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Fish

Horns Rev Offshore Wind Farm II

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EIA Report
Fish

Horns Rev 2 Offshore Wind Farm

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Summary

This EIA report reviews and assesses the possible impacts on fish from the establishment of Horns Rev 2 Offshore Wind Farm.

Horns Rev 2 Offshore Wind Farm will be established in one of two designated areas situated north of the existing Horns Rev 1 Offshore Wind Farm. Like the latter, the new wind farm will be situated in an area characterised by a harsh marine environment with strong tidal currents and a rough sea, both of which cause very dynamic current and sediment regimes. It is against this very variable and fluctuating environment that all human activities and installations should be seen and assessed.

Despite the harsh environment Horns Rev is an important fish habitat. The sandy sediments and the grain size distribution are strongly reflected in the species composition, and the distribution of the individuals is strongly influenced by the current patterns. Regarding abundance and density sandeels (*Ammotydidae* spp.) dominate the fish fauna at Horns Rev, which is the reason for an intensive commercial fishery for sandeels in the area. Other abundant species are the flatfish plaice (*Pleuronectes platesa*) and dab (*Limanda limanda*) as well as sand goby (*Pomatoschistus minutus*), but many more species are recorded at Horns Rev. Some live permanently at Horns Rev or in the vicinity, while others are occasional or seasonal visitors. Thus, depending on the time of the year the different surveys carried out at Horns Rev rank the species differently regarding abundance. Fish of conservation interest occur only very sparsely and occasionally at Horns Rev.

Noise and vibrations are likely to be the most important impacts on the fish fauna, which is why hearing ability among the fish is an important issue. Based on the literature the most abundant species – sandeels, plaice and dab – are all believed to have low sensitivity to noise and vibrations. Other species are more sensitive due to fact that hearing ability is an important part of the sensory apparatus.

The wind turbines will be founded by use of either monopole or gravitation foundations. Which one of these two foundations will be used is not decided yet, but this report focuses on the monopile foundation since the use of this is associated with the highest levels of impacts, particularly in the form of noise and vibrations. In the case that gravitation foundations are to be used, the impacts on fish are believed to be similar or – more likely – smaller than they will be in the case that monopile foundations are to be used.

The life cycle of the wind farm comprises four phases – the pre-construction phase, the construction phase, the operation phase and the decommissioning phase. Each of these phases comprises a number of impacts – some general and some phase specific.

In the pre-construction phase seismic surveys of the sea floor may give rise to transient emissions of noise and vibrations from seismic guns and vessel activity in the wind farm area. Although unavoidable and associated with high but transient levels of noise, these impacts are considered insignificant to fish. They may flee from the impacted areas or avoid these during the surveys, but no lasting effects are to be expected.

The construction phase is considered the most important to fish in terms of impacts. First of all the erection of the turbines along with the establishment of scour protection is encumbered with high impacts of noise and vibrations, the most important source be the

pile-driving (in case of monopile foundation). Although fish to varying extent are sensitive to both noise and vibrations, the assessments lead all to the conclusion that no significant lasting effects on fish are to be expected. Indeed fish may flee from or avoid the areas with the highest impacts, but as the emissions of noise and vibrations come to an end, things are likely to return to normal within short time.

Secondly, the erection of the turbines and establishment of scour protection at each of the turbines will invariably cause a loss of natural habitat to fish. Amounting to only a few percent of the total wind farm area, this loss is considered insignificant, even to the most abundant and important fish species in the area, the sand eels. In terms of fish habitats the loss of sandy habitats is correspondingly associated with an increase in stony and rocky habitats, i.e. artificial reefs will come into existence.

In the operation phase the presence of the artificial reefs will increasingly have positive effects on the fish fauna, a process that is known as “the artificial reef effect”. Species not presently living at Horns Rev will be attracted to the artificial reefs, some because the stones and rocks constitute their preferred habitat, others because they constitute suitable spawning and nursery areas. Thus, due to the artificial reefs, the establishment of the wind farm is likely to cause a significant positive impact on the fish fauna in the form of increased species richness and diversity. However, in the operation phase there will also be negative impacts in the form of both noise and vibrations and in the form of electromagnetic fields around the power cables. Based on existing knowledge, including that from the monitoring of the fish fauna at Horns Rev 1 Offshore Wind Farm, nevertheless no significant impacts on the fish fauna are to be expected.

Decommissioning of the wind farm will take place when the turbines have served their time, expectedly at least 25 years. Decommissioning of the wind farm will to large extent comprise the same activities and thus the same impacts on fish as will the construction, although the emissions of noise and vibrations are believed to be less intensive. Like the establishment of the scour protection will cause a loss of sandy habitats and creation of stony and rocky habitats, so will a complete decommissioning cause loss of the artificial reefs and regeneration of sandy habitats. This reversal of the situation will invariably mean a loss of the richness and diversity associated with the artificial reefs, and although no lasting nor significant effects are expected on the large scale, the scour protections should preferably be left in place if nothing speaks against this.

In conclusion, the establishment of Horns Rev 2 Offshore Wind Farm invariably involve a number of human activities and alterations of the existing environment at Horns Rev, all of which are associated with impacts on the fish fauna. In a systematic review all negative impacts are nevertheless assessed to be of minor importance or insignificant to the fish fauna, spatially as well as temporally. Thus, no significant negative changes of the fish fauna are expected in the wind farm area or in the adjacent areas. On the other hand significant positive changes are expected due to the artificial reef effect.

Likewise no significant cumulative effects are expected, neither for Horns Rev 2 Offshore Wind Farm on its own or for the two offshore wind farms as a whole. But there may be a positive cumulative effect on the developmental pattern of the fish fauna at Hors Rev 2 Offshore Wind Farm due to the presence of already colonised artificial reefs at Horns Rev 1 Offshore Wind Farm.

Sammenfatning

Denne VVM-rapport indeholder en gennemgang og vurdering af mulige effekter på fisk fra etableringen af Horns Rev 2 Havvindmøllepark.

Horns Rev 2 Havvindmøllepark vil blive etableret i det ene af to udpegede områder, der er beliggende nord for den eksisterende Horns Rev 1 Havvindmøllepark. Som denne vil den nye havvindmøllepark blive placeret i et område, der er karakteriseret af et barskt marint miljø med kraftige tidevandsstrømme og ofte kraftig bølgegang. Begge dele forårsager meget dynamiske strøm- og sedimentforhold. Alle menneskelige aktiviteter og installationer i området skal derfor ses på baggrund af disse barske naturgivne forhold.

Til trods for de barske omgivelser er Horns Rev et vigtig habitat for fisk. De sandede sedimenter og kornstørrelsesfordelingen afspejles tydeligt i artssammensætningen, og fordelingen af individer er stærkt påvirket af strømforholdene. Hvad angår udbredelse og tæthed dominerer tobis (*Ammotydidae* spp.) fiskefaunaen på Horns Rev, hvilket er årsagen til et intensivt kommercielt fiskeri efter tobis i området. Andre hyppigt forekommende arter er fladfiskene rødspætte (*Pleuronectes platesa*) og ising (*Limanda limanda*) såvel som sandkutling (*Pomatoschistus minutus*), men der er registreret mange flere arter på og ved Horns Rev. Nogle lever permanent i området, mens andre forekommer der lejlighedsvist eller sæsonbetinget. Derfor angives hyppigheden af arterne forskelligt i forskellige undersøgelser, afhængigt af bl.a. årstiden. Fisk af fredningsmæssig interesse forekommer kun af og til og i meget lavt antal på Horns Rev.

Støj og vibrationer skønnes at være de vigtigste påvirkninger fra vindmølleparken på fiskefaunaen, hvilket skyldes, at hørelsen spiller en vigtig rolle for flere af fiskene i området. På grundlag af litteraturstudier vurderes de vigtigste arter - tobis, rødspætte og ising - at have lav følsomhed over for støj og vibrationer. Andre arter er mere følsomme, fordi deres høreevne er en vigtig del af deres sanseapparat.

Vindmøllerne vil blive funderet ved hjælp af enten monopæle eller gravitationsfundamenter. Det er endnu ikke besluttet, hvilken af disse to fundamenttyper, der vil blive anvendt, men i denne rapport fokuseres på monopæle, idet anvendelsen af disse sandsynligvis vil være forbundet med de kraftigste påvirkninger i form af støj og vibrationer. I tilfælde af, at der skal anvendes gravitationsfundamenter, forventes det, at effekterne på fisk vil være de samme - eller mere sandsynligt - mindre intensive, end hvis der anvendes monopæle.

Livscyklus for en vindmøllepark har fire faser – præ-konstruktionsfasen, konstruktionsfasen, driftsfasen og nedbrydningsfasen. Hver af disse faser indbefatter et antal påvirkninger - nogle generelle og andre fasespecifikke.

I præ-konstruktionsfasen kan seismiske undersøgelser af havbunden foranledige udsendelse af støj og vibrationer i forbindelse med brugen af seismisk udstyr og som følge af skibstrafik i mølleområdet. Selvom disse aktiviteter er uundgåelige og indbefatter høje, men forbigående støjpåvirkninger, anses effekterne at være ubetydelige for fisk. De vil muligvis flygte fra de påvirkede områder eller undgå disse, mens undersøgelserne står på, men der forventes ingen varige effekter.

Konstruktionsfasen betragtes som den vigtigste for fisk hvad angår påvirkninger. For det første er nedramningen af møllefundamenterne (monopæle) og etableringen af erosionsbeskyttelsen behæftet med omfattende udsendelse af støj og vibrationer. Selvom fisk i varierende grad er følsomme over for både støj og vibrationer, har vurderingerne ført til den konklusion, at der ikke kan forventes betydende eller varige effekter på fisk. Ganske vist vil fisk sandsynligvis flygte fra - eller undgå områderne med de kraftigste påvirkninger, men når rejsningen af møllerne er tilendebragt, forventes forholdene i mølleområdet normaliseret i løbet af kort tid.

Opførelsen af vindmøller og etablering af erosionsbeskyttelse ved hver mølle vil uvægerligt forårsage tab af naturlige levesteder for fisk, men fordi dette tab kun udgør nogle få procent af det samlede areal, vurderes det at være ubetydeligt, selv for de mest betydende fisk i området - tobis. Hvad angår fiskehabitater vil tabet af sandede habitater være ledsaget af en tilsvarende øgning af mængden af stenede habitater, dvs. at der vil opstå kunstige rev.

I driftsfasen vil tilstedeværelsen af kunstige rev i stigende udstrækning have en positiv effekt på fiskefaunaen, en proces, der er kendt som ”kunstig rev effekten”. Arter, der ikke for nærværende lever på - eller ved Horns Rev, vil blive tiltrukket af de kunstige rev. Nogle fordi sten og klipper er deres foretrukne levesteder, andre fordi de er egnede gyde- og opvækstområder. På den måde forventes opførelsen af mølleparken at få en betydelig positiv effekt på fiskefaunaen i form af øget artsrigdom og - diversitet. Der vil imidlertid også forekomme negative påvirkninger i form af både støj og vibrationer og i form af elektromagnetiske felter rundt om de strømførende kabler. Baseret på eksisterende viden, heriblandt erfaringerne fra undersøgelserne af Horns Rev 1 Havvindmøllepark, forventes der imidlertid ingen negative påvirkninger af betydning for fiskefaunaen.

Nedbrydningen af vindmølleparken og retableringen af mølleområdet forventes at skulle ske, når møllerne er udtjente, hvilket forventes at ske efter ca. 25 år. Nedbrydning af mølleparken vil i stor udstrækning omfatte de samme aktiviteter og vil således indbefatte de samme påvirkninger af fiskene som selve konstruktionen, selvom emissionen af støj og vibrationer forventes at blive mindre omfattende i nedbrydningsfasen. Ligesom etableringen af erosionsbeskyttelsen vil forårsage tab af sandede habitater og dannelse af stenede habitater, vil nedbrydningen forårsage tab af stenede habitater (de kunstige rev) og regenerering af sandede habitater. Denne forandring af situationen vil utvivlsomt betyde tab af den artsrigdom og -diversitet, der i driftsperioden opstår på grund af de kunstige rev, og selvom hverken varige eller betydende effekter forventes i stor skala, kan erosionsbeskyttelsen med fordel blive liggende, hvis intet taler imod dette.

Samlet set vil opførelsen af Horns Rev 2 Havvindmøllepark uvægerligt være forbundet med et antal menneskelige aktiviteter og ændringer af det eksisterende miljø for fiskene på Horns Rev. I en systematisk gennemgang vurderes alle negative påvirkninger ikke desto mindre at være af mindre betydning eller helt uden betydning for fiskefaunaen, rumligt så vel som tidsmæssigt. Der forventes således ingen afgørende negative ændringer af fiskefaunaen i mølleområdet eller de tilstødende områder, men derimod forventes der betydende positive ændringer som følge af den kunstige rev effekt.

Ligeledes forventes ingen kumulative negative effekter, hverken isoleret set for Horns Rev 2 Havvindmøllepark eller samlet set for de to havvindmølleparker, men der kan forekomme en positiv kumulativ effekt på udviklingsmønstret for fiskefaunaen i Horns Rev

2 Havvindmøllepark som følge af eksistensen af allerede koloniserede kunstige rev i Horns Rev 1 Havvindmøllepark.

1. Introduction

The Danish Government in 1996 passed a new energy plan, ”Energy 21”, that stipulates the need to reduce the emission of the greenhouse gas CO_2 by 20% in 2005 compared to 1988. Energy 21 also sets the scene for further reductions after the year 2005 (Miljø- og Energiministeriet, 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% in 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 was 426 MW in January 2004 (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 & ENERGI E2, 2005). The aim of this programme was to investigate the impacts on the environment before, during and after establishment of the wind farms. A series of studies of the environmental conditions and possible impacts from the offshore wind farms were undertaken for the purpose of ensuring that offshore wind power does not have damaging effects on the natural 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 1 Offshore Wind Farm.

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 up by investigations during and after the construction phase, and all environmental impacts were assessed. Detailed information on methods and conclusions of these investigations can be found in the annual reports (www.hornsrev.dk; www.nystedhavmoellepark.dk).

August 25, 2005 The Danish Energy Authorities issued permission to ENERGI E2 to carry out an Environmental Impact Assessment (EIA) at Horns Rev with particular reference to the construction of 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.

During the demonstration project Horns Rev 1 Offshore Wind Farm a number of surveys were conducted regarding the distribution and abundance of fish. Sandeels are the most abundant species and they are furthermore of great commercial interest in the area. Due to this a special investigation was carried out to determine possible impacts on the distribution of sandeels from the wind farm (Jensen et al., 2003; Jensen et al., 2004).

Traditional fishing methods are difficult to use in the Horns Rev area due to the harsh weather conditions and strong currents. Therefore a hydro-acoustic method was introduced in order to gather information on the distribution of fish in the vicinity of the turbine foundations as well as in the sandy areas between the foundations. Two hydro-acoustic surveys were carried out in 2004 and 2005 (Hvidt et al., 2005; Hvidt et al., 2006).

The present EIA report comprises an assessment of the possible impacts from the establishment of Horns Rev 2 Offshore Wind Farm on the fish fauna and the fish communities within the area, including the turbines and interconnecting cables but not the main power cable from the transformer platform to land.

The assessment is based on available information and data from the area and on experience harvested in the demonstration projects in Horns Rev 1 Offshore Wind Farm.

A comprehensive literature study has provided information about the biology of the fish species already occurring in the area as well as species expected to be attracted to the area due to habitat changes caused by the wind farm.

A provision of supplementary information on existing sediment conditions in the wind farm area was necessary in order to assess the impact from the establishment of the wind farm on benthic fish communities, in particular sandeels. This constitutes the basis for modelling of potential habitats and distribution within the wind farm area, since the distribution of sandeels is closely correlated with specific sandy sediment types.

Assessment of the effects before construction, during construction, in the operational phase and during decommissioning of the turbines is included in the report along with an assessment of the cumulative effects of the establishment of a new wind farm.

2. Horns Rev

The Horns Rev area is an extension of Blåvands Huk extending more than 40 km towards 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 and 5 km.

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

2.1. Topography and sediment

Larsen (2003) gives a detailed review of the geological formation of the Horns Rev area. In terms of geo-morphology Horns Rev consists of glacial deposits. The formation of the reef probably took place due to glacio-fluvial sediment deposits in front of the ice shelf during the Saale glaciation period. The constituents of the reef are 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 thick, formed the Horns Rev area as it is known today with ongoing accumulations of sand (Larsen, 2003). Horns Rev can be characterised as a huge natural ridge, that blocks the sand being transported along the coast of Jutland with the current. The annual transport of sand amounts to approximately 500,000 m^3 (Danish Hydraulic Institute, 1999) or even more (Larsen, 2003).

Despite the overall stability Horns Rev is subject to constant changes due to continuous hydrographical impacts such as currents and waves and sedimentations of sand, the latter of which cause the surface of the reef to rise over time (Larsen, 2003).

In the Horns Rev 2 Offshore Wind Farm area the sediment consists of almost pure sand with no or very low content of organic matter (<1%) (Leonhard & Skov, 2006). Formations of small ribbles are seen all over the area, caused by the impact from waves and current on the sandy sediment. Tidal currents create dunes and ribbles, showing evidence of sand transport in both northerly and southerly directions (observed by SCUBA divers, 2005). Larsen (2003) gives a more detailed review of the sediment flow at and around Horns Rev, Figure 2.1.

All structures in the area apart from those in the tidal channels indicate that the prevailing sediment transport direction east of the reef is towards south and southeast (Larsen, 2003). Large spatial variation regarding the sediment grain size distribution exists, Figure 2.2, and effects of strong currents is found on slopes facing larger depths. Here coarse sand can be found (Leonhard & Skov, 2006).

