	Minor	Permanent	High	Direct	Minor

7.2 Phase 3 – Operation

Sources of potential impact to the benthos during the operation phase are described below followed by an assessment of impact to the benthic communities.

The presence of the wind turbines and scour protections might induce impact on the hydrodynamic regimes and will present hard structures accessible for colonisation of epifouling organisms introducing a new habitat type within the wind farm area. The presence of the wind turbines might also introduce underwater noise and vibration.

Construction of multiple turbines could potentially affect the hydrographical regime in and around the development area. Power cables connecting the turbines could likely induce both an electric and electromagnetic field to the seabed just above the cable, which could influence electro sensitive species or species using the earths magnetic field to navigate during migration. A diagram of the expected linkages between the activities, environmental factors and the affected ecological effects is presented in Figure 7.2.

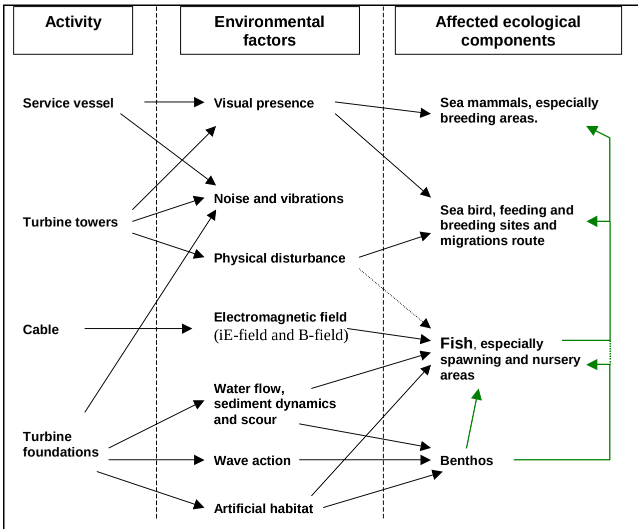

Figure 7.2. *Diagram of operational effects (adapted from Elliot, 2002; Hiscock et al., 2002). Blue lines indicate changes in biological interactions*

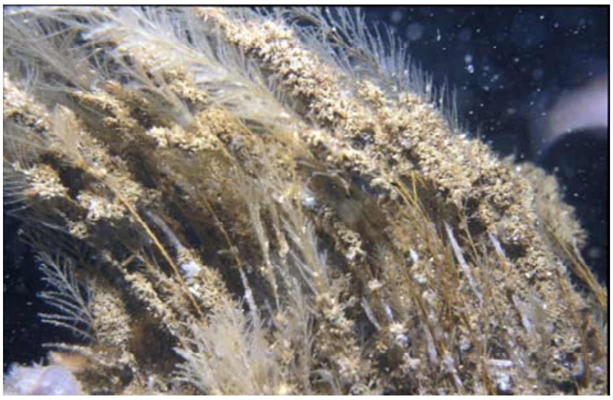

Photo 8. *The white weed Sertularia cupressina .© Elsam Engineering and Bio/consult.*

7.2.1 Introduction of hard substrate

As a secondary aspect of establishing offshore wind farms, sub-surface sections of turbine towers and scour protections will introduce new types of sub-littoral structures and increase the heterogeneity in an area previously consisting only of relatively uniform sand. The introduced habitats will be suitable for colonisation by a variety of marine invertebrates and attached algae. The hard bottom structures may act both individually and collectively as an artificial reef.

Structural complexity appears to be a condition for many productive and complex environments such as coral reefs, mangroves and sea grass meadows. These environments are productive, not only because they have a great turnover, but also because they offer a high degree of substrate complexity and an extensive spectrum of niche sizes, which are advantageous for young and juvenile organisms. The size, diversity and density of organisms on and in an artificial reef are conditional on the number and size of niches, but not necessarily on the presence of food. Algal growth on the reef contributes further to increased heterogeneity.

The hard substrate may increase the opportunities for epifauna to settle and may provide a substrate that is more attractive to mobile fauna than the previous ‘pre-wind farm’ seabed. The establishment of epifauna and flora on the hard substrates will increase the food available to fish, which again will lead to an increase in the food available to marine mammals and birds.

The presence of the deployed artificial hard substrate structures will lead to colonisation by many epibenthic organisms, which have not been in the area previously because of a lack of suitable habitat. Predictions of various qualitative or quantitative scenarios for fouling successions are highly dependant on the surrounding environment, the interaction between the different species of the fouling community and the predation or grazing on the fouling community by predatory or herbivorous species like the common star fish, sea urchins, snails, birds and others. Consequently, no unambiguous forecast can be made about species composition and community structures in the future introduced hard bottom benthic communities in the Horns Rev 2 Offshore Wind Farm area.

Colonisation of the deployed substrates will come from a combination of migration from the surrounding substrate and settling of larvae or spat. The recruitment will be governed by the sea currents carrying the larvae and spat to the foundation and by the location of the foundation with respect to depth, distance from recruitment source, etc. The recruitment will also be dependent on the type and heterogeneity of the foundation, which will always be seasonal in Danish waters.

The colonisation will often have a characteristic succession, starting with diatoms and filamentous algae, followed by barnacles and thereafter by a more diverse community (Falace & Bressan, 2000). The qualitative and quantitative composition of the fouling community will further vary with the water depth. There will be differences in the composition of the fouling community at particular depths on the monopiles and the scour protections.

