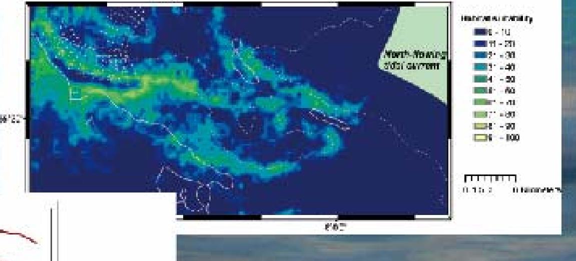
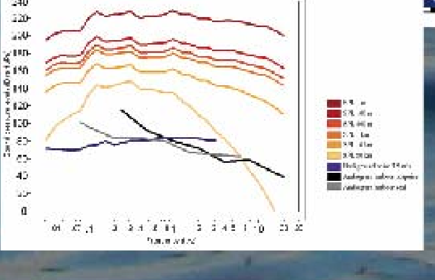
ENERGI E2

EIA Report
Marine Mammals

Horns Rev 2
Offshore Wind Farm





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EIA Report
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Horns Rev 2 Offshore Wind Farm

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Resumé

Konsekvenserne af anlægget af Horns Rev 2 Vindmølleparken på marsvin (*Phocoena phocoena*) og spættet sæl (*Phoca vitulina*) er vurderet på baggrund af det omfattende datamateriale indsamlet under det biologiske moniteringsprogram ved Horns Rev 1 vindmølleparken. De akustiske og visuelle data gav et tilfredsstillende billede af variationen i marsvinenes akustiske aktivitet og habitatkvaliteten i anlægsområdet. Datamaterialet dækkede tidsserier fra fem 'porpoise detectors' (PODs) og 51 finskala skibsbaserede surveys i perioden 1999 – 2005. Begrænsninger i anvendelsen af de eksisterende data blev identificeret i relation til forskellige udgaver af PODs og i relation til sæsonmæssig bias i surveydata. Dette blev der taget højde for ved at fokusere analyserne af akustiske data på T-POD version 1 og analyserne af survey-data til sen-sommerperioden.

Marsvin forekommer relativt talrigt ved Horns Rev med lokale bestandsestimater på 500-1000 dyr. Spættet sæl yngler i Vadehavet og passerer Horns Rev på vej mod fourageringsområder i de dybere områder af Nordsøen. Selvom marsvin forekommer overalt i området, viser de statistiske analyser af koblinger i de akustiske og visuelle data med fysiske oceanografiske data, at arten er koblet til diskrete, lokale processer, især opvæld drevet af tidevandsstrømme snarere end til processer i større skala drevet af densitetsforskelle. Opvældszonerne findes ved skrænterne af Horns Rev, inklusiv den sydvestlige skrænt i den sydlige del af Horns Rev 2 Vindmølleparken. Den modellerede habitatkvalitet for marsvin viste både vigtige områder koncentreret på den sydvestlige skrænt, den nordøstlige skrænt, de sydlige skrænter i Slugen og den sydøstlige skrænt. Den nordøstlige skrænt ser ud til primært at anvendes under sydgående tidevandsstrøm, mens den sydvestlige skrænt ved den sydlige del af Horns Rev 2 Vindmølleparken primært er vigtig under nordgående tidevandsstrøm. Dette område synes generelt at udgøre den vigtigste habitat for marsvin ved Horns Rev. Størrelsen af området med høj habitatkvalitet er omkring 10 km og måler omtrent 15% af det totale modellerede område. For marsvin blev der fundet en markant faldende gradient i habitatkvalitet fra den sydlige til den nordlige del af de to potentielle områder for anlæg af Horns Rev 2 Mølleparken. Habitatkvaliteten for spættet sæl, der kun kunne evalueres mod topografiske data, synes at være størst på den centrale, lavvandede del af revet, men arten udnytter også den lavvandede sydlige del af Horns Rev 2 vindmølleparken relativt intensivt.