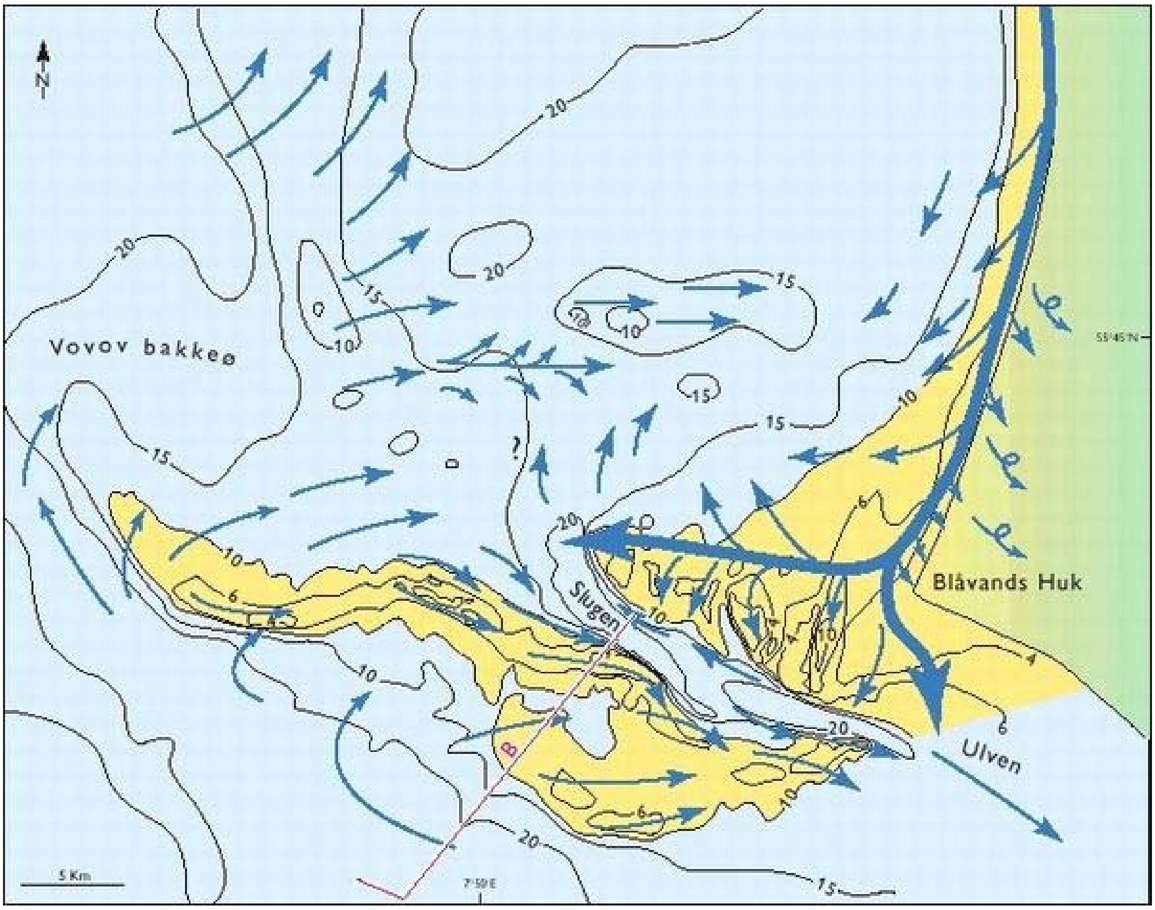


Figure 2.1 Possible sediment fluxes in the Horns Rev area. Accumulation takes place both on the plane seabed as well as on the slopes of spits and banks (After Larsen, 2003).

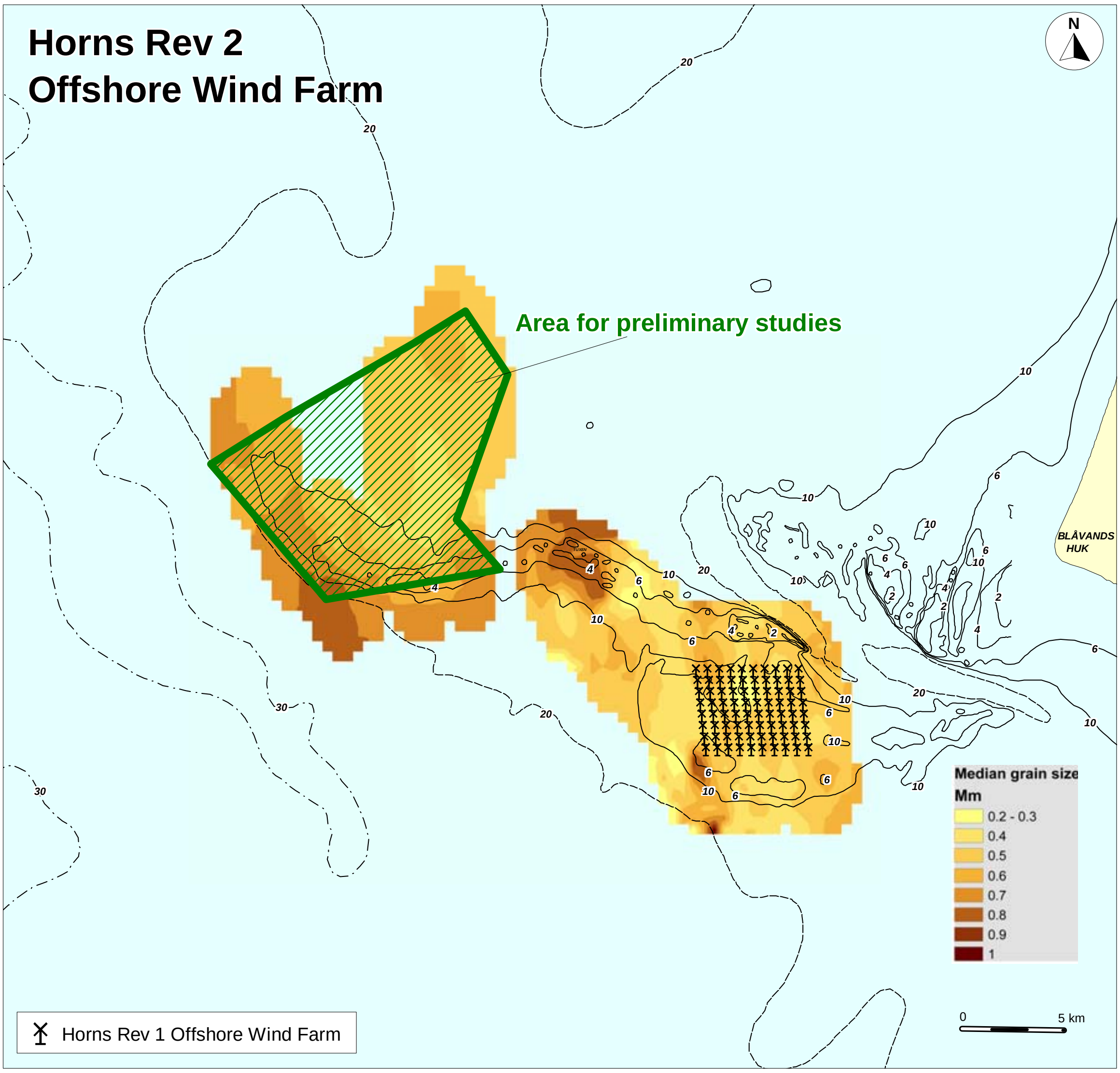


Figure 2.2. Map showing the distribution of sediment at Horns Rev, elaborated on basis of existing sediment data from the area.

2.2. Hydrography

Horns Rev is an area of relatively shallow waters, strongly influenced by waves and situated in and area with large tidal fluctuations. The mean tidal range in the wind farm area is about 1.2 m (Danish Hydraulic Institute, 1999). Within the wind farm area the water depth vary from about 4 m to 14 m. The bottom topography in and around Horns Rev along with the shallow waters causes the waves to be breaking in the wind farm area. The average height of the waves height is about 0.6 - 1.8 m.

The hydrography in the Horns Rev area is mainly determined by the intrusion of Atlantic water into the North Sea. Due to the hydrography of the North Sea most water moves erratically in northern direction towards Skagerrak in what is known as Jyllandsstrømmen (Leth, 2003).

However, regarding currents the tide is the most important source of currents at Horns Rev. The prevailing currents move in the north to south direction (220º SSW) with a mean water velocity of 0.5-0.7 m/s. Water velocities above 0.7 and up to 1.5 m/s are not unusual at Horns Rev (Bech et al., 2004; Bech et al., 2005; Leonhard & Pedersen, 2004; Leonhard & Pedersen, 2005).

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

The salinity in the area is 30-34 ‰, the level being determined by mixture of the Atlantic water with freshwater from the German rivers and relatively saline water from the North Sea.

Low transparency of the water prevails at Horns Rev due to high concentrations of suspended sediments in the water column is characteristic for the Horns Rev area, and consequently high temporal variability in the water transparency induced by the tidal currents, wind induced currents and seasonal plankton dynamics is found.

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 location of the wind farm.

The area selected by the Danish Energy Authority for the preliminary surveys and studies is shown in Figure 3.1. The establishment of the wind farm is expected to be in one of the designated 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.

For Horns Rev 2 Offshore Wind Farm two alternative sites are designated - a northern site and a southern. The northern site extends northwards from the reef. The southern site extents from east towards west and covers the reef only partly. Both sites cover and area of 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.

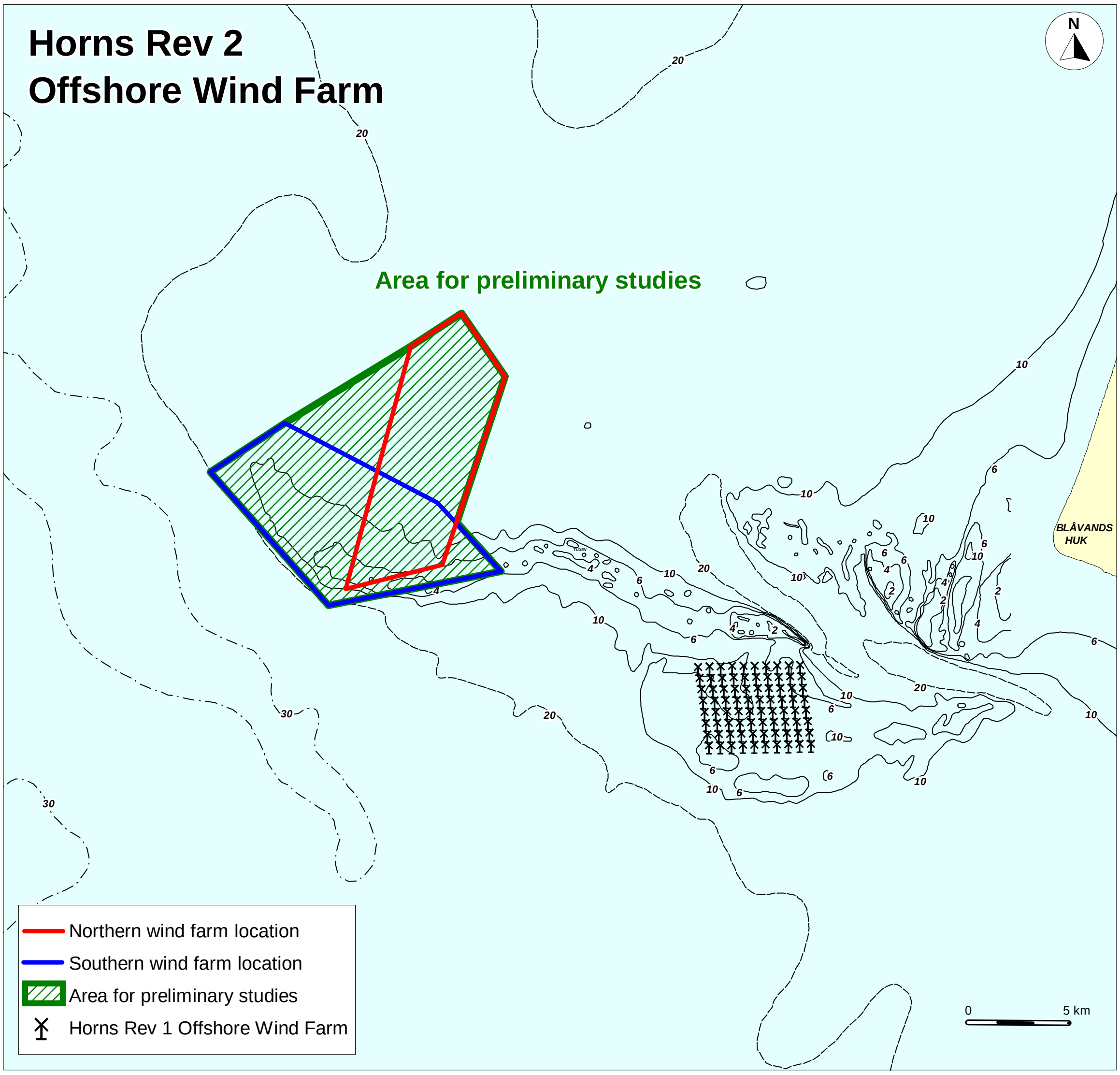


Figure 3.1. The area selected for the preliminary surveys and studies regarding the establishment of Horns Rev 2 Offshore Wind Farm.

3.2. The turbines

The type of turbine to be installed and the type of foundation has not yet been decided. Likewise the location of the turbines in either of the two designated sites has not yet been decided.

The wind turbine technology is undergoing rapid development with regard to design and effect as well as the physical size, and in order to ensure the possibility of taking advantage of this development all the way up to commencement of the construction, the final selection of the wind turbine type will not take place until 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.

Figures 3.2 and 3.3 show the expected row patterns of the turbines at the two alternative sites. However, the exact position is not yet mapped out as some adjustments may still be made depending on the results of the preliminary project and design studies.

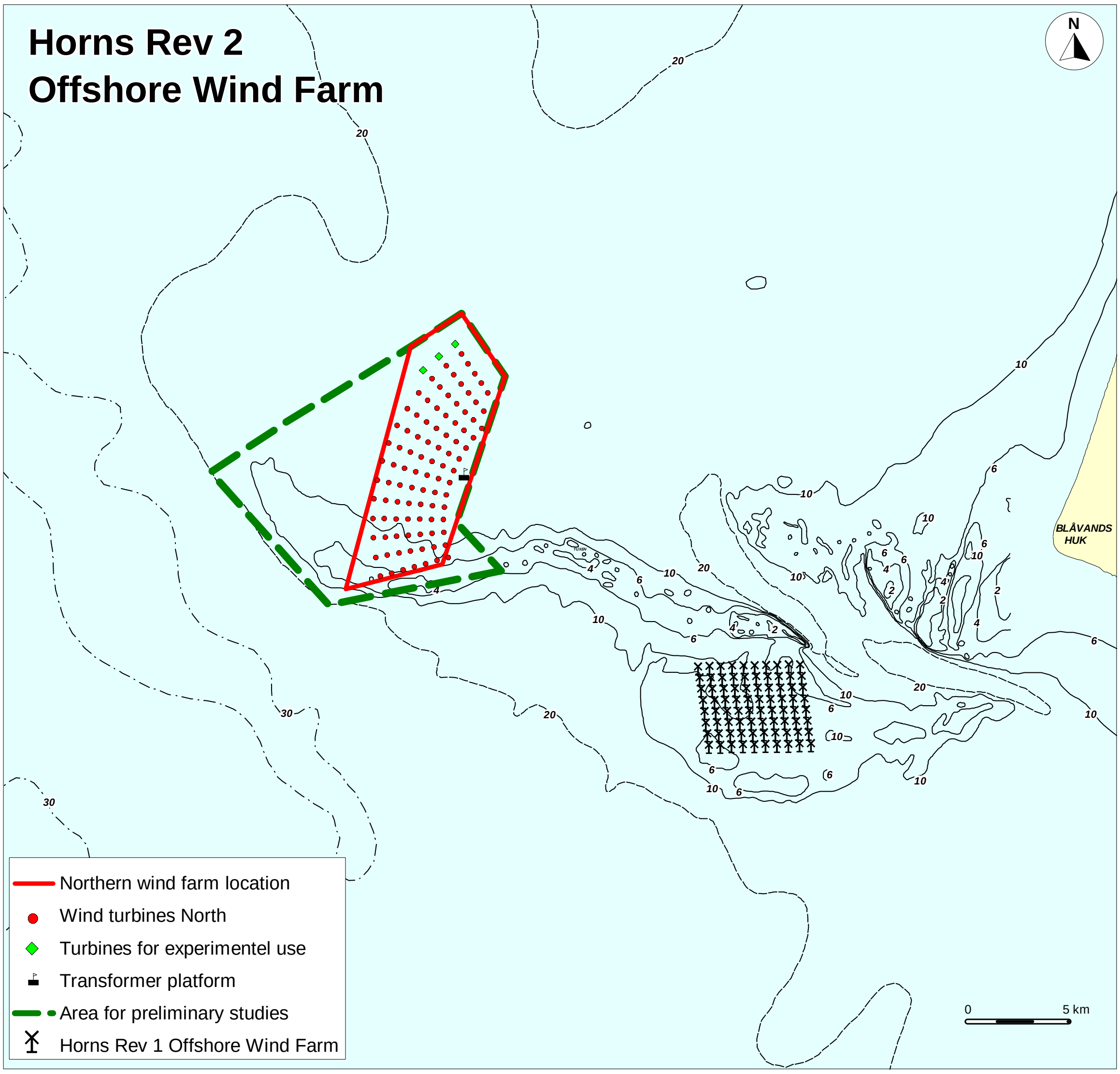


Figure 3.2. The proposed turbine positions at the northern site, the cable connecting the turbines and the transformer platform. Horns Rev 2 Offshore Wind Farm.