As found for the Horns Rev 1 Offshore Wind Farm (Leonhard and Pedersen, 2006), the wind farm area at Horns Rev II and its introduced hard bottom structures might also function as a sanctuary area for more species included in the Red List for threatened or vulnerable Wadden Sea species like the ross worm (*Sabellaria spinulosa*) and the white weed (*Sertularia cupressina*, Photo 8) (Nielsen et al. 1996; Petersen et al. 1996). *Sabellaria spinulosa* can form compact reef-like populations. After a heavy decline that started in the 1920s, it has again been seen in increasing numbers in parts of the Wadden Sea area (Nehring, 1999). *Sabellaria* reefs have not been recorded in the Danish part of the Wadden Sea (Nehring, 1999). *Sertularia cupressina* is the object of harvesting for decoration purposes in Europe (Gibson et al., 2001; Lotze, 2004).

The biomass produced on the introduced hard bottom structures might be many times greater than biomass produced by the native benthic community at Horns Rev, mainly due to habitats suitable for colonisation of the common mussel (*Mytilus edulis*).

A succession in seaweeds and epifauna is expected to be comparable to the epifouling communities found at the Horns Rev 1 Offshore Wind Farm. Species of brown filamentous algae (*Pilayella littoralis/Ectocarpus*) and green algae *Ulva (Enteromorpha)* are expected to be the most frequent and initial colonisers of seaweeds. These initial colonisers should be followed by more species of red algae. Initial colonisers of epifauna are likely to be species of amphipods (*Jassa marmorata* and *Caprella linearis*), barnacles (*Balanus crenatus*), common mussels (*Mytilus edulis*), different species of sea anemones, oaten pipes hydroids (*Tubularia indivisa*, Photo 9) and bristle worms (*Pomatoceros triqueter*).

More interesting species like the giant midge (*Telmatogeton japonicus*) are likely to establish on the turbine foundations. The amphipod (*Caprella mutica*), a newly introduced species into Atlantic waters, is also likely to be established on the wind turbine foundations at Horns Rev 2 Offshore Wind Farm.

Impact from predation (especially from the common starfish (*Asterias rubens*)), recruitment and competition for space will contribute to a continuously repeating succession process until a relatively stabile community is reached. A climax community is not expected within 5-6 years after hard substrate deployment. Occasionally disruption of community succession due to effects from storm events and hard winters may even prolong this process until a stable community is attained.

The introduced hard substrates are likely to be used as hatchery or nursery grounds for several species of crustaceans like the edible crab (*Cancer pagurus*).

Table 7.4. Assessment of impact from hard substrate introduction.

Issue	Importance	Magnitude	Persistence	Likelihood	Other	Significance
Introduction of new hard substrate communities	Local	Minor	Permanent	High	Direct	Minor

7.2.2 Physical presence of the wind turbines

Wind turbines are large structures that will change the physical characteristics of the area markedly. Impacts to the benthic communities from the physical presence of the wind turbines, apart from effects of the introduction of hard substrate habitats, will only effect changes in the general current regimes within the wind farm area and changes in the local current regimes close to the wind turbine foundations.

The presence of the wind turbines might cause a reduction in the current velocities inside the wind farm area. Modelled reduction in current velocities by a maximum of 2% was found for Horns Rev 1 Offshore Wind Farm (Elsam, 2000). Close to the wind turbine foundations, changes in seabed and associated benthic communities might be caused by current turbulence. Modelling for Horns Rev 1 Offshore Wind Farm showed that changes in current velocities would be less than 15% within 5 metres from the monopole foundations (Elsam, 2000), although turbulence from turbines can be registered more than 100 m downstream from the foundations, Figure 7.3.

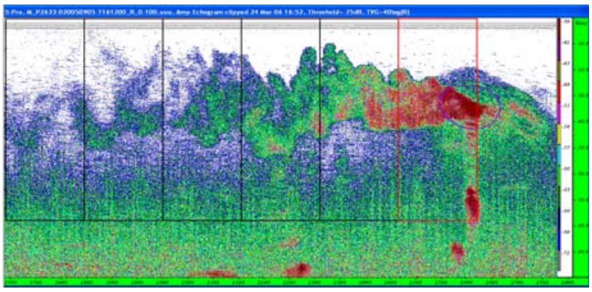

Figure 7.3. Turbulence from turbine foundation measured by echo sounder © Elsam Engineering.

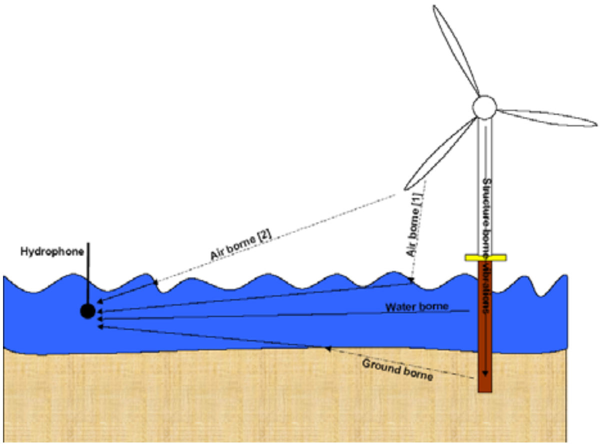

Figure 7.4 Wind turbine underwater noise transmission paths (After Nedwell & Howell, 2004).