Potentielle påvirkninger på de to arter er beskrevet ved at relatere de klassificerede områder med høj habitatkvalitet til detaljerede analyser af støj-relateret forstyrrelse på baggrund af *in situ* målinger og frekvensafhængige effektvurderinger. Vurderingerne fokuserer på effekter af undervandsstøj i forbindelse med ramning af monopæl-fundamenter. På basis af integration af modeller for spredning af undervandsstøj fra ramning og audiogrammer for de to arter estimeres en hørezone på 80 km og en reaktionszone på 20 km, inden for hvilken moderate til kraftige adfærdsændringer hos begge arter kan finde sted. For begge potentielle anlægsområder vil en radius på 20 km dække ca. 75% af området med høj habitatkvalitet for begge arter ved Horns Rev. Effekten forventes at være af kort varighed, og dyrene formodes at kunne udnytte anlægsområdet i perioderne mellem ramningerne, hvorfor denne samlede påvirkning som følge af forstyrrelse ved ramning vurderes at være moderat. Der vurderes ingen væsentlige påvirkninger på dyrenes kommunikation fra ramning.

TTS-zoner, inden for hvilke dyrene kan lide fysisk skade på hørelsen, estimeres til 1000 m og 250 m for henholdsvis marsvin og spættet sæl. Estimeringen af TTS-radius for marsvin er imidlertid usikker og vurderes potentielt at kunne være større end 1000 m, afhængig af om frekvensafhængig TTS anvendes. I tilfælde af at afværgeforanstaltninger ikke gennemføres vurderes konsekvenserne af TTS-effekten at være betydelig i den del af anlægsområdet, der overlapper høj habitatkvalitet. De anbefalede afværgeforanstaltninger i relation til TTS under ramning af monopæl-fundamenter er en kombination af sælskræmmer og pingere med ramp-up procedurer.

Kumulative effekter på havpattedyr vil være underordnede i forhold til effekterne ved ramning. Effekterne ved nedtagning af møller og fundamenter vil afhængig af fundamenttype ligne effekterne beskrevet for anlægsarbejdet.

Under produktion forventes Horns Rev 2 Vindmølleparken kun at påvirke de to arter i meget begrænset omfang. Den generelle effekt kan afhængig af væksten af hårdbundshabitater og tiltrækningen af byttefisk til disse habitater være positiv for havpattedyrene i anlægsområdet. Undervandsstøj genereret af turbinerne under produktion vil kunne høres i en afstand af 1-200 m for marsvin og 1000 m for spættet sæl, men dyrene formodes ikke at udvise nævneværdige adfærdsændringer inden for mølleparken.

Background and scope

In 1996 the Danish Government passed a new energy plan, ”Energy 21”, that states the need to reduce the emission of the greenhouse gas CO_2 by 20% in 2005 compared to 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 on 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 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 by investigations during and after the construction phase where all environmental impacts were assessed. Detailed information on methods and conclusions of these investigations can be found in the annual reports (www.nystedhavmoellepark.dk; www.hornsrev.dk).

On August 25 2005, The Danish Energy Authorities issued permission 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 be operational in 2009 with a total effect of approximately 200 MW, which is equivalent to 2% of the Danish consumption of electricity.

The increased demand for renewable energy has led to construction of offshore wind farms with high-powered turbines generating electrical power of several megawatts. In Europe, there are currently 17 maritime wind farms in operation with a combined power of 570 MW with many more being planned, especially in the shallow coastal zones of northern Europe (Great Britain, Netherlands, Germany and Denmark). The two largest facilities – with nominal power outputs of 160 MW each - are operating off the coast of Denmark, one near Rødsand (Nysted Offshore Wind Farm) and the other approximately 15 km off Esbjerg in the North Sea (Horns Rev 1 Offshore Wind Farm). The Horns Rev 1 Offshore Wind Farm was constructed by Elsam A/S and was operational in December 2002.

Due to the local abundance of harbour porpoise (*Phocoena phocoena*) and the nearby colonies of harbour seal (*Phoca vitulina*) marine mammals constituted an important component of the environmental programme at the Horns Rev 1 Offshore Wind Farm (Skov et al. 2002). At the time of writing this report the assessment of impacts on these two species of marine mammals from the Horns Rev 1 Offshore Wind Farm has not yet been finalised, but will be published in Tougaard et al., in prepp. However, effect studies carried out during the construction phase indicated behavioural reactions of harbour porpoises to ramming noise (Tougaard et al. 2003a). Harbour porpoises rely heavily on sound for orientation and foraging and are acoustically among the most sensitive cetacean species (Au et al. 1999a; Kastelein et al., 2002; Teilmann et al., 2002b; Verfuss et al., 2005). Harbour seals communicate through low-frequency calls when diving and have well developed underwater hearing (Riedmann, 1990; Kastak and Schustermann, 1998). The noise created during pile-driving operations involves sound pressure levels that are high enough to impair the hearing system of both species near the source and disrupt their behaviour at considerable distance from the construction site (Nedwell et al., 2003; Nedwell & Howell, 2004; Tougaard et al., 2004; Madsen et al., 2006; Thomsen et al., 2006a). Operational sounds are less powerful but have the potential to disrupt behaviours at distances of several hundred meters from the pile (Koschinski et al., 2003; Madsen et al., 2006).