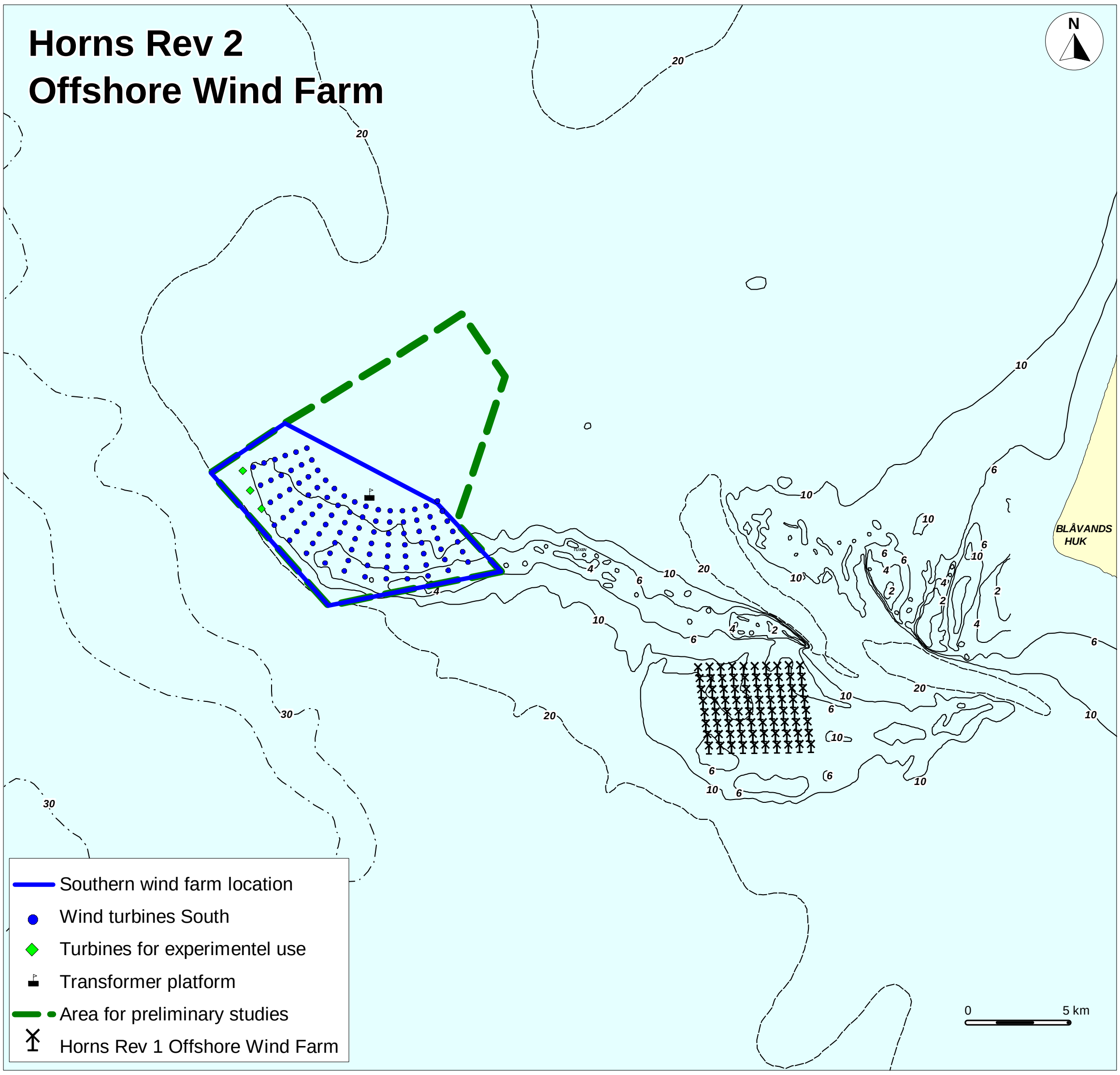


Figure 3.3. The proposed turbine positions at the southern site, the cable connecting the turbines and the transformer platform. Horns Rev 2 Offshore Wind Farm.

3.2.1. Foundation

The foundations of the turbines will either be gravitation foundations or monopiles. 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 0.2-0.3% of the entire wind farm area.

3.2.1.1. Gravitation foundation

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, but the weight of the basal disc is typically >1000 tones. The gravitation foundation is made of concrete or a steel case filed with heavy weight material such as stones, boulders and rocks. This type of foundation is typically used at water depths in the range 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. The scour protection is typically made from boulders and rocks.

3.2.1.2. The monopile foundation

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 metres into the seafloor, and has a diameter in the range 4-7 metres. The pile diameter and the depth of penetration are determined by the size of the turbine and the sediment characteristics. Opposite to the gravitation foundation no preparation of the seafloor is needed prior to the erection of the turbine. Pile driving is difficult if the seafloor holds large boulders hidden within the sediment. In such cases underwater blasting may be needed.

The monopile foundation also needs scour protection, especially when the turbine is situated in turbulent areas with high levels of flow velocities.

3.2.2. Scour protection

The scour protection is a circular construction with a diameter of 25-35m m depending on the type of wind turbine chosen. The scour protection is approximately 1-2m in height above the original seabed and consisting of a protective mattress of large stones with a subjacent layer of smaller stones.

3.2.3. The cable

The wind turbines will be interconnected by 33 kV cables sluiced down to a depth of one metre into the seabed. The cables will connect the turbines to a transformer platform. Each string of cable connects up to 14 turbines. From the transformer platform a submarine 150 kV power cable will be laid to shore. This cable is not included in the EIA.

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

3.2.3.1. Electromagnetic fields

Transportation of the electric power from the wind farm through cables is associated with formation of electromagnetic fields around the cables.

Electromagnetic fields emitted from the cables consist of two constituent fields: an electric field retained within the cables and a magnetic field detectable outside the cables. A second electrical field is induced by the magnetic field. This electrical field is detectable outside the cables (Gill et al., 2005).

In principle, the three phases in the power cable should neutralize each other and eliminate the creation of a magnetic field. However, as a result of differences in the distance between each conductor and differences in current strength, a magnetic field is still produced from the power cable. The strength of the magnetic field, however, is assumed considerably less than the strength from one of the conductors. Due to the alternating current, the magnetic field will vary over time.

4. Data sources

This chapter gives a short review of the data and information applied in the elaboration of the present EIA report. The report is mainly based on existing literature, and therefore the chapter contains no detailed descriptions of the methods except in cases where needed.

4.1. Sediment

Information about the sediment composition is considered important to assessments of both suspension events and fish habitats. On 28th January 2006 sediment samples were harvested in and around the Horns Rev 2 Offshore Wind Farm area.

Sampling methods and procedures are presented in (Leonhard & Skov, 2006) along with the results of the subsequent analyses of grain size distributions.

4.2. Questionnaire on fish at Horns Rev

In connection with the elaboration of a report on the commercial fishery in the Horns Rev area Krog interviewed a number of fishermen about the importance of Horns Rev as site of commercial fishing, including information about the species composition of the catch in the area (Krog, 2006).

In addition to this report, specific questions to 11 fishermen about their catches and personal observations were formulated in order get more detailed information on the fish communities and distribution in the wind farm area than could be obtained from the official fishery statistics and other available data sources. It deserves mentioning that commercial fishery at Horns Rev is mainly targeted on sandeels.

The results of the questionnaire are incorporated in the present report to support modelling of the sandeel habitats and to support the assessments of impacts on the fish fauna in the wind farm area.

4.3. Data on existing fish communities at Horns Rev

Information about the fish fauna and communities at and around Horns Rev is collected from various sources.

Fishery statistics have provided a substantial amount of quantitative data, but similar data have also been obtained from ICES surveys as well as surveys conducted during the Horns Rev 1 Offshore Wind Farm PSO programme (www.ICES.com).

The fishery statistics contain large amounts of data on the abundance of fish in the area. However, these data suffer from low geographical resolution and are thus not always fully attributable to the area of interest, although they are related to ICES squares.

Horns Rev 2 Offshore Wind Farm is located in the middle of ICES square 40F7. In the period 2000-2004 a total of 51 species was reported from this area. The high number of species was caused by the large habitat diversity in area represented by ICES square 40F7. The most abundant species in the catches in this specific ICES square were sandeels and sprat followed by plaice and cod. A more comprehensive description and assessment of the commercial fishery in the Horns Rev 2 Offshore Wind Farm area is given by Krog (2006).

The Dutch Fishery Institute conducted surveys around Horns Rev with scientific fishing gear in the period 1989-99 (Hoffmann et al., 2000). Unfortunately these data like the fishery statistics data suffer from poor geographical accuracy and are like most other data reported with reference to the ICES grid of squares (30x30 nautical miles). Nevertheless data from the Dutch surveys constitute a very important source of information about the fish fauna and communities in the area, especially the non-commercial species.

4.4. Modelling of sandeel habitat quality

Due to lack of factual information about the distribution and abundance of sandeel – one of the most important species at Horns Rev – the habitat quality was modelled on basis of sediment and hydrographical data. The model predictions were adjusted by incorporation of data from previous research sandeel fishery at Horns Rev (Jensen et al., 2003; Jensen et al., 2004). Further details on the modelling methods are given in (Leonhard & Skov, 2006).

The model predictions are used to assess the impacts from the wind farm on the potential and the factual sandeel habitats, the latter being described by Krog (2006).

4.5. Assessment methodology

4.5.1. Assessment of impacts

The main impacts of the establishment of Horns Rev 2 Offshore Wind Farm on the fish communities are identified and effects are assessed according to specific criteria shown in Table 4.1.

In determining the significance of an impact, ‘magnitude’ is assessed against ‘importance’ by ranging significance from ‘negligible’ to ‘major’ as shown in Table 4.2.

Table 4.1. 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 4.2. 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

4.5.2. Assessment of cumulative effects

Horns Rev 2 Offshore Wind Farm will be situated 10 - 12 km from Horns Rev 1 Offshore Wind Farm, the exact distance depending on which of the two mentioned areas become selected. Due to the presence of Horns Rev 1 Offshore Wind Farm close to the planned Horns Rev 2 Offshore Wind Farm area, cumulative effects will be evaluated. Likewise, cumulative effects from marine sand and aggregate extraction south of Horns Rev 1 Offshore Wind Farm will be evaluated.

Although the impacts from Horns Rev 2 Offshore Wind Farm are primarily assessed on its individual merits, it is possible that due to the presence of a similar wind farm only 10 - 12 kilometres away, will have impacts from the latter and therefore must be taken into consideration as cumulative impacts. Likewise regarding the effects on the biota in the area.

Similarly cumulative impacts and effects can be generated by the joint impacts from various activities in the lifetime of the wind farm

5. Existing fish communities

Horns Rev is a strongly wind exposed shallow water reef dominated by medium fine – coarse sandy sediments. Therefore the area is strongly affected by resuspension events caused by the wave action and the strong currents that prevail. This fact of nature set to large extent the basic terms of living for the fish communities, and determines thus the composition of the existing fish communities, qualitatively as well as quantitatively.

5.1. Basic characteristics

Current adapted species are typically found in areas with strong currents, e.g. Horns Rev, and they typically outnumber non-adapted species in such environments.

Adaptation of the species to the environment includes both morphological and behavioural features. Morphologically adapted species include oblong or needle shaped fish, flatfish and dorso-ventrally compressed fish. The needle shaped fish include needlefishes and sandeels whereas the dorso-ventrally compressed species include hooknose, dragonets and gurnard species. Generally, morphological adaptation in such rough environment enhances down force and helps the fish to maintain their position in an energetically profitable way. Behavioural adaptation is found in sand gobies and in all species of sandeels registered in the North Sea.

5.2. Species recorded at Horns Rev

The knowledge about the fish communities in the Horns Rev area is relatively sparse, mainly because traditional fishery is difficult to undertake due to the harsh weather conditions and strong currents.

Recently horizontal hydro-acoustic surveying, has been used to obtain information about the fish fauna and the distribution of the fish in Horns Rev Offshore Wind Farm area. A hydro-acoustic survey performed in the autumn of 2005 along with a survey using gill nets and trawling to identify occurring fish species in the area (Hvidt et al., 2006). Sand goby and sandeels were the most numerous species, but also plaice and dab were abundant in this survey.

Judged on basis of the available information about the fish fauna at Horns Rev the most common fish species are identified and ranked according to abundance, see Table 5.1.

*Table 5.1. List of the 10 most common fish species reported in four surveys at Horns Rev. (Hoffmann et al., 2000; Jensen et al, 2003; Jensen et al, 2004; Bio/consult, 2006). For each survey the species are ranked according to abundance/catch frequency. * Mainly lesser sandeel. ** Mainly great sandeel.*

Rank	Reported by fishermen 2000-2004	Dutch test fishery in the ICES square 40F7 1989-99	DFU trawling at Horns Rev 1 Offshore Wind Farm 2002 and 2004	Bio/consult trawling and gill nets at Horns Rev 1 Offshore Wind Farm 2005
1	Sandeel spp.	Dab	Sandeel spp.**	Sand goby
2	Plaice	Plaice	Sand goby	Sandeel spp.*
3	Sprat	Hooknose	Plaice	Plaice
4	Herring	Whiting	Dragonet	Dab
5	Atlantic cod	Dragonet	Dab	Horse mackerel
6	Sole	Grey gurnard	Whiting	Scald fish
7	Dab	Solenette	American plaice	Atlantic cod
8	Turbot	Goby spp.	Pipefish spp.	Red mullet
9	Flounder	Sole	Sprat	Dragonet
10	Haddock	Scald fish	Herring	Goldsinny wrasse
Note	-	Sandeel spp. NO. 21	-	-

The three Danish surveys list sandeels, plaice, dab and dragonet as the most common or frequent species. Species of goby are probably also common and widespread, but their distribution and frequency is likely to be underestimated because of their modest size in relation to the mesh sizes of the fishing gear.

Contrary to the Danish investigations the Dutch investigation does not list sandeels among the most common species in the Dutch investigations. Sandeels were ranked as number 21 in the Dutch investigation. A possible explanation is that the ICES area 40F7 is very heterogeneous as regards topography and sediment. The fishery survey was probably done at soft bottom and deep-water habitats, which are not typical sandeel habitats. This explanation is supported by the high catches of hooknose in the Dutch investigations. The hooknose prefers soft bottom and deep water to the more sandy sediments and shallow waters (Muus et al., 1998; Power & Attrill, 2002) that prevail at Horns Rev.

Regarding the fish fauna the Horns Rev area is characterized as a *Pleuronetctes platessa – Limanda limanda* community as described by Ellis, et al., 2000 and Kayser, et al., 2004. This community is founded on dominant presence of plaice and dab of cause, but also invertebrates such as the swimming crab (*Liocarcinus depurator*) and hermit crab (*Pagurus bernhardus*) occur in high number in this community. The latter species were also found at Horns Rev during fishery in 2005 and during infauna surveys (Beck et al., 2004; Hvidt et al., 2005; Leonhard & Klaustrup, 2005).

The *Pleuronectes platessa-Limanda limanda* community differs from the species composition of less sandy habitats, and therefore - in the present study - it is relevant to focus on the investigations carried out in the Horns Rev 1 Offshore Wind Farm area which is comparable to the Horns Rev 2 Offshore Wind Farm area especially from a sediment point of view. Special attention will be given to species that occurred with high densities in the investigations at the Horns Rev 1 Offshore Wind Farm area; i.e. sandeels and plaice, as these species are important ecologically as well as economically. Other species of ecological importance will also be discussed.

5.2.1. Sandeels (Ammotytidae)

A total of five species of sandeels are recorded in the North Sea: small sandeel, lesser sandeel and smooth sandeel that are planctivorous, and great sandeel and greater sandeel that are partially piscivorous (www.fishbase.org). Only small sandeel, lesser sandeel and great sandeel are common at the Horns Rev area.

Sandeels play an important role in the ecosystem at Horns Rev. Being planctivorous with a diet mainly consisting of zooplankton they constitute an important link between the lower and higher levels in the food web. The sandeels serve as food items for other fish species especially, haddock, cod, plaice turbot and Atlantic mackerel, and as important prey for some sea birds and marine mammals. (Furness, 2002; Lewy, et al., 2004; Temming et al., 2004; Daan, 1973; Link & Garrison, 2002; Muus et al., 1998: Kaiser et al., 2004). In addition the sandeels are important commercial species.

Generally, sandeels has high affinity of the turbulent sandy areas that are commonly represented at Horns Rev. A strong correlation between abundance of sandeels and sediment grain size has been documented (Wright et al., 2000; Jensen, et al., 2003; Temming, et al., 2004). The highest densities of sandeels are thus found in areas with a median grain size of 0.25-2 mm (diameter). Likewise, investigations have also shown that a weight fraction of silt/clay plus very fine sand of 6% is the limit above which sandeels avoids the sediment (Wright et al., 2000; Jensen et al., 2003; Temming, et al., 2004).

According to the result of the habitat suitability model, high habitat quality is found in 10.6 % of the northern site and 5.7 % of the southern location, Figure 5.1. Medium habitat quality is found in largest area in the southern site. Comparing the result of the model with knowledge of the main sandeel fishing areas no correlation was found. The differences are presumably due to the time of day or the season that input data for the model was collected in relation to the fishing season. The fishing season is normally from April to September with a peak in May, whereas the sandeel surveys at Horns Rev 1 Offshore Wind Farm were conducted during February-March, 2002 and March 2004. Likewise, preferred habitat suitability for burying may not be the best habitat for catching sandeel and is therefore avoided by the fishermen.