A decrease in water flow rate might result in increased deposition of fine particles altering the substratum characteristics. Most species inhabiting the benthic communities in the area are relatively tolerant to increased levels of fine particles but clogging of feeding and respiration structures might inhibit suspension-feeding bivalves. Only minor changes in hydrographical regimes are expected and impact on the general seabed characteristics and associated benthic communities is considered only negligible. An increase in the organic content of the sediment might favour the razor clam (*Ensis americanus*), which is the only species in the registered community with affinity for increased organic content in the sediment.

Table 7.5. Assessment of impact from change in hydrodynamic regimes.

Issue	Importance	Magnitude	Persistence	Likelihood	Other	Significance
Changes in hydrodynamic regimes	Local	Minor	Permanent	High	Direct	Minor

7.2.3 Noise and vibrations

During operation, noise may arise from a variety of sources, including aerodynamic blade noise, gearbox meshing noise and noise from other machinery (Nedwell et al., 2003; Wizelius et al., 2005) with noise emission frequencies below 1000 Hz (Lindell and Rudolphi, 2003).

Structural borne vibrations originating from mechanical vibrations generated in the nacelle is thought to contribute the most to underwater wind turbine noise (Nedwell & Howell, 2004). Possible wind turbine underwater noise transmission paths are shown in Figure 7.4.

The level of noise generated by the turbines is however far less than piledriving generated noise while it is assessed that the impact of noise on sensitive species of crabs during the wind farm operation is negligible.

Table 7.6. Assessment of impact from noise and vibration.

Issue	Importance	Magnitude	Persistence	Likelihood	Other	Significance
Noise and vibrations during operation	Local	Minor	Permanent	High	Direct	No impact

7.2.4 Electromagnetic fields

Submarine power cables, like the ones interconnecting the wind turbines in wind farms, invariably generate electrical and magnetic fields that are known to affect electrosensitive fish (e.g. Rodmell & Johnson, 2005; Gill & Taylor; 2001; Westerberg, 2000), but no literature exists on the effect of electric currents on benthic invertebrate species. Induced magnetic fields generated from submarine power cables may have an effect on magnetosensitive species like migratory crustaceans, which are thought to be sensitive to the Earth's magnetic fields (Gill et al., 2005). Gill et al. (2005) emphasized that the current knowledge is generally too variable and inconsistent to make informed assessments of the impacts on electrosensitive or magnetosensitive species from power cables.

The potential impact area around the cables is calculated to be less than 1% of the total wind farm area and a possible loss of habitat in the vicinity of the cables will probably be negligible. The potential impact on benthic invertebrates is consequently assessed to be negligible.

Table 7.7. Assessment of impact from electromagnetic fields.

Issue	Importance	Magnitude	Persistence	Likelihood	Other	Significance
Electromagnetic fields	Local	Minor	Permanent	Unknown	Direct	Negligible

7.3 Decommissioning

Decommissioning of the wind farm includes removal of the turbines and the foundations as well as the cables connecting the turbines. Removal of the foundations, the scour protections and the cable will result in disturbance of the seabed with an increased level of suspended solids in the water column. It is also likely that the removal procedure will include the usage of explosives, thus generating heavy noise and vibrations.

An overview of possible impacts during the decommissioning phase is given in Figure 7.5.

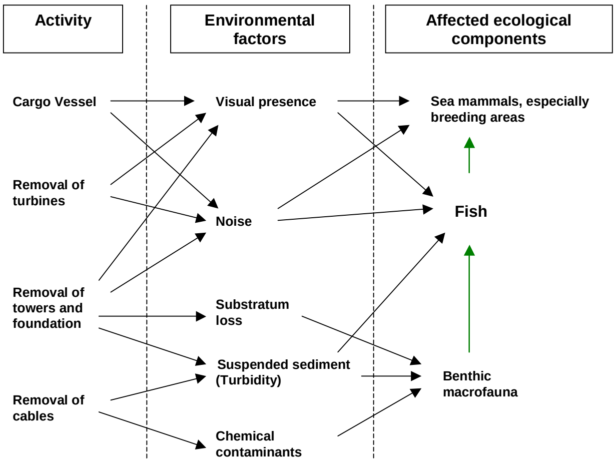

Figure 7.5. Effects and impacts in the decommissioning phase (adapted from Elliot, 2002; Hiscock et al., 2002). Blue colour indicates changes in the biological interactions

Photo 9. An initial coloniser, the oaten pipe hydroid Tubularia indivisa .© *Elsam Engineering and Bio/consult.*

Removal of the turbine foundations, scour protections and interconnecting cables would effectively be the reverse of the construction procedure. Re-suspension of sediment, causing effects of smothering, and increased suspended sediment levels are likely to be tolerated by the existing benthos community within the wind farm area with an impact being assessed as minor. Removal of hard structures, such as turbine foundations and scour protections, will result in substratum loss and an effective exclusion of fouling organisms established on it. Detached organisms might be exposed to carnivorous fish or invertebrates that might be temporarily attracted to the area during decommissioning.