The present report addresses key-issues for the planned Horns Rev 2 Offshore Wind Farm. The issue of noise-related disturbance has been addressed both in theory and empirically on the basis of a detailed analysis of the local habitat use. The large acoustic and survey databases from the baseline and monitoring activities from 1999-2005 provided the basis for a systematic study on the status and distribution of harbour porpoises at the Horns Rev 2 Offshore Wind Farm site. Due to the more limited amount of data on harbour seals, the occurrence of this species is treated more generally. Other species of marine mammals are not considered regular visitors to the Horns Rev area (Skov et al., 2002). We set-up a fine-scale hydrodynamic and topographic model for Horns Rev to gain a comprehensive and integrated insight into the fine-scale dynamics of harbour porpoises within the study area and the factors influencing trends in occurrence and acoustic activity. Impacts were assessed by linking the classified key habitats to detailed investigations of noise-related disturbance using *in situ* measurements together with a method of frequency-related impact assessment.

The two species in focus are the most abundant marine mammal species in European coastal waters, with a population of harbour porpoises in the North Sea estimated 270,000 with areas of highest densities off the British east coast, the central North Sea and Northern Frisia, including Danish coastal waters (Hammond et al., 2002). Several studies indicated the presence of a north-south gradient in densities along the German Wadden Sea with a possible calving ground off Sylt, Northern Frisia (Benke et al., 1998; Scheidat et al., 2004). Harbour seals are most often counted on haul-out sites. According to the trilateral Seal Management Plan, five coordinated aerial surveys per year are conducted in order to monitor the harbour seal population in the Danish, German and Dutch Wadden Sea (TSEG, 2005). The total number of harbour seals in the Wadden-Sea during the moult period in August 2005 was 14,200. This number was comprised of 1,720 in Denmark, 5,500 in Schleswig-Holstein, 3,600 in Lower-Saxony/Hamburg and 3,443 in the Netherlands (TSEG, 2005). Little is known about the occurrence of the species in offshore waters but previous studies indicate some seasonal site-fidelity and home-ranges of up to 50 km from the haul-out site (Thompson and Miller, 1990; Orthmann, 2000, Nickel et al., 2001; Scheidat et al., 2004). Preliminary results on satellite-tracked animals from Denmark indicate long feeding ranges and preferential feeding in deeper areas to the northwest of Horns Rev (Tougaard et al., 2003d).

As a signatory to the Convention on the Conservation of European Wildlife and Habitats (Berne Convention) and Article 12 of the EU Habitats Directive (1992), Denmark has implemented the full protection of harbour porpoises and harbour seals through the Hunting and Game Regulation No. 114 from January 1997. Harbour porpoises are listed as a species of European conservation priority in Annex II of the Habitats Directive. In addition, Denmark is a signatory to the agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS), which includes Resolution No. 4 on disturbance and the prevention of disturbance, e.g. from acoustic noise.

1. 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 km 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.

The Horns Rev area has a highly distinctive oceanographic setting, which is characterised by quasi-permanent fronts and up-wellings created by the convergence of estuarine and North Sea water masses, tidal currents and interactions with the striking bathymetry of Horns Rev.

1.1. 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, waves and sedimentation of sand; the latter of which causes 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 currents 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.

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). A large spatial variation exists regarding the sediment grain size distribution. Effects of strong currents are found on the slopes facing larger depths, where coarser sand can be found (Leonhard & Skov, 2006). The steepest slopes are found in the southwestern extreme of the area at the southern edge of the southern site of the planned wind farm.

Several shallow bank areas are found within the area, of which VovVov is located in the eastern parts of both the southern and northern wind farm site (Figure 1.1).