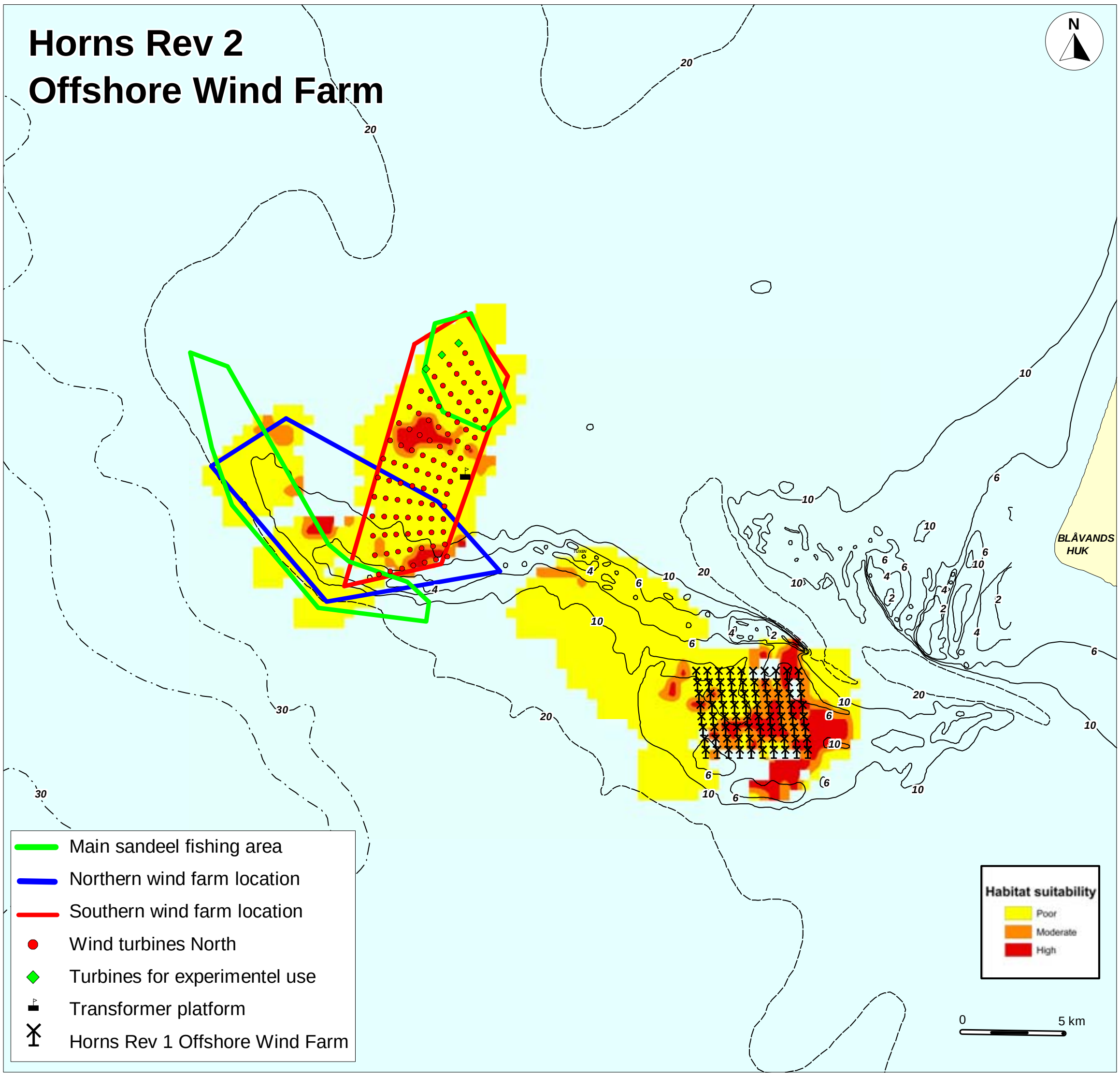


Figure 5.1. Map showing modelling results regarding the habitat quality for sandeels. In addition, the map also shows the main existing sandeel fishing areas.

Sandeels display a significant diurnal variation regarding activity. They feed actively during daytime while remaining inactively buried in the sediments during night-time. Furthermore they also display an annual variation, being active feeders during summertime while remaining inactively buried in the sand during wintertime.

The sandeel are demersal spawners, which means that they spawn their eggs at the surface of the sediments. The spawning areas are expected to be identical to the residence areas of adult sandeels. Hatching is followed by a 1-3 months long planktonic larval stage. The juvenile sandeels remain in the area where they have settled (Jensen et al. 2003), i.e. they do not migrate much.

5.2.2. Plaice

Plaice is the most frequently found species among the flatfish (Pleuronectiformes) in the Horns Rev area. Thus, plaice is considered a good indicator in the assessment of the flatfish habitat quality at Horns Rev.

Food composition and availability is generally assumed to be the most important distribution factor although also the physical habitat parameters such as sediment composition, current and wave exposure are of considerable importance.

Plaice depend on the access to sediments that allow the fish to bury themselves in all stages of life, and the correlation between sediment grain sizes is clear. Smaller individuals prefer finer grains while larger individuals prefer more coarse sediments. Due to the generally strong currents at Horns Rev there is a lack of finer sediments, and as a consequence of this the abundance of young plaice is low while the abundance of older plaice is high. The latter classifies Horns Rev as an important habitat to plaice and other species of flatfish, especially dab, which is reflected in Table 5.2. Plaice forage primarily on molluscs and polychaetes.

Plaice is an opportunistic species and its diet in the Horns Rev 2 Offshore Wind Farm area is supposed to consist of the most abundant or active species of invertebrates. At Horns Rev the most abundant species are found to be the bivalves *Ensis americanus*, *Goodallia triangularis* and the polychaete *Travisia forbesii* (Leonhard & Skov, 2006).

Especially *Ensis americanus* is found in the area. Furthermore, *Ensis americanus* is also found to be one of the preferred food species to plaice. Additionally, sand gobies and common shrimp are supposed to be an important part of the diet of the plaice, although not as important as the bivalves (Rijnsdorp & Vingerhoed, 2001).

5.2.3. Sand goby

Based on the existing data and information, sand goby is probably the most common and abundant fish species at Horns Rev regarding density of individuals. However, due to the small body size the total biomass of sand goby is small and constitutes only a marginal fraction of the total fish biomass in the area.

Sand gobies larger than 25-30 mm actively migrates to deeper areas typically beyond 10 metres, where they spawn. Hence, sand gobies are expected to use the deeper parts of Horns Rev to spawn (Fonds, 1973).

Horns Rev may also be an important foraging area despite the fact that gobies constitute an important food source to piscivorous species in the area and therefore are subjected to a high level of predation. A study of stomach content has shown that sand gobies feed mainly on small crustaceans like copepods, amphipods and mysids (Fonds, 1973). They may therefore play an important role linking the lower levels in the food chain with the higher levels.

5.2.4. Dragonet

Dragonet is registered in high densities at Horns Rev. In recent decades dragonet has become a more common and abundant species in the area and it is today among the common species at Horns Rev (Jensen et al., 2003).

The dragonet is registered at both soft and sandy sediments, but is also observed to seek shelter from the harsh current regimes in the vicinity of mussel banks and reef areas (turbine foundations at Horns Rev 1 Offshore Wind Farm). Dragonet is an opportunistic feeder with a diet consisting mainly of invertebrate species such as bivalves and polychaetes (Prista, et al., 2003).

5.2.5. Atlantic cod

Atlantic cod is not primarily connected with sandy habitats, but are found in a found in a wide range of habitats. However, despite the sandy environment Horns Rev can be of potential importance to cod as foraging area because it here finds an abundance of some of the preferred food items such as shrimps, sand gobies and sandeels (Stensholt, 2001; Daan, 1973). Furthermore, Atlantic cod is known to forage in relation to boulder reefs.

5.2.6. Fish of conservation interests

Five of the fish species recorded at Horns Rev during the last 17 years are listed in the Red data book of endangered species in the Wadden Sea. Grey gurnard, lesser weaver and snake pipefish are strictly marine species, whereas sea trout and river lamprey are diadromous species, i.e. they spawn in freshwater rivers. All the red-listed species of the Wadden Sea are recorded at Horns Rev (Hoffmann et al., 2000).

Furthermore, the Bern Convention on the conservation of marine wildlife and natural habitats has listed sand goby and common goby as species, the conservation of which requires cooperation between states (countries). Additionally, the EU Habitats Directive has listed the two shad species (allis shad and twaite shad) as species of conservation interest along with river lamprey and salmon (in freshwater), all of which are species that requires establishment of adequate protection measures.

Sand goby and river lamprey are both found at Horns Rev. The rest of the species mentioned may occur occasionally at Horns Rev.

5.3. Commercial versus non-commercial fish species

Fish species are traditionally divided into two groups, commercial and non-commercial species. This separation is artificial and in many respects inappropriate because the ecological interaction between the two groups is significant, and non-commercial species thus have a significant influence on the commercial species. The reason that non-commercial species are often “forgotten” in studies of fish biology and ecology is that they are normally not included in fishery statistics. Therefore it is difficult to assess their importance, occurrence and influence on economical interesting species.

Because of the sparse amount of interaction data available for sandy habitats, no ecological modelling of the fish community will be applied in this report. The report however includes modelling of the distribution of sandeel habitats due to the close linkage between sandeels and sediment grain size without incorporation of biological interactions. Furthermore, an updated list of the most abundant species at Horns Rev is presented.

5.4. Hearing abilities in fish

For auditory sensing fish use the lateral line, the ear and the swim bladder. However, not all fish have a swim bladder. Both the lateral line and the ear detect water motions; the lateral line is sensitive to relative movements of a few Hz to several thousands Hz between the fish and the surrounding water; the ear is responsive to the relative motion between the otoliths (the saccule, lagena, and utricle) and the fish's body, and to sound pressure (Popper & Fay, 1993). The otolith organs of fish are capable of detecting particle motion 'directly' via the inertial response of the otoliths to motion, and 'indirectly' via the swim bladders fluctuating volume in a pressure field.

Additionally, the lateral line detects particle motions outside the body of the fish, and is probably used to detect nearby prey or predators. The lateral line itself detects movements in the surrounding water and is also, like the ear responding over a frequency range of a few Hz to 200 Hz. Additionally, the lateral line has in some species pressure detection abilities if connected to the swim bladder.

The difference in hearing between fish species is caused by some adaptations. Fish having specialisations that enhance hearing have been referred to as hearing "specialists", whereas fish that do not have such specialisations (e.g. Weberian ossicles, swim bladder diverticulae and gas filled bullae) are referred to as hearing "generalists". Hearing "specialists" tend to detect sound pressure with greater sensitivity and in a wider bandwidth than "generalists".

In the context of this report the ability of fish to sense noise and vibration is considered very important since a wind farm generates noise and vibrations during all phases of its life cycle.

5.4.1. Hearing generalists

The hearing "generalists" are quite insensitive to sound frequencies above 1-3 kHz, but sensitive to low frequencies, i.e. not only audible sounds but also vibrations in the subsonic range.

Some hearing "generalists" have a swim bladder while others lack a swim bladder. It is generally assumed that presence of a swim bladder will enhance the hearing capability since the swim bladder enhance the particle displacement aspect of the sound stimulus by transducing the sound pressure to particle displacement (Bone et al., 1995).

The hearing capability of "generalists" without a swim bladder is considerably lower than the hearing capability of "generalists" with swim bladder. As a result of this, hearing capability of "generalists" without a swim bladder will decrease quickly above 0.1 kHz. This is due to the fact that frequencies above 0.1 kHz can only barely affect the otoliths alone and make them oscillate without the amplifying effect of the swim bladder. Fish without a swim bladder are therefore virtually deaf at frequencies above 0.25 kHz (Westerberg, 1993). Furthermore, generalists with a swim bladder can be divided into two groups, one group having a duct from the swim bladder to the inner ear, and the other group not having this physiological specialisation. The duct makes some generalists capable of detecting sound frequencies as high as 3 kHz, whereas fish without duct are sensitive to frequencies up to approximately 0.5 kHz. The Atlantic cod has two air filled ducts, which is why cod has better hearing than most other generalists (Westerberg, 1993, Engell-Søensen & Skyt, 2002).

It has recently been questioned whether the swim bladder serves an auditory enhancement function in bonefish that lack a mechanical coupling between the swim bladder and the inner ear (Yan et al., 2000).

5.4.2. Hearing specialists

Behavioural studies have shown that several species of hearing "specialists" can detect sounds up to 180 kHz (or even higher), whereas hearing "generalists" can only detect sound frequencies below 1-3 kHz.

As previously mentioned hearing "specialists" among fish have evolved specialised structures (e.g. Weberian ossicles, swim bladder diverticulae and gas-filled bullae) to enhance their auditory frequency range and threshold sensitivity.

Hearing-"specialists" are primarily pressure-sensitive. The response to sound pressure is thought to be mediated by a coupling between the swim bladder or gas-filled bullae in the head of the fish and the inner ear. Due to this coupling the motion of the swim bladder or bullae, as it expands and contracts in a pressure field, is transported to ear by particle motion.

The hearing "specialists" comprise three different groups (Yan, 1998):

1. Fish in which the first three vertebrae of the vertebral column have been modified into the Weberian ossicles. These ossicles physically connect the rostral end of the swim bladder to the fluid system of the inner ear at the midline between the two saccules. No fish of this type is known at Horns Rev.

2. Fish with rostral projections of the swim bladder directly to the ear. No fish of this type is known at Horns Rev.

3. The presence of separate gas-containing bullae in the head close to the inner ear. This type of fish is represented by clupeoides (herring-like fish) at Horns Rev.

Specialisations of hair cell orientation patterns also appear to be closely associated with enhanced hearing, regardless of which organs are involved (Popper & Fay, 1993). Table 5.2 gives an overview over physiological adaptations to hearing among fish.

Table 5.2. Physiological adoptions in hearing generalists and specialists among fish and their sensitivity to noise (From Nedwell et al., 2003). Species in bold letters are common at Horns Rev.

Species	Common name	Family	Swim bladder connection	Sensitivity
Raja clavata	Thornback scate	Ralidae	No swimbladder	Low
Anguilla anguilla	European eel	Anguillidae	None	Medium
Clupea harengus	**Herring**	**Clupeoidae**	**Prootic auditory bullae**	**High**
Sprattus sprattus	**Sprat**	**Clupeoidae**	**Prootic auditory bullae**	**High**
Myoxocephalus scorpius	Short-spined sea scorpion	Cottidae	No swimbladder	Low
Gadus morhua	**Atlantic cod**	**Gadidae**	**None**	**Medium**
Merluccius merluccius	European hake	Gadidae	None	Medium
Melanogrammus aenglefinus	Haddock	Gadidae	None	Medium
Scomber scombrus	Atlantic mackerel	Scombridae	None	Medium

Pleuronectes platessa	**Plaice**	**Pleuronectidae**	**No swim bladder**	**Low**
Limanda limanda	**Dab**	**Pleuronectidae**	**No swimbladder**	**Low**
Ammotyidae indet.	**Sandeel indet.**	**Ammotyidae**	**No swimbladder**	**Low**

5.4.3. Hearing thresholds in fish species

The human ear is capable of hearing frequencies from approximately 20 Hz to 20 kHz. Sounds above 20 kHz are ultrasonic and not detectable, whereas sounds below 20 Hz are sub- or infrasonic and only detectable to few people with extreme hearing abilities. The hearing threshold in fish, regarding both bandwidth and level, differ significantly between fish species, and to fish sound levels above 1 kHz is considered as ultrasonic, i.e. above the hearing threshold to most fish species. Within the hearing range each species has a frequency band where hearing is most acute (Approximate peak range (Hz)), Table 5.3.

Regarding underwater acoustics the range from 0 - 300 dB re 1µ Pa represents sound levels from very low to very high. To integrate sound in models a generic dB_{ht} (deciBel hearing threshold) scale has been developed. This scale weights the sound pressure level (SPL) at different frequencies bandwidth. Noise levels in excess of 90 dB above the threshold level (dB_{ht} species) may induce behavioural effects, especially avoidance reactions, provided that the noise is within the detectable frequencies band (Nedwell & Howell, 2004). The hearing abilities in some fish are presented in Table 5.3.

The denotation of sound in water is re 1µ Pa - 1m, and represents the pressure level at 1 metre from the source. However, noise is rarely measured 1 metre from the source due to complex interactions causing irregularities in the sound filed near the source. Therefore, indirect measurements in the far field are more often used for calculation of the re 1µ Pa - 1m unit, using linear regressions.

*Table 5.3. Overview over important parameters for hearing abilities among selected fish species. *(Nedwell et al., 2004a) ** (Suga et al. 2005) ***(Belanger & Higgs). Peak frequency indicates the part of the overall hearing frequency range to which the species are particularly sensitive.*

Species	Scientific name	Hearing frequency (Hz)	Approximate peak frequency (Hz)	Threshold at peak frequency (Hz), dB re 1µ Pa - 1m.
Atlantic cod*	*Gadus morhua*	10-800	20-100	63.4-94.8
Dab*	*Limanda Limanda*	30-300	110	89
Haddock*	*Merluccius merluccius*	30-500	100-300	80.4-84.9
Herring*	*Clupea harengus*	20-4000	50-200	75
Ling*	*Molva molva*	40-600	200	80.8
Pollack*	*Pollachius pollachius*	40-500	200-300	91.6-91.9
Atlantic salmon*	*Salmo salar*	30-400	160	95.2
Little skate*	*Leucoraja erinacea*	100-1000	200	123
Japanese sandeel**	*Ammodytes personatus*	128-512	128-181	116
Round goby***	*Neogobius melanostomus*	100-600	-	140

6. Sources of impacts

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

Each of these 4 phases are associated with various impacts or impacts of different strength on the site of location of the wind farm and the associated fish fauna, resulting in a number of effects that will be reviewed and assessed in chapter 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, Table 6.1:

Table 6.1. Overview over the main sources of impacts associated with the different phases or life stages of an offshore wind farm. The sources are listed without indication of relative importance.

Source of impact	**Phase**			
	Pre-construction	Construction	Operation	Decommissioning
Noise and vibrations	X	X	X	X
Suspension of sediments	X	X		X
Electromagnetic fields			X	
Traffic	X	X	X	X

In addition to these main impacts some of the phases and the overall establishment of a marine wind farm is connected with other sources of impacts, among which the physical loss of natural habitats and the likewise physical introduction of new habitats deserves special mentioning as negative respectively +/- positive impacts.