Removal of foundations might leave the seabed with holes, hollows or grooves, which over time, will be filled in by sediment. The seabed will return to a normal pattern over time with a redistribution of sediments and be colonised by species characteristic of the *Venus* or *Goniadella-Spisula* community. Full recovery of the benthic infaunal community at the turbine sites is expected within a few years and less then the life expectancy span for the slowest growing of the character species, like *Spisula solida* or *Chamelea gallina*, because of active colonisation from these species. The impacts are expected to be equal to the same type of impacts during construction.

Table 7.8. Assessment of impact from decommissioning activities.

Issue	Importance	Magnitude	Persistence	Likelihood	Other	Significance
Suspension and redistribution of sediment	Local	Minor	Temporary	High	Direct	Negligible
Removal of Introduced hard substrate	Local	Minor	Permanent	High	Direct	Minor

7.4 Cumulative effects

Cumulative effects occur on the local scale (Horns Rev 2 Offshore Wind Farm) as well as the regional scale including the entire Horns Rev area. The assessments of impacts and effects from Horns Rev 2 Offshore Wind Farm need to also include the cumulative effects derived from the presence of a wind farm that is only approximately 10 km away and sand extraction and aggregation areas south of Horns Rev, Figure 7.6 in close vicinity of Horns Rev 1 Offshore Wind Farm.

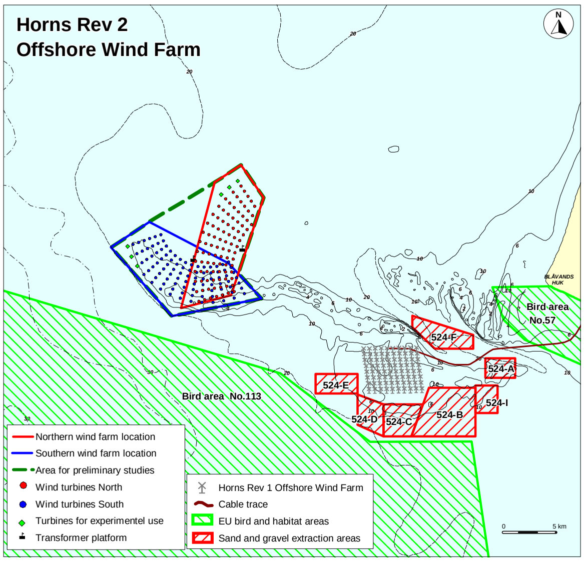

Figure 7.6. Areas for raw material extraction close to Horns Rev 1 Offshore Wind Farm.

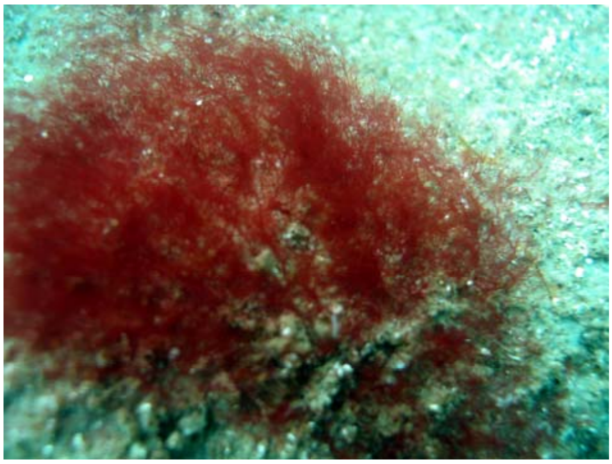

Photo 10. The red algae Polysiphonia fibrillosa

7.4.1 Preconstruction and construction

Piling activities are not likely to occur simultaneously at the two wind farm sites, therefore no cumulative effects from piling generated noise are considered.

Simultaneous dredging activities in the wind farm area and in the sand extraction and aggregation areas will not generate cumulative effects from an increase in suspended sediments and smothering due to the distance between the areas and the sediment structure in the Horns Rev area. Effects from dredging are considered very local for the areas of concern.

Changing of substrate type from pure sand to hard substrate and loss of preconstruction habitats for more wind farms is very unlikely to generate cumulative impacts on the benthic communities since no vulnerable, rare or preserved species are identified or known from the Horns Rev area.

Table 7.9. Assessment of cumulative effects from preconstruction and construction activities.

Issue	Importance	Magnitude	Persistence	Likelihood	Other	Significance
Pile driving	Local	Minor	Temporary	Low		No impact
Dredging activities	Local	Minor	Temporary	Low		No impact
Loss of habitats	Local	Minor	Permanent	Low		No impact

7.4.2 Operation

The existence of artificial hard substrate structures at Horns Rev 1 Offshore Wind Farm might contribute to a faster and more diverse colonisation of hard substrates at a newly established offshore wind farm at Horns Rev. The cumulative impacts might then benefit the establishment of vulnerable and threatened species like the ross worm (*Sabellaria spinulosa*) and the white weed (*Sertularia cupressina*). A faster colonisation of red algae, Photo 10, on the newly deployed hard substrates is considered as a cumulative effect of more wind farms in the Horns Rev area. The introduction of more substrates from more offshore wind farms might generate a cumulative effect of introducing higher species richness with higher biodiversity compared to the native infaunal community in the Horns Rev area. Geographically close wind farms might function as stepping stones thereby accelerating the intrusion of invasive and alien species.