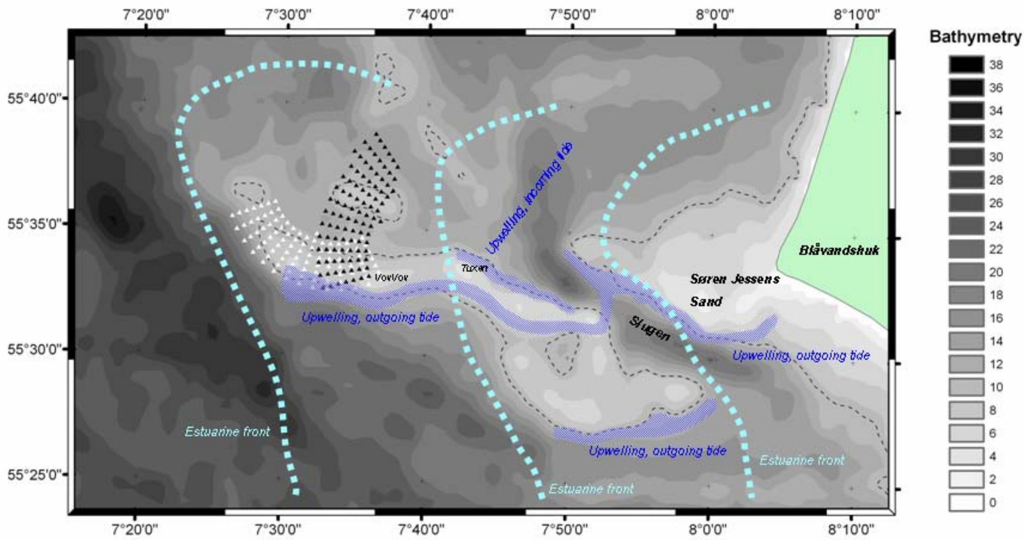


Figure 1.1. Map showing the physical environment of Horns Rev, with names of the topographic and hydrographic structures and processes mentioned frequently in the report. The 10 m (dotted line) depth contour, typical up-welling zones (blue raster) and potential position of the estuarine front (light blue dotted line) are indicated.

1.2. Hydrography

Horns Rev is an area of relatively shallow water, strongly influenced by waves and situated in an area with large tidal fluctuations. The mean tidal range in the wind farm area is about 1.2 m, but drops to around 0.5 m in the northern part of the northern site (Danish Hydraulic Institute, 1999). Within the wind farm area, the water depth varies from about 4 m to 14 m. The steep topography causes the waves to break in the wind farm area. The average wave height is about 0.6-1.8 m.

The hydrography of Horns Rev can be characterised as a frontal complex determined by the large-scale convergence between North Sea water masses and estuarine water masses from the south as well as by small-scale fronts and up-welling created by interactions between tidal currents and topography. The large-scale frontal system is mainly driven by wind and current conditions in the North Sea and inflow rates of freshwater from the Elbe and other large rivers in Germany (Dippner, 1993). The mean position of the estuarine front at the latitude of Blåvandshuk is located at the western tip of Horns Rev (Skov & Prins, 2001). However, in comparison to the position of the northern and southern wind farm sites, the front may be located in different locations during different climatic scenarios. Hence, the salinity range in the wind farm sites spans from 30 ‰ to above 34 ‰. Many other parameters that separate the North Sea from the estuarine water masses follow the large-scale dynamics, including transparency of the water due to concentrations of suspended sediments in the water column, chlorophyll *a*, nutrients and other anthropogenic discharges. The estuarine water mass moves erratically in a northern direction towards Skagerrak in what is known as Jyllandsstrømmen (Leth, 2003). Despite the tidal currents, rough waves and constant mixing of the water, the whole area is moderately stratified due to the influence from brackish water.

The tidal currents essentially move in a north to south direction (220º SSW) with a mean water velocity of 0.5-0.7 m/s. Water velocities of 0.7 m/s 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). The interaction between the steep topography and the tidal currents create small up-welling zones at the northern slopes during south-flowing tide, at the southwestern slopes during outcoming tide and at the eastern slope at Søren Jessens Sand in Slugen. Thus, the southern edge of both the southern and northern wind farm sites are characterised by bi-diurnal up-welling activity.