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. Noise in the Horns Rev area is generated by such physical actions as wind, wave, rain, and ice scouring. 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 and the 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, and sound produced during the construction and decommission phase is 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 are 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 are originates from various sources. The most intense and thus most significant noise is generated during piling of foundations (Table 6.2). The piling is expected to continue for several months and may drown all other noises during that period.

The anthropogenic noise sources associated by the establishment of an offshore wind farm are many. The most significant activities and their associated peak sound level (dB re 1µ Pa) and the frequency bandwidth (Hz) is shown in Table 6.2.

*Table 6.2. Noise generated construction activities associated with establishment of an offshore wind farm. For comparison is listed 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

Avoidance reaction is present when 50 % of a group of individuals show escape response. Strong avoidance reaction is present when 80 % show escape response (Nedwell et al., 2003). The distances of avoidance in Table 6.3 are generated using pile driving activity as source of noise.

Table 6.3. Distances of avoidance for 3 fish species (Nedwell et al., 2003).The three species listed in the table are primarily selected due to existence of data. Furthermore Atlantic cod (hearing "generalist" with swim bladder) and dab (hearing "generalist" without swim bladder) are both present at Hors Rev while salmon, only infrequently present at Horns Rev, is selected as representative of "generalists" with poor hearing capabilities.

Species	Scientific name	Distance of avoidance (m)
Salmon	Salmo salar	1,400
Atlantic cod	Gadus morhua	5,500
Dab	Limanda limanda	1,600

7. Assessments of effects

7.1. General effects

This chapter gives an overview over the general effects of the main impacts and serves as reference or background information to the assessments listed for each of the main impacts in the four phases.

7.1.1. Effects of noise and vibrations on fish

Generally, the amount of information on the impact of sound (noise and vibrations) on fish is sparse, and the assessment is made under the assumption that the ability to detect sound (noise and vibrations) is more or less the same within all fish families occurring at Horns Rev.

The effect of noise on fish is dependant on several factors. In addition to the frequency (Hz) and the sound pressure level (dB) also the background sound level affect the resulting response of the fish to man-made noise. Furthermore, the angle between the fish and the source as well as the distance between the fish and the source of noise are of importance to the overall effect of the noise on the fish.

The response to noise in fish differs from species to species (Wahlberg & Westerberg, 2005). As already mentioned, not all species have a swim bladder or other morphological structures that enhance hearing abilities. Therefore differences exist among fish regarding the ability to detect sound (noise and vibrations) (table 5.3), and therefore the effect of noise is expected to vary much among species and groups of fish.

For assessment of the effects of noise and vibrations it is necessary to distinguish between frequencies between 20 Hz and 1 kHz (hence forward designated as the pressure component) and frequencies below 20 Hz (hence forward designated as the acceleration component). Hearing specialists and generalists with swim bladder are able to detect noise frequencies between 20 Hz and 1 kHz, and generalist without swim bladder may only detect noise (vibrations) below 20 Hz.

7.1.1.1. Pressure component (acoustic field)

The figures in Table 5.3 and Table 6.2 show that fish can detect almost all the man-made sounds (noises and vibrations) associated with the establishment and operation of an offshore wind farm, Table 7.1, if no ambient noise exists.

Pile driving and seismic surveys are the activities expected to have the highest impact on most fish species, but also vessel activity is expected to impact on fish. Unfortunately, no firm information exists on the decrease of energy of the noise with increasing distance from the source (transmission loss), and thus the spatial effects cannot be derived from these tables. However, at water depths below 50 m transmission loss may be described by cylindrical dispersion (10 log R, R = radial distance from the source of noise). Several field studies indicated a higher transmission loss in shallow waters, depending on local conditions (Nedwell et al., 2003; Nedwell and Howell, 2004), whereas another study predicted a small transmission loss in shallow water at frequencies below 1 kHz and depths below 20 metres (Wahlberg & Westerberg, 2005), indicating that noise in this frequency range may be transmitted over long distances.

Information about the ability of fish to detect noise is derived from Table 5.4 Atlantic cod - a hearing generalist with swim bladder - is of interest because is it present in the wind farm area and may represent the group of fish with well developed swim bladder, and salmon - also a generalist but normally with an only small amount of air in the swim bladder – is of interest because it represents the group of fish without or with poorly developed swim bladder.

Sound detection in fish depends on several parameters. The detection threshold can be described as:

$$DT = SL - TL(r) - HT$$

DT = Detection threshold

SL = Source level

TL = Transmission loss

HT = Hearing threshold

The hearing threshold limits the hearing capability of all flatfish and sandeel at Horns Rev, whereas the cod, whiting and horse mackerel may be limited by the ambient noise through transmission loss. Hence, effect of noise within the acoustic field is only expected in species limited by the ambient noise.

Table 7.1 shows the detectable ranges of turbine noise of three different species at two different wind speed regimes. The figures in Table 7.1 rest on the assumption that fish can detect turbine noise at a sound level similar to or marginally above the background level.

The ratio between the man-made noise and the background noise is essential to assessment of the resulting impact from the sources of man-made noise on fish. The detection distance of cod decreases significantly if the turbine noise is 10 dB (arbitrary) above the background sound level. The calculated distances are 1.5 km and 2 km respectively at wind speeds of 8 m/s and 13 m/s.

In the assessment of the spatial impact of noise on fish two conservative values - 5 km and 10 km (slightly less than the 7 km and 13 km listed in Table 7.1) have been chosen to illustrate the affected area as regards Atlantic cod.

Table 7.1. Estimated detections distance of turbines at different metrological conditions (masking noise), (Wahlberg & Westerberg, 2005). Goldfish – a freshwater fish with swim bladder and physiological adaptations - is included for comparison.

Wind speed (m/s)	Atlantic cod (generalist)	Atlantic salmon (generalist)	Goldfish (specialist)
8	63 Hz / 13 km	100 Hz / 0,4 km	63 Hz / 25 km
13	180Hz / 7 km	100 Hz / 0.5 km	180Hz / 15 km

The fact that fish are able to detect noise does not necessarily imply that the noise induces an avoidance reaction. Information on the spatial avoidance reaction among fish is given in Table 6.3.

In an experiment the abundance of Atlantic cod was found to increase with a factor 2 in the vicinity of a turbine when the turbine was stopped (Wahlberg & Westerberg, 2005), which indicates that an avoidance response to the turbine noise occurred. Avoidance is also expected to occur at Horns Rev, although the temporal and spatial extent of the reaction is not known. Affected distances may however be less than indicated by the figures table 7.1 because of the high levels of ambient noise at Horns Rev (waves etc.).

7.1.1.2. Acceleration components (particle acceleration)
At frequencies below approximately 20 Hz fish seem to be affected by the particle acceleration (vibrations) rather than by the pressure component of the acoustic field. The maximum displacement at turbine towers is 0.5 m s^{-2} (Wahlberg & Westerberg, 2005). Salmon and possibly also other species may show avoidance by particle displacements in excess of 0.01 m s^{-2}.

Vibrations generated by wind turbines are either monopole (one source of noise) or dipole (two or more sources of noise). The particle displacement of a monopole sound source drop below 0.01 m s^{-2} at approximately 7 metres from the source or origin (turbine), whereas the critical range of a dipole source is approximately 4 metres.

Fish without swim bladder are virtually deaf to noise in the acoustic field and use instead particle displacement as their way of “hearing”. The group of fish without swim bladder is at Horns Rev represented by the flatfish species plaice and dab as well as the sandeels. These species are therefore expected to avoid frequencies below 20 Hz wherever the particle displacement exceeds 0.01 m s^{-2}, i.e. in the vicinity of the turbine towers.

7.1.1.3. Effect on biological interactions
Fish are known to utilise biological noise to obtain information about the environment in terms of presence of prey and/or predators (Popper, 2003). Man-made noise may- to the extent that it does not induce avoidance - mask the biological noise and thereby weaken the fish’ ability to obtain information about their immediate surroundings.

In addition, acoustic communication is frequently used among fish in courtship and expression of aggression and may thus play an important role to many fish species. Haddock, a gadoid (cod-like fish) species, uses sound as a mean of communication during spawning. Haddock sends out grunts in the range 114 to 120 dB with frequencies ranging from 200 to 500 Hz. This frequency range coincides to large extent with that of the sound image created by turbines. Assuming a detection threshold of 0 dB, the distance of communication in haddock is calculated to be approximately 4 metres with a background noise of 82 dB created by wind speed of 13 m/s (Wahlberg & Westerberg, 2005). This range in communication may also be found in other gadoid species such as the cod, but no documentation exists.

At distances where wind farm noise exceeds the background noise, communication among fish may be inhibited Thus, noise is expected to impact on fish behaviour; especially among hearing generalists with swim bladder and specialists that utilise reefs as foraging areas.

7.1.1.4. Habituation to noise and hearing loss

Fish exposed to devastative sound levels or high impacts of sounds for prolonged periods of time may be subject to permanent loss of hearing abilities and thus become more vulnerable to predators and/or become unable to detect prey as usual. Both effects will reduce the probability of survival and may induce reduced growth.

However, it is possible that fish becomes habituated if they are exposed to modest noise levels even for prolonged periods of time (Wahlberg & Westerberg, 2005) and it has also been found that fish can regenerate their sensory hair cells (Popper, 2003) after short exposures to devastative sound levels. As it is the case and known from e.g. human life, the duration of noise exposure and the magnitude of the sound pressure level is of great importance to the overall effect of the sound exposure.

A low to medium high noise level may in the beginning induce an avoidance reaction, but the fish may in time habituate to the noise. Man-made noise is typical a point source noise compared with the "natural" background noise, and may start suddenly and without warning. Therefore, man-made noise is typically a local phenomenon that may at first induce avoidance reactions. Later the fish will return to the habitat provided the sound levels are low and allow habituation to take place.

7.1.2. Effects of suspended sediment

Extraordinary suspension of sediments typically occurs during all but the operation phase. Levels of suspended sediments are expected to peak during the construction and decommissioning phases, whereas the levels in the pre-construction phase are lower, depending however on the character of the activities and on the intensity of activities necessary to carry out prior to the construction.

The effects of suspended sediment can be divided into three categories (Newcombe & MacDonald, 1991):

1) Lethal effects – killing of individuals and reduction of population size
2) Sub-lethal effects – tissue damage and injuries or physiological inhibition
3) Behavioural effects– changes of the activity pattern compared to an undisturbed environment.

The sensitivity of fish to suspended sediments depends for one thing on the life stage of the fish. Suspended sediments have in general higher impact on eggs and larvae than on juvenile and adult species. Lethal concentration of suspended sediment is 100 - 1000 times lower for eggs and larvae compared to juvenile and adult individuals in most species (Engell-Sørensen & Skyt, 2001).

Apart from the life stages the effects of suspended sediments on fish also depend on particle density (concentration of suspended solids), the size distribution of the suspended particles, the angularity of the particles, the mineral composition, the adsorption characteristics of the particles and oxygen and temperature levels (Hygum, 1993). Generally, large and angular particles have a higher impact than small and irregular grains (Hygum, 1993). However, larger particles only remain in suspension for a short period of time, and the duration of the impact is therefore normally short.

The higher the concentrations of suspended sediment, the higher the impact on aquatic organisms. Newcombe & MacDonald (1991) showed in a regression analysis that concentration alone is relatively poorly correlated with the effects on aquatic organisms. The combination of concentration and duration of exposure is however much more striking as regards the effects of suspended sediment.

At Horns Rev the construction work will not take place over the whole area at the same time. As an example, it is estimated that erecting a single turbine will take only one day under favourable weather conditions. The direct disturbance resulting from the construction or the removal of the turbine foundations and from spooling down/out the cables within the wind farm area is calculated to affect only approximately 1.3 - 1.4% of the total area.

Even in the worst-case scenario both the concentration and the duration of suspended sediments are expected to be less than the natural sediment suspension during the harsh, but common weather conditions prevailing at Horns Rev. Furthermore, the strong current and high rate of water exchange assure that the concentration of suspended sediments is rapidly diluted. Thus, suspension of sediments as a result of the activities associated with the establishment of a wind farm is not expected to induce any lethal effect nor any significant sub-lethal effects to the fish. However, behavioural changes and escape response are possible in areas during periods of high construction activity. A quick return of fish is nevertheless expected after cessation of the disturbance.

The effects of a given impact of sediment spill and suspension events depend not only on the intensity and duration of the impact, but also on other factors in the surrounding environment. For example, the sensitivity of fish to suspended sediments increases with water temperature because a higher water temperature causes an increase in the metabolic rate and an associated increase in the respiration rate, which in turn causes a higher rate of accumulation of suspended sediments in the gills.

7.1.3. Effects of electromagnetic fields

Sub-marine power cables like the ones interconnecting the wind turbines in wind farms invariably generate electric and magnetic fields, and such fields are known to affect electro-sensitive fish (e.g. Rodmell & Johnson, 2005; Gill & Taylor; 2001; Westerberg, 2000). However, effects from electric power cables are generally poorly described and understood in terms of environmental impact and the assessment of effects often rests on a weak basis of factual knowledge.

The observed responses among fish to electromagnetic fields are mainly behavioural changes in the form of avoidance (Rodmell & Johnson, 2005) and changes of swimming directions (Westerberg, 2000). A possible implication from impacts of the electromagnetic fields could thus be repelling of fish, thereby disturbing or altering normal behaviour and, at the extreme excluding the fish from access to and use of habitat.

There is no evidence that attraction to electromagnetic fields happens as little as this would have a detrimental effect on fish. Indications of attraction of Atlantic cod to a newly buried power cable area at Nysted Offshore Wind Farm in 2003 were probably due to greater food availability from construction activities rather than attraction caused by the fields around the cable (Bio/consult as, 2006)

Fish species able to detect electromagnetic fields typically inhabit the benthic zone, either throughout or at some stages in their life stages. In the Horns Rev 2 Offshore Wind Farm area the most important species associated with the sea bottom are plaice, dab, sandeel and dragonet. Sandeels are the ones with the strongest association with the sediments since they bury in the sediments during winter and in the night-time.

An extensive literature review carried out by Gill et al. (2005) show evidence of a response by several fish species to electromagnetic fields, among these also plaice, which is one of the ecologically and economically important fish species at Horns Rev.

Atlantic cod, which occurs occasionally in the wind farm area and is expected to become more abundant in the area after establishment of the wind farm due to the artificial reefs, is also potentially affected by electromagnetic fields. Furthermore, European eel and Atlantic salmon are also sensitive electromagnetic fields around the power cables, but both these species occur only sporadically and temporarily at Horns Rev. According to the review study, no evidence of sensitivity to electromagnetic fields is presented for any other of the species occurring in the area.

The thresholds of sensibility of fish to electromagnetic fields are not very well known. Avoidance responses for dogfish were observed with an electric field of 10 µV per cm (Rodmell & Johnson, 2005), which is the maximum electric field expected to be formed by an unburied 3-core sub-marine 150 kV /600 A power cable (Gill & Taylor, 2001).

The cables interconnecting the wind turbines in Horns Rev 2 Offshore Wind Farm are expected to be rated at much lower voltage (33 kV 3-core cables) and will be buried between the turbines at depths of approximately 1 m. The resulting electric field around on the cables at the sediment surface will expectedly be much lower than 10 µV per m.

In German wind farms electromagnetic fields have been measured around 3-cored cables connecting the wind farms with the inland shore. The magnetic fields were less than 10 µT (microtesla) or weaker than the magnetic field generated by a household vacuum cleaner. One metre from the cable the magnetic field was reduced to less than 3 µT. In comparison the natural magnetic field in the ground in Germany is approximately 45 µT. (ABB Power Technologies, 2003). The calculated electromagnetic field of the power cable connecting Nysted Offshore Wind Farm with the mainland shore (132 kV 3-core cable) is approximately 5 µT on the sea bottom one metre above the cable (Eltra, 2000).

Gill et al. (2005) emphasize that the current knowledge is generally too variable and inconsistent to make informed assessments of the impacts on electro-sensitive species from power cables. The existing knowledge about the species-specific responses and thresholds of sensibility is sparse or lacking. Taking furthermore into account that no exact data exist on the strength of the electromagnetic fields generated during the operation of the wind turbines, there is but an only very weak basis for assessment of the impacts from the cable networks connecting the turbines with each other and with the transformer station in the wind farm area.

In conclusion, electro-sensitive species at Horns Rev are few, and thus - despite our lack of knowledge - the overall effect of the electromagnetic fields around the power cables between the wind turbines on fish distribution patterns is probably very small or insignificant. If any of the occurring fish species will become affected by the electric or electromagnetic fields in the cable trace areas they will probably flee to other, unaffected areas. 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 be probably be negligible.

7.1.4. Habitat changes

Construction of a wind farm in a marine area is associated with both short-term and long-term effects on the existing biological communities, primarily due to changes of the existing habitats.

Table 7.2 summarises the possible short-term and long-term effects on fish in a wind farm area.

Table 7.2. Summary of major short-term and long-term effects on fish at Horns Rev 2 Offshore Wind Farm. Information modified from Centre for marine and coastal studies (2002).

Short-term effects	Long-term effects
Behavioural and physiological responses to noise generated during seismic and acoustic surveys.	Changes in sediment composition and sediment patterns due to changes in local current and wave dynamics.
Behavioural and physiological responses to underwater noise and vibrations generated by construction activities.	Behavioural and physiological responses to underwater noise and vibrations generated by the turbines during operation.
Changes of distribution patterns due to suspension and redistribution of sediments.	Permanent changes in the benthic habitats, “Artificial reef-effect”.
Changes due to spill of chemical agents.	Behavioural changes due to electric and electromagnetic fields in the vicinity of the power cables in the farm area.