Interdicting trawling activities inside the wind farm areas will be beneficial to the benthic communities by enabling the species to mature to their natural sizes and enabling very sensitive species to be established. This might be a cumulative effect from the establishment of more wind farms in close vicinity to each other by preventing effective trawling between wind farm sites.

It is unlikely that the regional hydrological regimes and sediment characteristics will change as an effect of more wind farms.

It is expected that cumulative effects from more wind farms close to each other might result in more diverse and more mature infaunal communities in areas between the wind farms and in more diverse epifouling communities at the hard substrate structures inside the wind farms.

Table 7.10. Assessment of cumulative effects from operation activities.

Issue	Importance	Magnitude	Persistence	Likelihood	Other	Significance
Introduction of hard substrates	Local	Minor	Permanent	Low		Minor
Fishery ban	Regional	Minor	Permanent	Uncertain		Unknown

7.4.3 Decommission

Decommissioning of the Horns Rev 2 Offshore Wind Farm will generate similar impacts to the construction activities and therefore, cumulative impacts are considered as insignificant.

Table 7.11. Assessment of cumulative effects from preconstruction and construction activities.

Issue	Importance	Magnitude	Persistence	Likelihood	Other	Significance
Decommission	Local	Minor	Temporary	Low		No impact

7.5 Mitigation

As impacts on benthos are assessed to be no more than minor, no specific mitigation measures are necessary.

8 Conclusions

The impacts on the benthic communities are summarised in Table 8.1.

There are no protected or sensitive benthic communities at the planned wind farm sites. The benthic communities consist of a mixture of mainly two characteristic benthic faunal assemblages; the *Venus* community and the *Goniadella-Spisula* community. These communities are adapted to energetic environments and tolerant to smothering and redistribution of sediments. Impacts from construction and operation activities are considered as minor.

The sediment at the wind farms sites consist of pure medium to coarse sand with low or no content of fine sand. The sediment is therefore not likely to contribute to a significant increase in suspended sediment during construction activities and no impact on benthic communities is foreseen from the site of activity or dredging. Considerations of spillage are only of concern if gravity foundations are used.

The direct loss, change or physically disturbed seabed is less than 0.2% of the wind farm area. These areas change permanently from soft bottom communities to hard bottom communities associated with the turbine structures and scour protections. Succession in the fouling community is foreseen and mature community structure is not expected within 5-6 years after hard substrate deployment.

Cumulative effects might result in more diverse and more mature infaunal communities in areas between the wind farms caused by reduced trawling activities and in more diverse epifouling communities at the hard substrate structures caused by rapid colonisation of species from nearby wind farms.

As impacts on benthic communities are assessed to be no more than minor, no mitigation measures are proposed.

Table 8.1. Summarised impacts on benthic communities from construction and operation activities associated with the establishment of Horns Rev 2 Offshore Wind Farm.

Impact	Criteria	Preconstruction	Construction	Operation	Decommissioning
Noise and vibrations	Importance Magnitude Persistence Likelihood Other Significance	Local Minor Temporary High Direct Negligible	Local Minor Temporary High Direct Negligible	Local Minor Permanent High No impact	Local Minor Temporary High Direct Negligible
Suspension and redistribution of sediments	Importance Magnitude Persistence Likelihood Other Significance		Local Minor Temporary Low-high Direct Negligible		Local Minor Temporary High Direct Negligible
Change in substrate type	Importance Magnitude Persistence Likelihood Other Significance		Local Minor Permanent High Direct Minor	Local Minor Permanent High Direct Minor	Local Minor Permanent High Direct Minor
Loss of seabed area	Importance Magnitude Persistence Likelihood Other Significance		Local Minor Permanent High Direct Minor	Local Minor Permanent High Direct Minor	
Electromagnetic fields	Importance Magnitude Persistence Likelihood Other Significance			Local Minor Permanent Unknown Direct Negligible	
Introduction of hard substrate	Importance Magnitude Persistence Likelihood Other Significance			Local Minor Permanent High Direct Minor	Local Minor Permanent High Direct Minor
Changes in hydrodynamic regimes	Importance Magnitude Persistence Likelihood Other Significance			Local Minor Permanent High Direct Minor	
Cumulative effects	Importance Magnitude Persistence Likelihood Other Significance	Local Minor Temporary Low No impact	Local Minor Temporary Low No impact	Local-regional Minor Permanent Uncertain Unknown	Local Minor Temporary Low No impact

9 References

ABB Power Technologies. 2003. Netzanbindungen fur Offshore-windparks. Seekabel erwarmung und felder. Workshop in Rostock.

Bech, M. 2006. Bundfauna VVM-grundlag. Horns Rev II – Havmøllepark. Indsamling af infauna samt sediment 2006. Data-rapport. Report to Energi E2 (In Danish). Bio/consult.

Bergman, M.J.N., M. Fonds, S.J. de Groot and J.W. van Santbrink. 1996. Direct Effects of Beam Trawl Fishery on bottom Fauna in the Southern North Sea. In Andersen J., H. Karup and U.B. Nielsen (Eds.) Scientific Symposium on the North Sea Quality Status Report 1993, 18-21 April 1994, Ebeltoft, Denmark: 204-209.