2. The wind farm area

2.1. Description of the wind farm area

The Horns Rev 2 Offshore Wind Farm will be located about 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 for the environmental studies is shown in Figure 2.1. The establishment of the wind farm is expected to be in one of the designated sites. The exact position of the wind farm 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 have been designated - a northern and southern site. The northern site extends northwards from the reef. The southern site extents from east towards west and partly covers the reef. Both sites cover an 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.

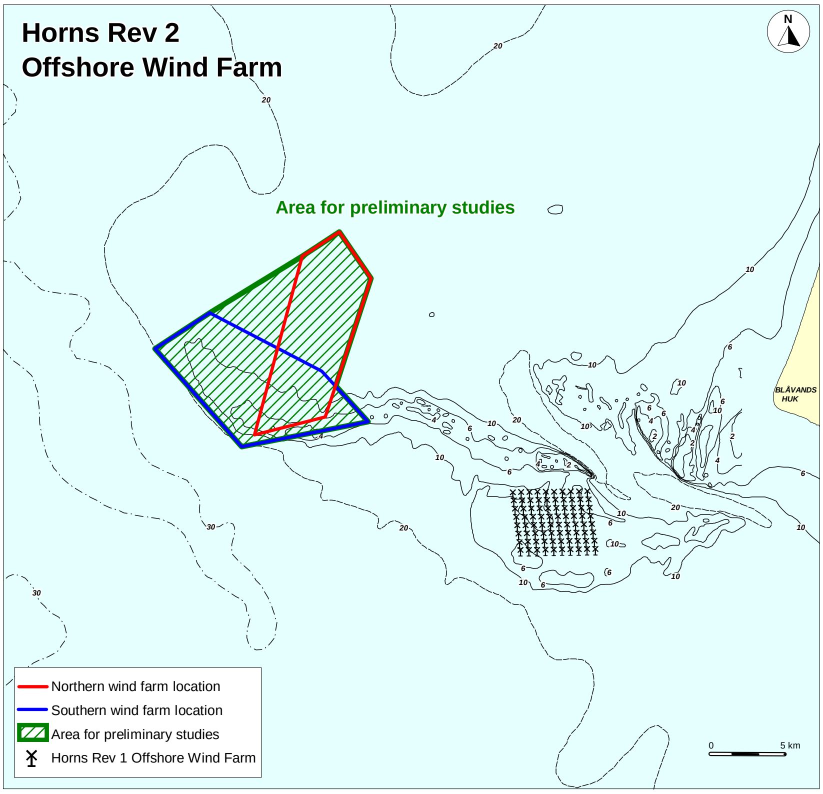


Figure 2.1. The area selected for the environmental studies regarding the establishment of Horns Rev 2 Offshore Wind Farm.

2.2. The turbines

The type of turbine to be installed and the type of foundation has not yet been decided. Likewise the location of the wind farm 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.

Figure 2.2. and Figure 2.3. show the expected row patterns of the turbines at the two alternative sites. However, the exact position is not mapped out yet as some adjustments may still be made.