7.1.4.1. Short-term effects

During the pre-construction, construction and decommissioning phases of the wind farm, many of the fish species in the area will be disturbed in various ways. For example some will disappear from relatively small areas (only small areas are affected at certain times during the construction period) due to temporary disturbances in the form of noise, suspended sediment, underwater movements and other activities on the sea bottom. When the pre-construction and construction activities are completed, the affected fish will presumably return eventually.

7.1.4.2. Long-term effects

The establishment of a wind farm is associated with a number of long-term effects. Permanent changes (in the life time of the wind farm) result from establishment of foundations and scour protections. These construction elements will probably cause changes in the local current and wave dynamics.

However, in addition, introduction of hard substrates to the sandy environment will cause significant changes in the habitat structure. As a result of this species richness and by that the biological diversity in the area will increase since stones and rocks around the bases of turbines allow sessile organisms to colonize and build fouling communities. In addition the hard substrates will provide new habitats for fish in terms of foraging, hiding, spawning and nursery. This increase of species richness and biodiversity due to man-made structures is commonly known as the “artificial reef-effect”.

The introduced substrates are suitable for colonisation by a variety of marine invertebrates and attached algae, which have not been present in the area before because of lack of suitable substrates and habitats. The establishment of epifauna and flora on the hard substrates will increase the food available to fish and attract new species, thus increasing the number of species as well as the density.

Due to the effects on ecosystems in the sea the establishment of artificial reefs are generally regarded as positive changes.

As part of Horns Rev 1 Offshore Wind Farm ecological impact monitoring programme, monitoring was performed on the benthic and epifouling communities (Leonhard, 2000; Leonhard, 2002; Leonhard & Pedersen, 2004; Leonhard & Pedersen, 2006). The monitoring was aimed to detect and describe impacts from the introduction of hard substrate on the benthic communities and the succession in the epifouling communities. The monitoring was performed from 1999 to 2005, before and after the erection of the wind farm. During the surveys SCUBA divers made observations of the fish in the area.

The demonstration programme in Horns Rev 1 Offshore Wind Farm showed that the monopiles were colonised by epifauna within only 5 months after the erection of the wind turbines (Leonhard, 2000). The establishment of epifauna and flora on the hard substrates has increased the food availability to fish and hence an increase in the food available to marine mammals and birds.

Diver observations and results of gillnet fishery in the scour areas during the surveys in Horns Rev 1 Offshore Wind Farm showed that several new fish species had been introduced to the area after the erection of the wind farm (Maks Klaustrup, pers. comm.). Ballan wrasse (*Labrus bergylta*), goldsinny-wrasse (*Ctenolabrus rupestris*), corkwing wrasse (*Symphodus melops*), bip (*Trisopterus luscus*) and lumpsucker (*Cyclopteus lumpus*) are known as facultative reef species. Short-spined sea scorpion (*Myoxocephalus scorpius*), hooknose (*Agonus catapharactus*) and long-spined bullhead (*Taurulus bubaris*) are also considered closely connected to the hard bottom habitats. Additionally, rock gunnel (*Pholis gunnellus*), which is occasionally associated with hard substrates, was found in the scour protection areas. Atlantic cod, which had previously been caught occasionally in low numbers at Horns Rev, was observed searching for prey and hiding near the turbine foundations during autumn in 2003, 2004 and 2005.

Leonhard & Pedersen (2006a) assume that the biomass produced in relation to the introduced hard bottom structures may be many times greater than biomass produced by the native benthic community at Horns Rev at similar areas of seabed. However, this is not documented for fish, since no specific surveys have been carried out at Horns Rev or similar areas, Hydro-acoustic surveys at Horns Rev 1 Offshore Wind Farm and Nysted Offshore Wind Farm showed no statistically significant differences regarding the temporal and spatial distribution of fish inside respectively outside the wind farm (Hvidt et al., 2004; Hvidt et al., 2005a; Hvidt et al. 2005b; Hvidt et al., 2006). This may partly be explained by failure of the hydro-acoustic method in detecting benthic species among the stones and rocks of the scour protections and very low numbers of pelagic and semi-pelagic fish during the surveys.

Hard structures are foraging and hiding areas as well as spawning and nursery areas for a number of fish species. The reef species will obviously spawn in the area and the hard structures will serve as habitats for juveniles and fry. The pelagic species herring (*Clupea harengus*), which occurs at Horns Rev, is a demersal spawner and the hard structures will be a possible spawning area for this species. However, spawning often occurs in brown algae sea beds to avoid predators to eat the eggs, and so far brown algae are not common in Horns Rev 1 Offshore Wind Farm. Thus, at present conditions are not optimal for spawning of herring.

In Nysted Offshore Wind Farm divers have observed fry of garfish (*Belone belone*) at the scour protections (Maks Klaustrup, pers. comm.). This indicates that garfish is attracted to the hard structures and they may probably use the hard structures in the Horns Rev 1 Offshore Wind Farm area for spawning, although it has not yet been observed. Species of goby (*Pomatoschistus* spp.) are demersal spawners, which deposit their eggs on hard structures like shells of mussels. Accumulated shells in the scour protection area are probably used for spawning by goby although this is not yet observed (Maks Klaustrup, pers. comm.).

A preliminary study of the development of fouling communities on a meteorological measuring mast at Horns Rev in 1999 showed an established community of algae and invertebrates only 5 months after deployment (Bio/consult, 2001). The preliminary study also showed that the current and the near-bottom transport of sand apparently limited the fouling communities. Sand scouring is so extreme in the area that the lowest areas of the foundation were devoid of fouling communities.

Although the artificial reef effect is generally considered positive, a full understanding is not yet obtained. Therefore the benefits in the form of higher species richness, higher biodiversity and higher biomasses may easily overshadow the losses of natural communities. However, Elliot (2004) questions whether anyone is qualified to decide this.

7.1.4.3. Electromagnetic fields

The Danish Fisheries Institute did not expect electromagnetic fields around power cables to have any impact on fish migration (Hoffmann, 2000) although Westerberg (1994) found a difference, but not significant, between power producing and non-power producing wind turbines in the behaviour of tagged (by radio transmitter) eel. It was not possible to point out which factor caused the observed change of behaviour.

7.2. Phase specific effects

As mentioned above the life cycle of an offshore wind farm comprises the following four phases:

1. The pre-construction phase during which all preliminary studies and surveys are conducted.

2. The construction phase during which the turbines are erected and the foundations and scour protections are constructed and the cables connecting the turbines are buried in the sediment

3. The operation phase in which the wind farm produces electricity that is transported to a common transformer unit in the farm area and from there to shore through the main cable

4. The decommissioning phase during which the wind farm installations are completely or partly removed and/or demolished

Realizing that these four phases result in different impact and effect scenarios, each phase is dealt with separately below.

7.3. Pre-construction phase

Prior to the establishment of the offshore wind farm measurements of the meteorological, geological and hydrographical characteristics will be made. The pre-construction phase includes vessel activity (traffic), acoustic surveys and seismic surveys (noise) and core sampling of the sediment (suspension of sediment), all of which will generate disturbances of the environment and thus impact the biological communities.

7.3.1. Overview

An overview of possible impacts from the pre-construction activities on the fish communities is outlined in Diagram 7.1.

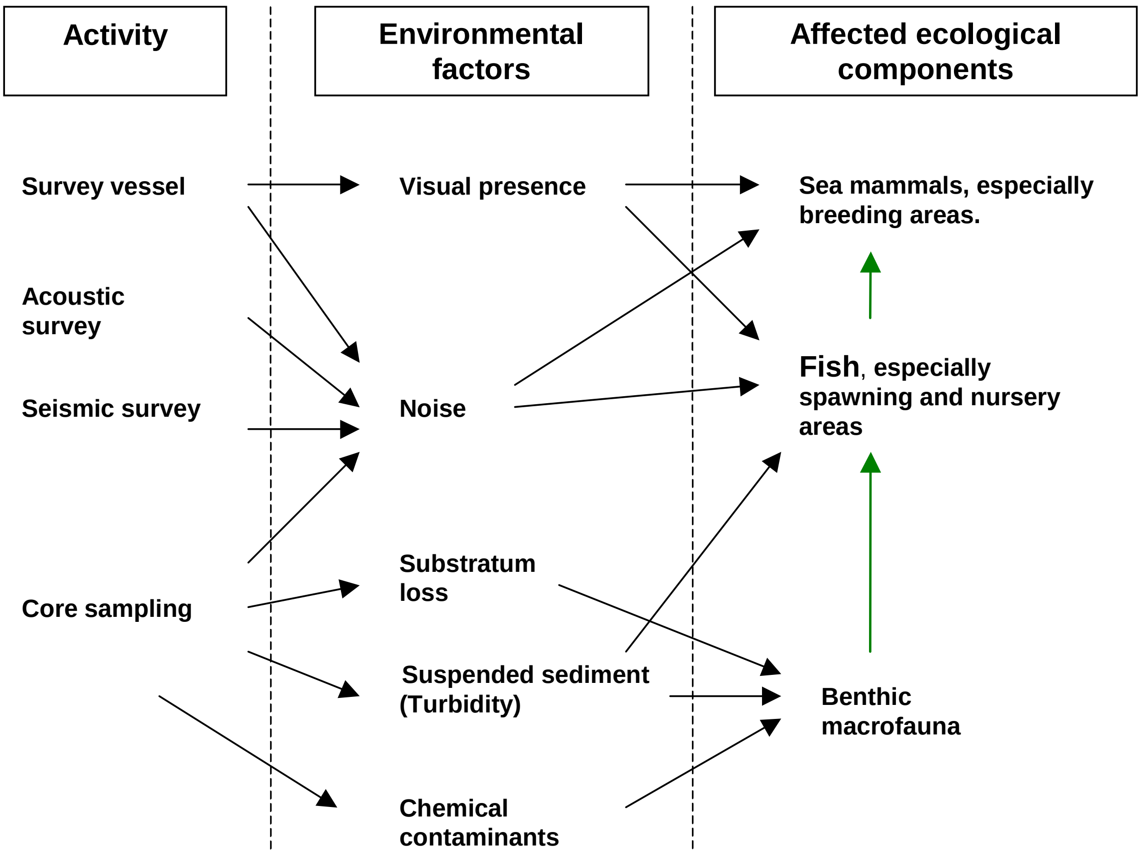


Diagram 7.1. Sources of impacts and targets of effects in the pre-construction phase (adapted from Elliot, 2002; Hiscock et al., 2002). Green colour indicates changes in the biological interactions.

7.3.2. Suspension of sediments

Regarding suspension of sediment the activities in the pre-construction phase comprise investigations and analyses of sediment types and sediment characteristics that may cause some suspension of sediments. The suspension events are however not expected to be of any appreciable magnitude or duration, and thus no measurable or significant effects are expected on the fish fauna and the fish communities in the area.

7.3.3. Noise and vibrations

During the pre-construction phase noise and vibrations will occur as a result of the vessel traffic and the seismic investigations. Table 6.2 shows that the noise generated by the pre-construction vessel activities are of the same magnitude as noise generated by fishing vessels, while seismic air gun surveys have a higher impact level. However, the seismic air gun has shown not to induce any lethal effects or avoidance reactions among buried sandeels, but a change of behaviour was observed. The sandeels increased their tail beats and furthermore an increase in C-starts (avoidance behaviour) occurred. The increased level of tail beat lasted for 3 day before returning to normal level. The C-start does not affect the survival of the sandeel, thus no effect of noise in the pre-construction phase on sandeel is expected (Skaar, 2004).

Realizing that different fish species have different hearing capabilities, resulting in different thresholds for triggering avoidance behaviour, it is very difficult to state the exact effect of the increased noise level. Anyway, taking into account the short duration of the seismic investigations, no long-term effects are expected on the fish stocks in the area.

Fish that have swim bladder may be more sensitive to the use of seismic air guns. This is exemplified in a study performed by Løkkeborg & Soldal (1996). They found a decline in catches of both cod and haddock as far as 18 nautical miles from the air gun. The catches by both long line and trawl were reduced by approximately 70 % within the seismic survey area and abundance and catch rate did not return to pre-shooting level within the first 5 days after the seismic shooting had ended. The decline was most noticeable among large specimens, i.e. larger than 60 cm. These findings show that seismic survey activity has a potential effect upon hearing generalist possessing a swim bladder. Hence, such activity at Horns Rev is expected to have an effect on cod, whiting and horse mackerel etc. Additionally, effects of the air gun may occur among hearing specialists. Similar avoidance reactions have been found in blue whiting and spring spawning herring (Hastings & Popper, 2005). Though effects have been found, the overall effect of the use of seismic air gun is considered insignificant due to the short duration of the seismic surveys.

7.3.4. Traffic

During the pre-construction phase an increased traffic level is expected in the area, resulting in an increase of the noise level. However, no significant effects are expected, especially not in the long term.

In the short term the presence of vessels in the wind farm area may induce a number of transient impacts such as noise and disturbance caused by the mere presence of the vessels, all of which are considered insignificant.

7.3.5. Artificial reef effect

Apart from the possible errection of a meteorology mast, no specific constructions will be made in the pre-construction phase. Since the meteorology mast is not expected to display any significant reef effect (due to exposure and heavy erosion), no artificial reef effects are expected in the pre-construction phase.

7.4. Construction Phase

7.4.1. Overview

Establishment of a marine wind farm is associated with a number of construction activities including primarily: traffic (vessels), pile driving, preparation of the seabed, sediment removal and deposition and cable laying. These activities result in different impacts on the biological communities in the area.

An overview of possible impacts from the construction activities on the fish communities is shown in Diagram 7.2.

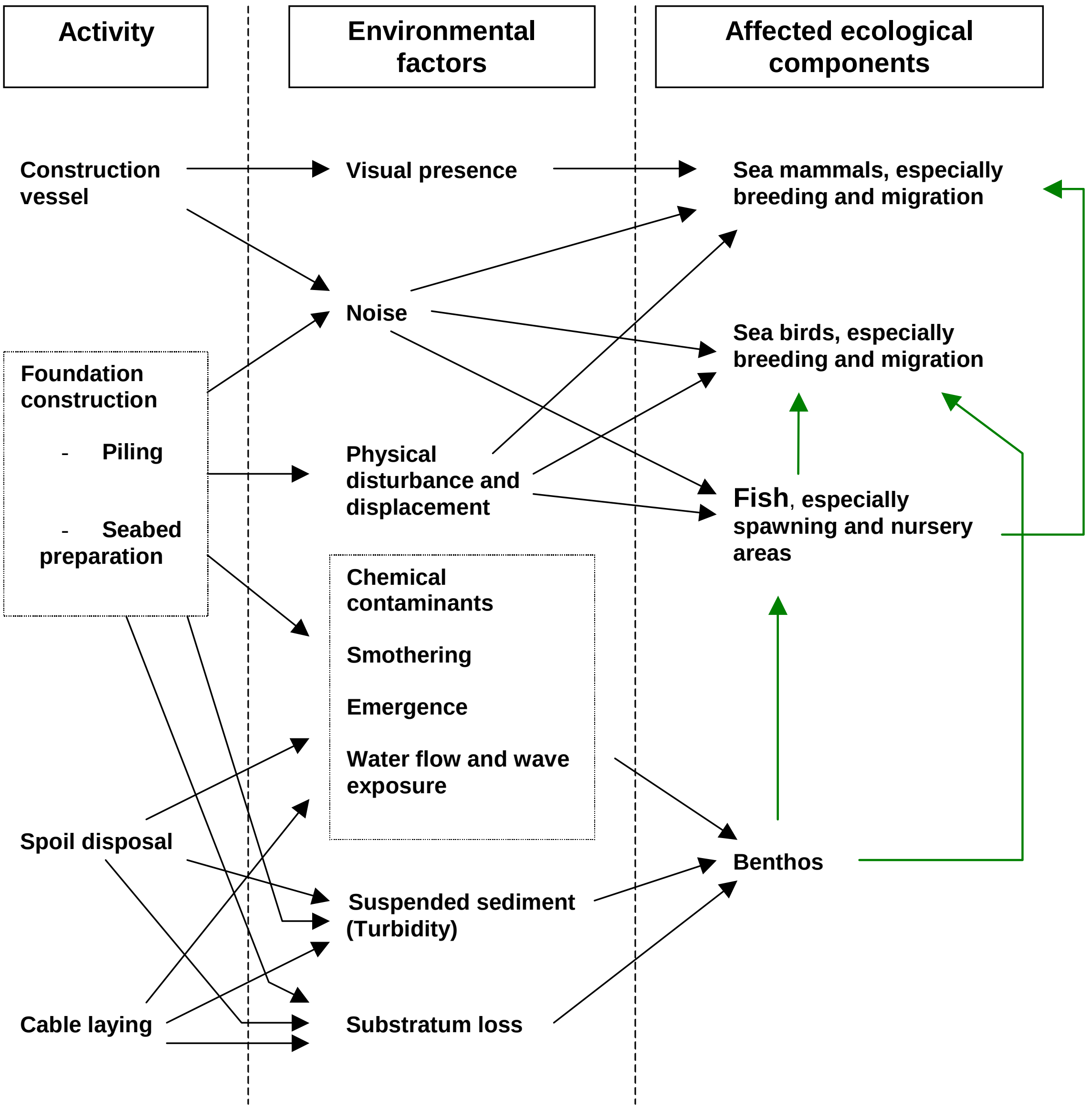


Diagram 7.2. Sources of impacts and targets of effects in the pre-construction phase (adapted from Elliot, 2002; Hiscock et al., 2002). Green colour indicates changes in the biological interactions.

The diagram illustrates that the construction phase is associated with various impacts on the fish fauna, and among the phases in the life cycle of the wind farm the construction phase is considered the most important.

7.4.2. Suspension of sediments

Various disturbances of the sediment in the wind farm area will invariably take place in the construction phase in connection with dredging for construction of foundations and scour protection and for sluicing down the cables. The affected area amounts to 1.3-1.4 % of the total wind farm area dependant on the foundation type. Typical disturbances are the formation of plumes of suspended sediment and the subsequent sedimentation of suspended sediments. The magnitude of these plumes is dependent on the type of foundation chosen (monopile or gravitation foundations), Table 1.3.