Bergman, M.J.N. and J.W. van Santbrink. 2002. Fishing mortality of populations of megafauna in sandy sediments. In Kaiser, M.J. and S.J. de Groot. The effects of Fishing on Non-target Species and Habitats. 2. reprint. Blackwell: 49-68.

Birkett, L. 1953. Changes in the compositions of the bottom fauna of the Dogger Bank area. Nature 171: 265

Budelmann, B. U. and J. Z. Young. 1994. Directional sensitivity of hair cell afferents in the Octopus statocyst. J. Exp. Biol. 187: 245-259.

Centre for Marine Ecology and Costal Studies. 2002. Burbo Offshore Wind Farm EIA impact assessment – Technical report, Marine ecology. Centre for Marine and Coastal Studies ERC University of Liverpool.

Chícharo, L., A. Chícharo, M. Gaspar, F. Alves and J. Regala. 2002. Ecological characterization of dredged and non-dredged bivalve fishing areas off south Portugal. J. Mar. Bio. Ass. U.K. 82 (1): 41-50.

Clarke, K. R. & R.M. Warwick. 1994. Change in marine communities: an approach to statistical analysis and interpretation. Natural Environment Research Council, UK: 1-114.

Danish Environmental Agency. 1996. Energy 21. The Danish Government's action plan for Energy 1996. The Danish Energy Authority, Ministry of Environment and Energy.

Danish Hydraulic Institute (DHI). 1999. Havvindmøllefundamenter ved Horns Rev – Hydrografiske data. ELSAMPROJEKT A/S.

Degraer, S., M. Vincx, P. Meire & H. Offringa. 1999. The macrozoobenthos of an important wintering area of the common scoter (Melanitta nigra). J. Mar. Biol. Ass. U.K. 79: 243-251.

Dewarumez, J.M., D. Devoult, L.E.S. Anorve & S. Frontier. 1992. Is the 'muddy heterogeneous sediment assemblage' an ecotone between the pebbles community and the Abra alba community in the Southern Bight of the North Sea? Netherlands Journal of Sea Research.30: 229–238.

DONG. 2006. Walney Offshore Wind Farm. EIS 2006. 1-296.

Elliot, M. 2002. The rose of the DPSIR approach and conceptual models in marine environmental management: an example for offshore wind power. Marine pollution bulletin, 44; iii-vii, 2002.

Elsam Engineering and Energy E2. 2005. Review report 2004. the Danish Offshore Wind Farm Demonstration Project: Horns rev and Nysted Offshore Wind Farms. Environmental impact assessment and monitoring: Report commissioned by The Environmental Group: 1-135.

Elsamprojekt. 2000. Havmøller Horns Rev. Vurdering af Virkninger på Miljøet. VVM–redegørelse. Rapport til Elsam I/S og Eltra amba.

Eltra. 2000. Beregning og måling af magnetfelter omkring kabler og vindmøller. Notat elt2000-240.

Falace, A. and G. Bressan. 2000. "Periphyton" colonization: Principles, Criteria and Study Methods. *In* A. C. Jensen *et al*. (eds.): Artificial Reefs in European Seas: 435-449.

GEUS. 2002. Personal communication.

GEUS, Carl Bro, Bio/consult og Dansk Hydraulisk Institut. 2000. The Baltic Gate. VVM redegørelse for sandindvinding. Hovedrapport. Rapport til Stigsnæs Innovators/ Skælskør Kommune.

Gibson, R., B. Hextall and A. Rogers. 2001. Photographic Guide to the Sea & Shore Life of Britain & North-west Europe. Oxford: 1-436.

Gill, A.B. and H. Taylor. 2001. The potential effects of electromagnetic fields generated by cabling between offshore wind turbines upon Elasmobranch Fishes. Research Project for Countryside Council for Wales. University of Liverpool.

Gill, A.B., Gloyne-Phillips I., Neal K.J. & Kimber, J.A. 2005. Cowrie 1.5. Electromagnetic fields review. The potential effects of electromagnetic fields generated by sub-sea power cables associated with offshore wind farm developments on electrically and magnetically sensitive marine organisms – a review. Final report. COWRIE-EM FIELD 2-06-2004.

Hiscock, K., Tyler-Walters, H and Jones, H. 2002. High Level Environmental Screening Study for Offshore Wind Farm Developments – Marine Habitats and Species Project. Report from the Marine Biological Association to The Department of Trade and Industry New & Renewable Energy Programme. (AEA Technology, Environment Contract: W/35/00632/00/00.)

Hoffmann, E., J. Astrup, F. Larsen and S. Munch-Petersen. 2000. Effects of marine wind farms on the distribution of fish, shellfish and marine mammals in the Horns Rev area. Danish Institute for Fisheries Research, Department of Marine Fisheries: 1-42. Report request. Commissioned by Elsamproject.

Jensen, K. R. and J. Knudsen. 2005. A summary of alien marine benthic invertebrates in Danish waters. Oceanological and Hydrobiological Studies Vol. XXXIV, Supplement1: 137-162.