At present two types of foundations are under consideration for Horns Rev 2 Offshore Wind Farm (monopile or gravitation foundations). Table 7.3 shows the magnitudes and duration of important elements of work in the construction phase for each of the two types of foundations mentioned.

Table 7.3. Overview over the expected magnitude and duration of important elements of work in the construction phase (erection of one turbine), for each of the two types of foundations mentioned for Horns Rev 2 Offshore Wind Farm (Engell-Sørensen & Skyt, 2001).

	Gravitation	Monopile
Material removed (m^3) Total	106,000	16,000
Foundation material (concrete) (m^3) Total	102,000	15,000
Sediment spill (m^3) Total	4,000	1,000
Duration per turbine of - Preparation - Installation - Scour protection	 7 days 6 hours 4 days	 2 days 4 hours 2 days
Stones and rocks used per turbine (m^3)	500	100

Table 7.3 states that the sediment works are much more comprehensive for the gravitation foundation than for the monopile foundation as are the amounts of foundation material to be laid out at and the volumes of sediments to be removed from the sea floor.

The extension/propagation of the plumes are strongly dependent on the local current conditions at the time of construction, but generally the sediment plumes generated from the gravitation foundation are expected to be considerable higher than sediment plumes generated from the monopile foundations (Engell-Sørensen & Skyt, 2001).

Sediment plumes may have impact on especially the eggs of demersal spawners (fish spawning at the bottom) and newly settled larvae of plaice, dab and sandeel. However, since the affected areas are expected to be very small compared to the total wind farm area, and since the duration of the impact is short, no significant negative effects are expected. Any sediment plume should also be seen and assessed in the light of the suspension events that occur at Horns Rev due to the natural wind regime.

Regarding adult fish the situation is considered similarly unproblematic because they are able to flee from the affected areas during periods of high impact and then return upon cessation of the disturbances. Adult fish that are not able to flee the area will be subject to an increased risk of clogging of their gills, but compared to the temporarily high natural levels of suspended sediments at Horns Rev, the impact from the construction activities is considered to be without any real importance, spatially as well as temporally.

7.4.3. Noise and vibrations

The construction phase implies a number of noise and vibration generating activities such as vessel traffic, dredging, trenching and piling.

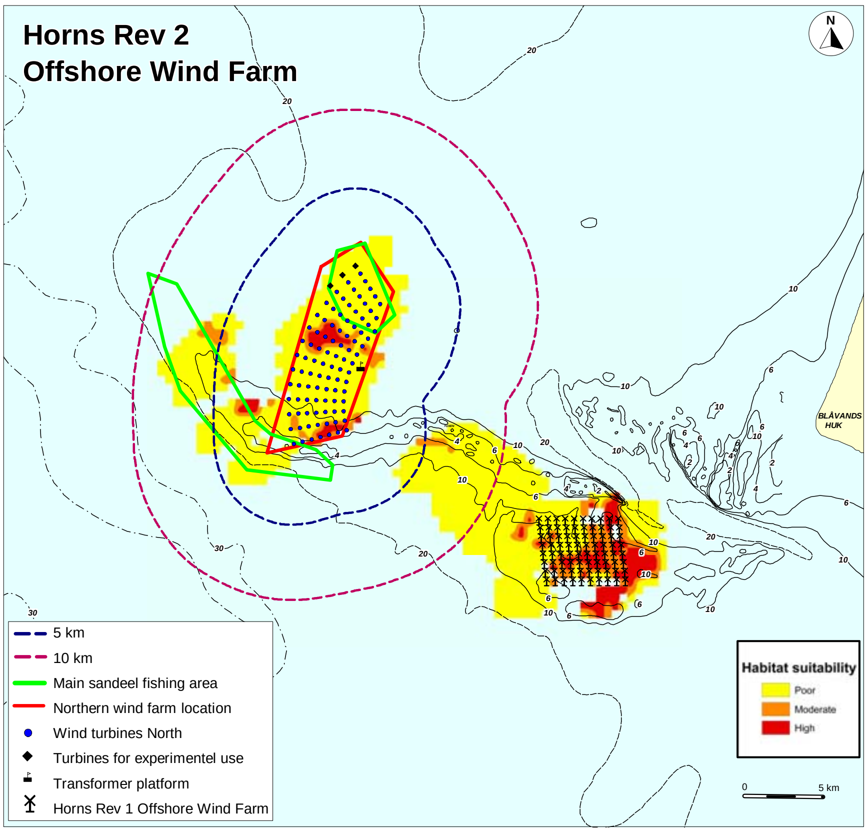
The noise generated in the construction phase is mainly related to construction of the gravitation foundations and scour protections due to the dumping of stones and rocks, not least if this involves the use of steel cases. Noise in the acoustic field is expected to be low, but the acceleration component (particle displacement) is expected to be relatively high, but not of any magnitude resulting in long-term effects.

However, use of the monopile foundation is associated with the strongly noise and vibrations generating piling, Table 6.2. Although monopiles with larger diameter may be used, the total amount of noise generated is expected to remain more or less the same.

Almost all fish species at Horns Rev are believed to be sensitive to the noise generated by the pile driving. Near the source of noise there is a risk of lethal effects and in larger distances from the source impacts on behaviour such as schooling are known to occur (Hastings & Popper, 2005).

The possible effects from pile driving are exemplified by cod (generalist – good hearing ability) and salmon (generalist – poor hearing ability) with avoidance distances of 5.5 and 1.6 km, respectively.

Although able detect the noise as far as 13 km from the source, cod will however only display avoidance reactions within 5.5 km from the source. This means that avoidance reaction for cod is likely to occur in all of the western part of Horns Rev, Figure 7.1.



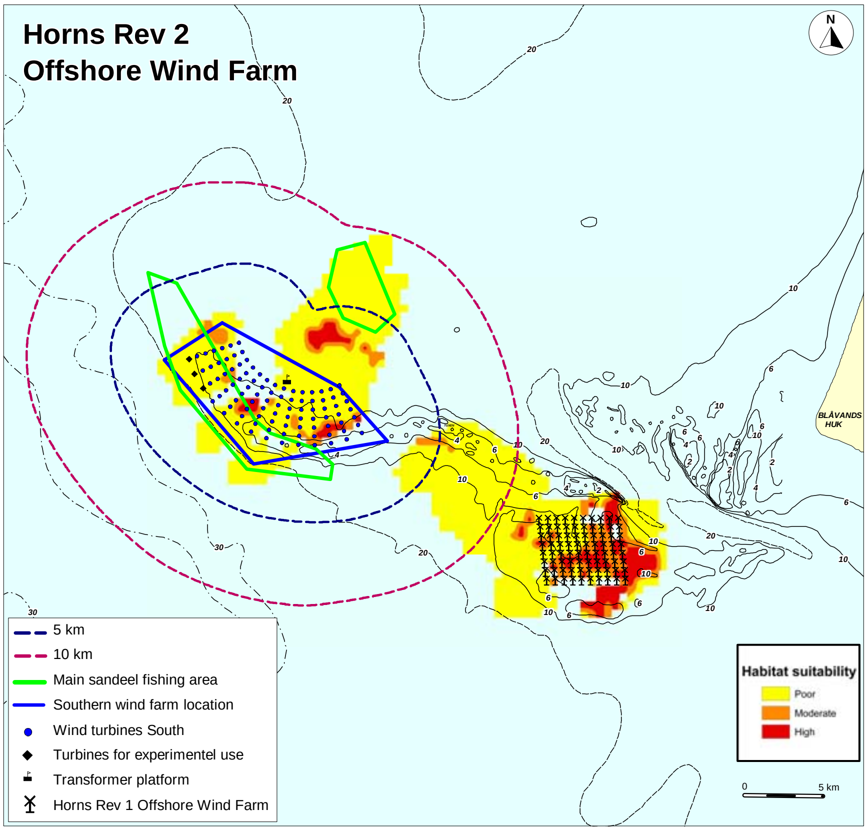


Figure 7.1. The distribution of modelled habitat suitability to sandeel and main sandeel fishing areas.

By using salmon to illustrate the situation for the less sensitive species, at Horns Rev primarily sandeel and flatfish, avoidance reactions are only to be expected for a limited part of the western part of Horns Rev, leaving the major part of the total habitat unaffected by high impacts, Figure 7.1. However, there is some difference between the two designated sites (northern and southern). By selection of the southern site a major part of the existing sandeel habitats (suitable for burying) will remain unaffected, while selection of the northern site will affect a larger part of the suitable habitats. Selection of the northern site will however keep a larger part of the existing sandeel fishing areas clear of impacts from the wind farm.

Impact from pile driving activities is considered as moderate to fish but temporary within a restricted area.

7.4.4. Traffic

The construction phase is associated with intense vessel traffic. The magnitude of the noise from the different vessels operations in this phase is shown in Table 6.2, and all types of traffic related noise will be registered by the fish and thus induce effect. Apart from the intensity of the vessel traffic the effects on the fish fauna are the same as listed for the pre-construction phase. Like it is the case in the pre-construction phase, the duration of the construction activities is short, and no long-term effects are expected.

During the construction phase pile driving is the most important source of noise in the wind farm area and the noise from the pile driving is likely to drown all noises generated by the vessel activities in the area.

7.4.5. Habitat changes

The establishment of the wind farm at Horns Rev implies destruction of existing habitats as well as generation of new habitats. The effected area is however very small, 0.2-0.3 % of the total wind farm area (35 km^2).

7.4.5.1. Loss of existing habitats

At establishment of turbine foundations and scour protections amounting a total of 0.2-0.3 % of the total wind farm area invariably implies permanent (= the life time of the wind farm) destruction of a minor part of the total sandy habitats. This loss is considered insignificant in terms of total habitat availability at Horns Rev.

The dredging operations performed during the construction phase will invariably but only temporarily affect the existing spawning areas for demersal spawners such as sandeel but the effect to the total population of sandeel is considered insignificant.

7.4.5.2. Artificial reef effect

Due to the fact that the dominant substrate type at the wind farm area is sand, the erection of wind turbines with foundations and scour protections made from stones and rocks will introduce hard bottom substrate to the area, thus resulting in completely new habitats in the area.

A colonisation similar to the one observed at the turbine foundations and scour protections in Horns Rev 1 Offshore Wind Farm is likely to occur also at Horns Rev 2 Offshore Wind Farm. The colonisation may even be faster at Horns Rev 2 Offshore Wind Farm because the reef species are already present in the neighbouring Horns Rev 1 Offshore Wind Farm area, see chapter 7.7 – cumulative effects.

Although colonisation is fast, only the initial phases of the colonisation are expected to take place during the relatively short construction phase. Thus, in terms of artificial reef effect the construction phase implies mainly the establishment of the physical basis for the future developments of hard substrate communities.

7.5. Operation phase

7.5.1. Overview

Operation of a marine wind farm is associated with a number of specific impacts: maintenance traffic (vessels), noise and vibrations from the turbines, disturbances of the natural light regime due to reflections caused by the wings of the turbines and electromagnetic and electric fields generated around the cables.

An overview of possible impacts on the fish communities during the operation phase is given in Diagram 7.3.

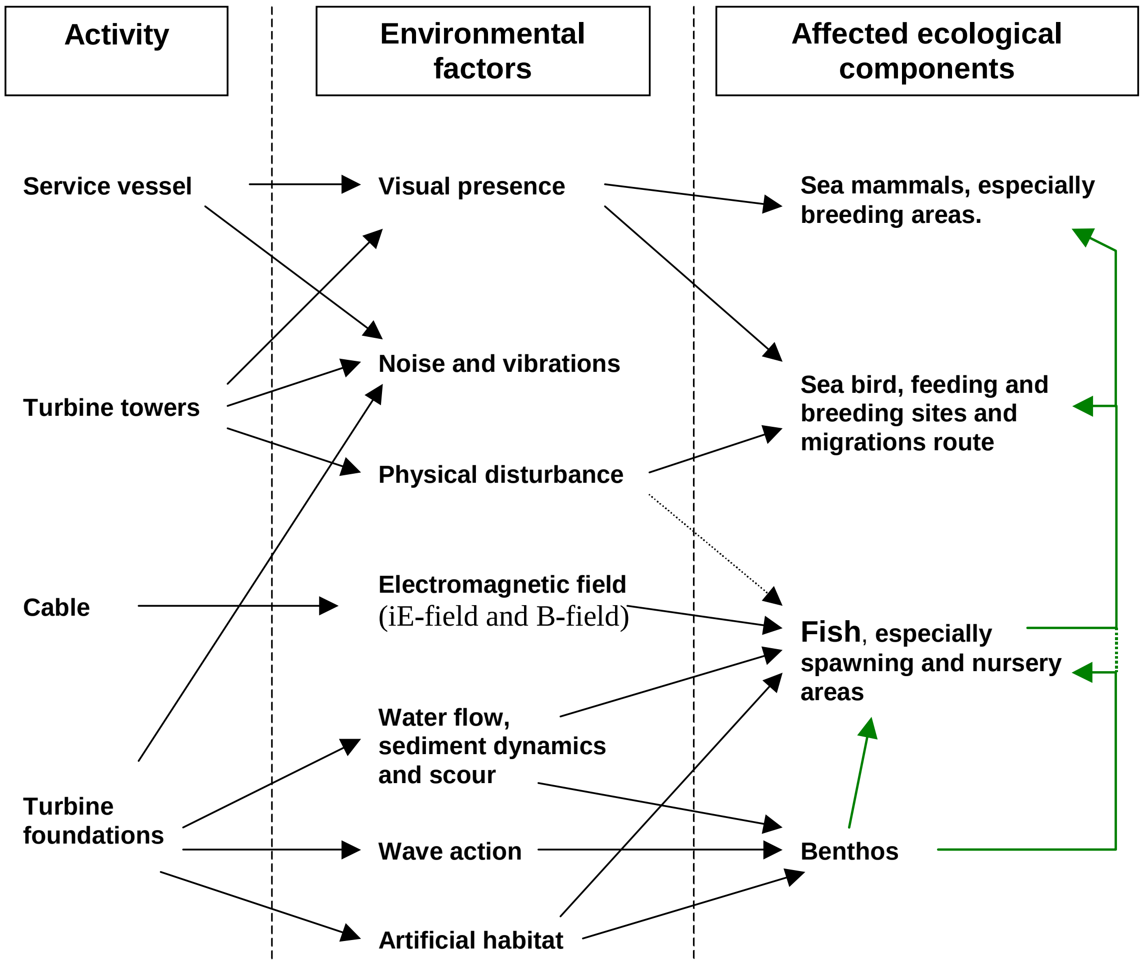


Diagram 7.3. Effects and impacts in the operation phase (adapted from Elliot, 2002; Hiscock et al., 2002). Green colour indicates changes in the biological interactions.

7.5.2. Suspension of sediments

No man-made suspensions of sediments are expected the operation phase.

7.5.3. Noise and vibrations

During operation noise and vibrations are created by the action of the gearbox and generator. In addition, the wing blades generate aerodynamic noise during rotation. The noise and vibrations will be transmitted through the steel tower into the foundations and from there into the seabed and the surrounding water.

Based on Nedwell & Howell (2004) it is estimated that fish are consistently scared away from turbines only at ranges shorter than 4 m (wind speed higher than 13 m/s). Outside this 4 metre zone the acoustic effects of offshore wind turbines on fish are is restricted to masking of communication and orientation signals rather than causing physiological damage or significant avoidance reactions (Wahlberg & Westerberg 2005). Furthermore, it was assumed that the detection distance to offshore wind farms for different fish species representing various hearing capabilities varies between 0.4 km and 25 km when wind speeds range from 8 to 13 m/s, e.g. the avoidance distance for Atlantic cod would be 1.5 km to 2 km, provided no other noise interfere.

The response of fish to noise and vibrations differ from species to species, due to specific differences regarding hearing thresholds. At Horns Rev particle displacement induced by the turbines is expected to influence all species, both hearing generalists and specialists, within a range of 5-10 metres from the turbines. This expected distance of impact is marginally larger than the four metres assumed by Wahlberg & Westerberg (2005) as already mentioned. The acceleration component is essential to sound detection by fish lacking a swim bladder (Nedwell et el. 2004). The important species of this group in the area are flatfish and sandeels. The avoidance reaction in the worst-case scenario is expected to be 10 metres, i.e. not beyond the expected scour protection. The scour protection is not an important habitat to flatfish and sandeels even though these species may forage at the periphery of the scour protection (Maks Klaustrup, pers. obs.). Noise in the operation phase is therefore not expected to influence fish without swim bladder. Furthermore, the study at Horns Rev 1 Offshore Wind Farm showed an increase of the density of sandeels of approximately 300% within the wind farm area and a decrease of approximately 20 % in the control area. Hence, it is not expected that Horns Rev 2 Offshore Wind Farm will have any negative effect on the sandeel populations in the area.

Bearing in mind that Horns Rev is a windy place with a high natural background noise level, the effects of the additional noise and vibrations from the wind turbines on the fish communities in the area are considered insignificant. This assessment is strongly supported by the situation at Horns Rev 1 Offshore Wind Farm.

7.5.4. Traffic

Running maintenance of the turbines involves some vessel activities in the wind farm area, but this is considered insignificant as regards the fish fauna and the fish communities.

The traffic during the operational phase is restricted to smaller vessels participating in the maintenance operations. As mentioned earlier the noise from these is of such a low level that no effects on the fish community are expected.

7.5.5. Electromagnetic fields

The power cables connecting the turbines will invariably induce both electric and electromagnetic fields to the sea bed around and immediately above the cable traces.

Although intensive investigations concerning the possible effects on fish migration and behaviour has been carried out at Nysted wind farm no clear evidence of any effect has been detected, not even for eel that is considered to be among the most sensitive species.