Kaiser, M.J., A.S. Hill, K. Ramsay, B.E. Spencer, A.R. Brand, L.O. Veale, K. Prudden, E.I.S rees, B.W. Munday, B. Ball and A.J. Hawkins. 1996. Benthic disturbance by fishing gear in the Irish Sea: a comparison of beam trawling and scallop dredging. Aquatic Conservation: Marine and Freshwater Ecosystems, vol. 6: 269-285.

Kingston, P. & E. Rachor, 1982. North Sea level bottom communities. ICES CM 1982/L:41: 1–15.

Kirkegaard, J.B. 1969. A quantitative Investigation of the Central North Sea. Polychaeta. Spolia 29. 1–284.

Kröncke, I., C. Bergfeld. 2001. Synthesis and New Conception of North Sea Research (SYCON) 12. Working group 10. Review of the Current Knowledge on North Sea Benthos. Berichte aus dem Zentrum für Meeres- und Klimaforschung dern Universität Hamburg: 1-138.

Larsen, B. 2003. Blåvands Huk – Horns Rev området – et nyt Skagen?. Temanummer Geologi nyt fra GEUS nr. 4 (2003)

Leonhard, S.B. 2000. Horns Rev Offshore Wind Power Farm. Environmental Impact Assessment of Sea Bottom and Marine Biology: 1-36. Report request. Commissioned by Elsam I/S.

Leonhard, S.B., J. Pedersen. 2005. Hard Bottom Substrate Monitoring Horns Rev Offshore Wind Farm. Annual Status report 2004: 1-79. Report request. Commissioned by Elsam Engineering A/S.

Leonhard, S.B. and J. Pedersen. 2006. Behthic communities at Horns Rev before, during and after construction of Horns Rev Offshore Wind Farm. Report commissioned by Elsam Engineering. Bio/consult: 1-123.

Lindell, H. and E. Rudolphi. 2003. Utgrunden off-shore wind farm – Measurement of underwater noise. Ingemansson Technology. Report commissioned by Airicole, GE Wind Energy and SEAS/EnergiE2:1-32.

Lotze, H.K. 2004. Ecological History of the Wadden Sea: 2000 Years of Human-induced Change in a Unique Coastal Ecosystem. Wadden Sea Newsletter 2004 – 1: 22-23.

MNCR. 2006. Joint Nature Conservation Committee. Marine biotope dictionary (Version 97.06). http://www.jncc.gov.uk/mermaid.

Nedwell, L. and Howell, D. 2004. A review of offshore windfarm related underwater noise sources, Report No. 544 R 0308, October 2004.

Nedwell, J., J. Langworthy and D. Howell. 2003. Assessment of sub-acoustic noise and vibration from offshore wind turbines and its impact on marine wildlife; initial measurements of underwater noise during construction of offshore windfarms, and comparison with background noise. Report No. 544 R 0424. Subacoustech. Commissioned by COWRIE: 1-68.

Nehring, S. 1999. Oyster beds and *Sabellaria* reefs. In the Wadden Sea. Quality Status Report.

Nielsen, R., D. Schories, W. Härdtle, K. Reise & W.J Wolff. 1996. Red List of Marine Macroalgae of the Wadden Sea. Helgoländer Meeresunters. 50 Suppl., 39–42.

Offutt, G. C. 1970. Acoustic stimulus perception by the American lobster *(Homarus Americanus)* (Decapoda). Experientia 26:1276-1278.

Petersen, G.H. 1977. The Density, Biomass and Origin of the Bivalves of the Central North Sea. Meddr. Danm. Fisk.- og Havunders. N.S Vol. 7: 221–273.

Petersen, G.H., P.B. Madsen, K.T. Jensen, K.H. van Bernem, J. Harms, W. Heiber, I. Kröncke, H. Michaelis, E. Rachor, K. Reise, R. Dekker, G.J.M. Visser & W.J. Wolff. 1996. Red List of Macrofaunal Benthic Invertebrates of the Wadden Sea. Helgoländer Meeresunters. 50 Suppl., 69–76.

Piersma, T. and K. Camphuysen. 2001. What can peak mortalities of eiders tell us about the state of the Dutch Wadden Sea ecosystem? Wadden Sea Newsletter 2001-1: 42-45.

Rayment, W.J. 2001. *Fabulina fabula* and *Magelona mirabilis* with venerid bivalves in infralittoral compacted fine sand. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 03/02/2006]. Available from: <http://www.marlin.ac.uk>

Rodmell, D. and M. Johnson. 2005. The Development of Marine Based Wind Energy Generation and Inshore Fisheries in UK Waters: Are They Compatible? In: M. Johnson and C. Wheatley (Eds. Who owns the sea?, (Who owns the sea workshop proceedings, Tjarno, Sweden, 24 - 27 June 2002).

Salzwedel, H., E. Rachor & D. Gerdes. 1985. Benthic macrofauna communities in the German Bight. Veröff. Inst. Meeresforsch. Bremerh. 20: 199–267.

Simmons, M.; Dolman, S. and Weilgart, L. 2004. Ocean of Noise. A Whale and dolphin Conservation Society science report, 2004.

Ursin, E. 1960. A Quantitative investigation of the Echinoderm Fauna of the central North Sea. Meddr. Danm. Fisk.- og Havunders. N.S Vol. 2 nr. 24: 1–204.