Compared with the fact that the pattern of the cables from the individual turbines to the transformer is planned to be sluiced down in such a way that only up to 14 turbines will be connected to the same cable, relatively weak electric and electromagnetic fields are expected around the cables.

Although the wind turbines will be connected by a network of cables it is envisaged that the resulting electromagnetic fields inside the wind farm area will be of such low magnitude that no significant effect on the fish stocks in the area are to be expected.

7.5.6. Artificial reef effect

Colonising of foundations and scour protections will continue during the operation phase, and more new species will inhabit the hard structure habitats as the biomasses of sessile organisms and flora increase. Additionally, the artificial reefs will eventually become spawning and nursery areas for a number of species, and the fish diversity is expected to increase during the operation phase.

Succession of sessile organisms and fish in connection with the hard structures is an continuous process and fish species composition and abundance will probably change during the operation phase due to the general maturation of the reef ecosystems.

The artificial reefs cover less than 0.3 % of the total wind farm area and thus the loss of habitats for the species inhabiting the sandy environment will be insignificant and the overall effect of the hard structures is considered to be positive.

7.5.7. "Reserve – effect"

In addition to the reef effect it deserves mentioning that erection of the wind farm at Horns Rev will exclude commercial fishery from taking place within the wind farm area for a period of at least 20 years (expected minimum life time of the wind farm). During this period (mainly the operation period) fish communities will be allowed to develop without the present impact from fishery. This may result in a reserve effect.

7.6. Decommissioning phase

Decommission of the wind farm includes removal of the turbines and the foundations as well as the cables connecting the turbines. Removable of the foundations and the scour protections and the cable will result in disturbance of the seabed and 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 on the fish communities during the decommissioning phase is given in Diagram 7.4.

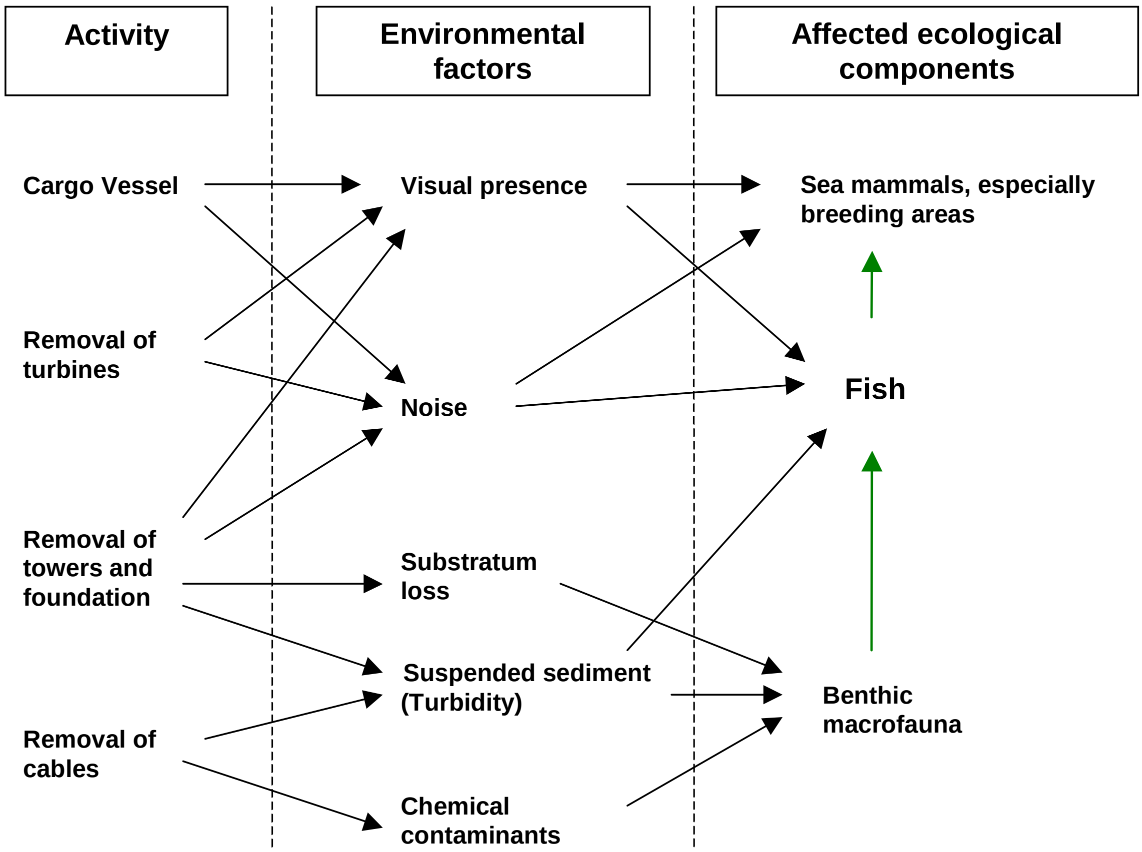


Diagram 7.4. Effects and impacts in the decommissioning phase (adapted from Elliot, 2002; Hiscock et al., 2002). Green colour indicates changes in the biological interactions.

7.6.1. Suspension of sediments

During the decommissioning phase some dredging activities are expected in connection with the removal of the turbines and their foundations along with the cables.

Due to the fact that no larger dredging activities such as preparation of foundations are expected, and due to the fact that no measurable effects on the fish stocks was expected during the much more intensive construction phase, neither measurable nor significant effects are expected due to the suspended solids generated during the decommissioning activities.

However, in case that the foundations are completely removed from the sea floor, accumulated sediments from within the foundations may be released to the surrounding water, causing a temporary rise in the concentration of suspended solids. But due to the strong currents and wave actions the duration of the event is expectedly insignificant as is the impact on the fish.

7.6.2. Noise and vibrations

Removal of the turbine foundations may involve the use of explosives, in which case fish larvae and adult fish will invariably be affected by lethal and sub-lethal impacts depending on distance to the blast. Furthermore, dependant on the season where the explosives are used, the noise and vibrations may induce increased mortality among larvae and fry. Regarding adult fish, some are expected to be able to escape before or just after the first explosions, while others with stronger connection to the foundations (reef) are likely to experience higher mortality.

Alternatively the turbine foundations must be removed mechanically. This process is assumed to be far less associated with noise and vibrations than is the construction. Therefore it is assumed that the overall impact by noise and vibrations will result in no significant effects among the fish (Centre for Marine and Coastal Studies, 2002)

7.6.3. Traffic

The decommissioning of the wind farm will imply increased traffic compared to the operational phase but the magnitude is expected to be smaller than during the construction phase. On this basis it is assumed that no significant effects on the fish will occur from traffic in the decommissioning phase.

7.6.4. Loss of hard bottom habitats and regeneration of sandy habitats

Like the establishment of the wind farm causes introduction of new hard bottom substrates to the sandy environment and thus generates new habitats, removal of the latter will “rewind the film” as regards both the hard bottom habitats and the sandy habitats and their content of biota.

While immigration and succession at the new hard bottom substrate is a fairly slow process, the decommissioning is a fast process that leaves most of the fish with only few chances to escape. Being derived their habitats, many of the organisms that have colonised the foundations and the scour protections will be exposed to heavy predation during decommissioning, either because they cannot escape or because they cannot avoid the predators while escaping.

Thus, in terms of the biological content, the loss of habitats during decommissioning will be far more dramatic than the loss of habitats that took place during construction.

In case of total removal of all stones and rocks a rapid regeneration of the sandy habitats is expected due to the high impact from currents and waves. However, the regeneration of the biological communities in the regenerated sandy habitats is a slower process, yet probably much faster than the colonisation of the hard bottom habitats. This is to large extent due to the short migration distances from the surrounding sandy habitats. The complete regeneration of the sandy habitat communities is expected to take place within few years.

7.7. Cumulative effects

Cumulative effects occur on the local scale (Horns Rev 2 Offshore Wind Farm) as well as the regional scale (Horns Rev including Horns Rev 1 Offshore Wind Farm). The assessments of impacts and effects of Horns Rev 2 Offshore Wind Farm need to include also the cumulative effects derived from the presence of a wind farm only approximately 14 km away.

7.7.1. Pre-construction phase

No significant cumulative effects are expected in this phase, neither locally nor regionally.

7.7.2. Construction phase

Due to the distance between the two wind farm areas, noise generated by the operation of the turbines at Horns Rev 1 Offshore Wind Farm, is not likely to cause any significant impacts on the fish communities in Horns Rev 2 Offshore Wind Farm, cf. Figure 7.1. Thus, noise generated during the operation phase at Horns Rev 1 Offshore Wind Farm is not expected to cause any cumulative effects on fish at Horns Rev 2 Offshore Wind Farm regarding noise.

Regarding suspension of sediments, traffic and electromagnetic fields, no cumulative effects are expected.

Regarding the colonisation of the foundations and scour protections at Horns Rev 2 Offshore Wind Farm the presence of Horns Rev 1 Offshore Wind Farm only approximately 14 km away is likely to enhance the colonisation processes.

7.7.3. Operation phase

During operation the two neighbouring wind farms will superimpose a noise field onto the area between the two wind farms, potentially inducing an impact zone where fish are capable to detect operation noise from either of the two wind farms. However, avoidance reactions are confined to vicinity of the turbines and no cumulative effects are expected neither in the area between the wind farms nor within the two wind farms.

Regarding the artificial reef effect, the operation phase constitutes the most important period in terms of colonisation and maturation of the ecosystems and communities associated with the foundations and scour protections. As for colonisation, the presence of existing reef communities at Horns Rev 1 Offshore Wind Farm is likely to cause further enhancement of the processes that started in the construction phase. This may lead to a faster "saturation" of Horns Rev 2 Offshore Wind Farm compared to Horns Rev 1 Offshore Wind Farm.

In addition to these more obvious effects, the simultaneous presence of two wind farms at Horns Rev may be associated with a synergetic effect causing higher species richness and diversity at each of the two wind farms than would be expected if they were not neighboured by other wind farms.

7.7.4. Decommissioning phase

The cumulative effect of decommissioning is expected to be negligible due to the short duration of the activities.

7.8. Mitigative and preventive measures

The necessary activities comprised by the establishment of a marine wind farm are potentially harmful to the environment in which the turbines are erected. However, much damage can be avoided or the impacts reduced by due diligence in the way the activities are planned and carried out.

Below is listed some proposals for mitigative measures in the four different phases of the life cycle of the wind farm.

7.8.1. Pre-construction phase

In addition to general precautions no special mitigative measures are given for this phase.

7.8.2. Construction phase

The construction phase contains the most intensive impacts regarding suspension of sediments and emission of noise and vibration. Not much can be done to minimise the magnitude of the individual impacts, but much can be done to reduce the cumulative impacts within the wind farm, both spatially and temporally:

A ramming up procedure should be applied during pile driving activities and only a few pile driving operations should be executed simultaneously. This will reduce the cumulative impacts on fish and allow the fish to flee to adjacent areas with lower impact levels. If the pile driving gradually becomes intensified, fish will be able to move away and in time also move to areas where the turbines have already been erected, i.e. to areas where acceptable noise levels have been regenerated (Centre for Marine and Coastal studies, 2002). Although activities with known impacts and effects should preferably take place in periods when the affected fish are least vulnerable to the impacts, there is no evidence to support recommendation of any additional mitigative measures.

7.8.3. Operation phase

No mitigative measures are proposed for the operation phase.

7.8.4. Decommissioning phase

Due to the generally accepted positive effect of artificial reefs and due to the invariable loss of biota associated with a complete removal of the foundations and scour protections, it is suggested that these structures are not removed during decommissioning.

8. Conclusions

Table 8.1 and 8.2 give tabular overviews over the conclusions that are drawn on basis of the assessments in chapter 7 by use of the assessment criteria listed in chapter 4.

Regardless of the type of foundation the preconstruction phase implies a number of activities, all of which are believed to have an overall low or negligible impact on the fish communities and thus call for no mitigative measures in addition to due diligence.

In the construction phase the use of the monopile foundation is associated with a higher level of noise and vibrations than is the use of the gravitation foundation. Since noise and vibrations cannot be avoided, the overall impact from use of the monopile foundation is believed to be moderately high and thus calling for mitigative measures only in the form of a ramming up procedure, while the impact from the use of gravitation foundations is believed to be smaller. In both cases the most obvious way to reduce the impacts is to plan and carry out the construction works in a way that minimises the negative effects. Thus, no radical changes of the construction methods are found necessary in addition to due diligence.

In the operation phase no impacts calling for mitigative measures are believed to occur. In contrast, there is believed to occur a noticeable positive effect – the artificial reef effect – on the species richness and the biodiversity in the wind farm area.

The decommissioning phase basically implies the same type of impacts as the construction phase while the strength of the impacts are believed to be smaller and thus less significant. Thus, in addition to due diligence in the work, no special mitigative measures are called for.

In case of removal of the foundations and the scour protections, the artificial reefs will be removed and by that the habitats of a number of species and communities. This must be considered a significant negative impact on the affected species and communities, but the overall effect is believed to be insignificant, thus calling for no mitigative measures in addition to due diligence. However, if there is no special reason for removing the foundations (rocks and stones) they may be left in the wind farm area.

Overall, the erection of Horns Rev 2 Offshore Wind Farm is believed to be associated with only minor or negligible impacts or more serious, but at the same time transient impacts, the negative effects of which can be minimised by due diligence while carrying out the impacting works. Thus, regarding fish the erection of the wind farm is not believed to impose any significant negative effects on the fish fauna at the affected parts of Horns Rev.

Table 8.1. Conclusive assessments of effects from major impacts in connection with establishment of Horns Rev 2 Offshore Wind Farm - The monopile foundation. Criteria for the assessments are given in chapter 4.5.1.

Monopiles

Impact	Criteria	Pre-construction	Construction	Operation	Decommissioning
Noise and vibrations	Importance	Local	Local	Local	Local
	Magnitude	Negligible	Moderate	Minor	Negligible
	Persistence	Temporary-short	Temporary-short	Permanent	Temporary-short
	Likelihood	High	High	High	High
	Other	Direct	Direct	Direct	Direct/indirect
	Significance	Negligible	Moderate	Minor	Negligible
Suspension of sediments	Importance	Local	Local	Local	Local
	Magnitude	Negligible	Negligible	Negligible	Negligible
	Persistence	Temporary-short	Temporary-short	Permanent	Temporary-short
	Likelihood	Low	High	Low	High
	Other	Direct/indirect	Direct	Direct	Direct/indirect
	Significance	Negligible	Negligible	Negligible	Negligible
Traffic	Importance	Local	Local	Local	Local
	Magnitude	Negligible	Minor	Negligible	Minor
	Persistence	Temporary-short	Temporary-short	Permanent	Temporary-short
	Likelihood	High	High	High	High
	Other	Direct	Direct	Direct	Direct
	Significance	Negligible	Minor	Negligible	Minor
Electro-magnetic fields	Importance			Local	
	Magnitude			Minor	
	Persistence			Permanent	
	Likelihood			High	
	Other			Direct/indirect	
	Significance			Minor	
Reef effect	Importance	Negligible	Local	Local	Local-regional
	Magnitude	Negligible	Minor	Minor	Minor
	Persistence	-	Temporary-short	Permanent	Permanent
	Likelihood	Low	High	High	High
	Other	-	Direct/indirect	Direct/indirect	Direct/indirect
	Significance	Negligible	Minor	Minor	Minor
Cumulative effects	Importance	Local	Local	Local-regional	Local-regional
	Magnitude	Negligible	Minor	Minor	Minor
	Persistence	Temporary-short	Temporary-short	Permanent	Permanent
	Likelihood	Low	Medium	Medium	High
	Other	-	Direct/indirect	Direct/indirect	Direct/indirect
	Significance	Negligible	Minor	Minor	Minor

Table 8.2. Conclusive assessments of effects from major impacts in connection with establishment of Horns Rev 2 Offshore Wind Farm - The gravitation foundation. Criteria for the assessments are given in chapter 4.5.1.

Gravitation foundations

Impact	Criteria	Pre-construction	Construction	Operation	Decommissioning
Noise and vibrations	Importance	Local	Local	Local	Local
	Magnitude	Negligible	Negligible	Minor	Negligible
	Persistence	Temporary-short	Temporary-short	Permanent	Temporary-short
	Likelihood	High	High	High	High
	Other	Direct	Direct	Direct	Direct/indirect
	Significance	Negligible	Minor	Minor	Minor
Suspension of sediments	Importance	Local	Local	Local	Local
	Magnitude	Negligible	Minor	Negligible	Minor
	Persistence	Temporary-short	Temporary-short	Permanent	Temporary-short
	Likelihood	Low	High	Low	High
	Other	Direct/indirect	Direct	Direct	Direct/indirect
	Significance	Negligible	Minor	Negligible	Minor
Traffic	Importance	Local	Local	Local	Local
	Magnitude	Negligible	Minor	Negligible	Minor
	Persistence	Temporary-short	Temporary-short	Permanent	Temporary-short
	Likelihood	High	High	High	High
	Other	Direct	Direct	Direct	Direct
	Significance	Negligible	Minor	Negligible	Minor
Electro-magnetic fields	Importance			Local	
	Magnitude			Minor	
	Persistence			Permanent	
	Likelihood			High	
	Other			Direct/indirect	
	Significance			Minor	
Reef effect	Importance	Negligible	Local	Local	Local-regional
	Magnitude	Negligible	Minor	Minor	Minor
	Persistence	-	Temporary-short	Permanent	Permanent
	Likelihood	Low	High	High	High
	Other	-	Direct/indirect	Direct/indirect	Direct/indirect
	Significance	Negligible	Minor	Minor	Minor
Cumulative effects	Importance	Local	Local	Local-regional	Local-regional
	Magnitude	Negligible	Minor	Minor	Minor
	Persistence	Temporary-short	Temporary-short	Permanent	Permanent
	Likelihood	Low	Medium	Medium	High
	Other	-	Direct/indirect	Direct/indirect	Direct/indirect
	Significance	Negligible	Minor	Minor	Minor

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