Vanosmael, C., K.A. Willems, D. Claeys, M. Vincx & C. Heip. 1982. Macrobenthos of a sublittoral sandbank in the southern Bight of the North Sea. J. Mar. Biol. Ass. U.K. 62: 521-534.

Westerberg, H. 2000. Effect of HVDC cables on eel orientation, In Merck, T. & H. von Nordheim (Eds.) Technische Eingriffe in Marine Lebensraume. Bundesamt für Naturschutz: 70-76.

Wizelius, T., G. Britse and A. Widing. 2005. Vindkraftens Miljöpåverkan. Utvärdering av regelverk och bedömningsmetoder. Högskolan på Gotland: 1-83.

www.electricity.org.uk/uk-inds/environ/emf_fact.htn. Sources for home page: National Radiological Protection Board (NRPB), UK and National Grid Company, UK.

Appendices

Appendix 1. List of positions

Sampling was performed at the following locations.

Station	Depth (m)	WGS84_MIN_x''	WGS84_MIN_Y''	Remarks
1	11,5	07°27.292'	55°36.117'	Sampled by Haps bottom corer
3	11,2	07°26.576'	55°35,712'	Sampled by Haps bottom corer
5	10,9	07°27.292'	55°34.903'	Sampled by Haps bottom corer
9	12,9	07°28.725'	55°33.284'	Sampled by Haps bottom corer
10	7,9	07°30.874'	55°33.284'	Sampled by Haps bottom corer
11	20,2	07°30.874'	55°32.070'	Lots of "marine snow" and partikles in sample
12	6,7	07°31.590'	55°32.474'	Sampled by Haps bottom corer
14	4,6	07°34.455'	55°32.474'	Loose sand, wave ripples.
15	6,0	07°36.603'	55°32.879'	Mussel shells, hermit crabs
16	11,3	07°35.171'	55°33.688'	Packed sand, mega ripples
17	10,7	07°33.739'	55°33.688'	Packed sand, mega ripples. More common sea stars, razor shells
18	11,7	07°33.739'	55°34.093'	Packed sand, mega ripples
19	12,9	07°35.887'	55°34.903'	Packed sand, mega ripples
20	12,8	07°35.887'	55°35.307'	Packed sand, mega ripples
21	12,6	07°33.739'	55°35.307'	Packed sand, wave ripples more razor shells
22	12,9	07°35.171'	55°35.712'	Fine sand, no wave ripples
23	13,3	07°33.739'	55°36.117'	Mega ripples (interval 0.7 m)
24	14,8	07°33.739'	55°36.926'	Mega ripples (interval 0.7 m)
25	15,1	07°34.455'	55°36.926'	Mega ripples (interval 0.7 m)
26	13,3	07°36.603'	55°36.521'	Mega ripples (interval 0.7 m)
27	12,7	07°37.320'	55°36.926'	Mega ripples (interval 0.7 m)
28	14,3	07°37.320'	55°37.735'	Mega ripples (interval 0.7 m)
29	15,6	07°35.887'	55°38.140'	Mega ripples (interval 0.7 m)
30	14,8	07°36.603'	55°38.949'	Mega ripples (interval 0.7 m)

Appendix 2. Species list.

Complete list of species. Horns Rev 2006			Common name	
Group	**Taxon**	**Author**	**English**	**Danish**
ANTHOZOA				
	Actiniaria indet.			
NEMERTINI				
	Nemertini indet.			
NEMATODA				
	Nematoda indet.			
POLYCHAETA				
	Pisione remota	(Southern)		
	Phyllodoce groenlandica	Ørsted		
	Exogone sp.			
	Nephtys hombergii	Savigny		
	Nephtys sp.			
	Goniada maculata	Ørsted		
	Goniadella bobretzkii	(Annenkova)		
	Protodorvillea kefersteini	(McIntosh)		
	Orbinia sertulata	(Savigny)		
	Spio filicornis	(O.F. Muller)		
	Spiophanes bombyx	(Claparéde)		
	Aonides paucibranchiata	Southern		
	Scolelepis squamata	Müller		
	Magelona mirabilis	(Johnston)		
	Travisia forbesii	Johnston		
	Polygordius appendiculatus	Fraipont		
	Lanice conchilega	(Pallas)		
	Lysilla loveni	Malmgren		
COPEPODA				
	Harpacticoida indet.			
CUMACEA				
	Lamprops fasciata	G.O. Sars		
AMPHIPODA				
	Pontocrates arenarius	Bate		
BIVALVIA				
	Mytilus edulis	L.	Common mussel	Blåmusling
	Goodallia triangularis	(Montagu		
	Spisula solida	(L.)	Thick trough shell	Tykskallet trugmusling
	Donax vittatus	(da Costa)		Kilemusling
	Chamelea gallina	(L.)	Striped venus clam	Venusmusling
	Thracia phaseolina	(Lamarck)		Papirmusling
	Ensis americanus	(Gould in Binney)	Razor shell	Amerikansk knivmusling
BRYOZOA				
	Electra pilosa	(L.)		
ECHINODERMATA				
	Asterias rubens	L.	Common starfish	Alm. Søstjerne
	Echinocyamus pusillus	O.F. Müller		
CORDATA				
	Branchiostoma lanceolatum	(Pallas)		