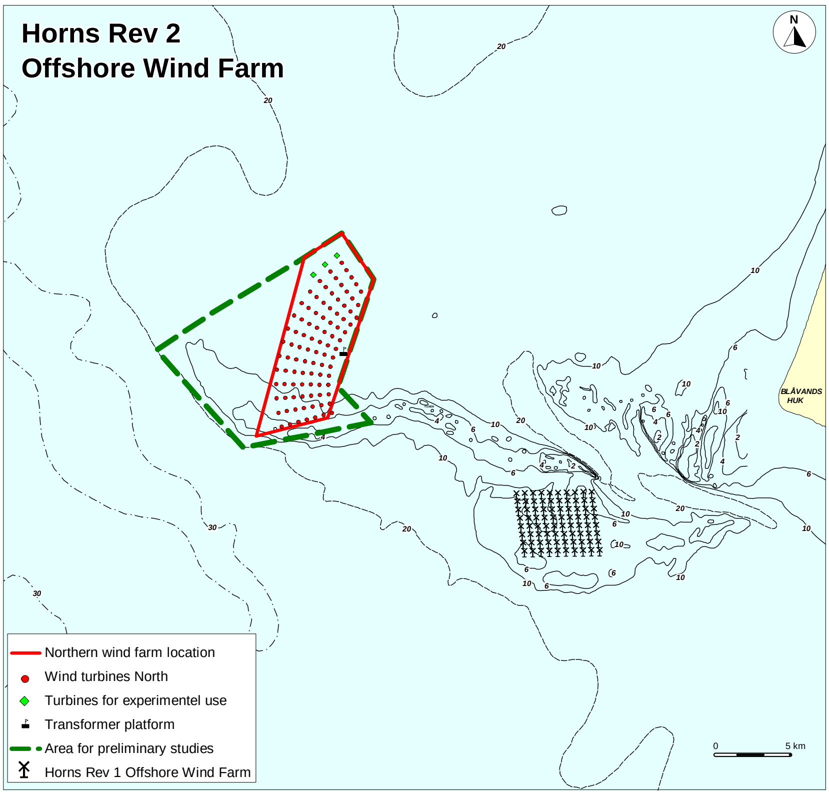


Figure 2.2. The proposed turbine positions at the northern site. Horns Rev 2 Offshore Wind Farm.

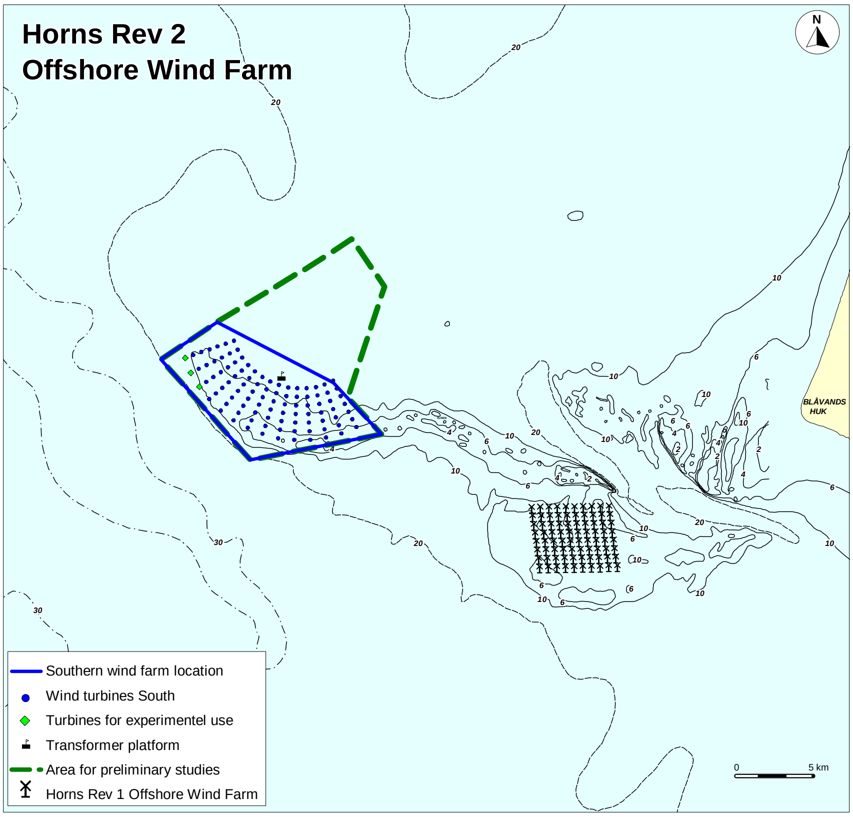


Figure 2.3. The proposed turbine positions at the southern site. Horns Rev 2 Offshore Wind Farm.

2.2.1. Foundations

The foundations of the turbines will either be gravitation foundations or mono-piles. The size and type of the mono-piles, and the method for pile driving has not yet been decided. For both types a scour protection is necessary to minimize erosion due to strong currents at the site. The foundations including protection will occupy an area less than 0.3% of the entire wind farm area.

2.2.1.1. Gravitation foundations

The gravitation foundations consist 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 tonnes. 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.

2.2.1.2. Mono-pile foundations

The foundations of the existing wind turbines at Horns Rev 1 Offshore Wind Farm are so-called mono-pile foundations. The mono-pile 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 mono-pile foundation also needs scour protection, especially when the turbine is situated in turbulent areas with high levels of flow velocities.

2.2.2. 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.

2.2.3. The cable

The wind turbines will be interconnected by 36 kV cables sluiced down to a depth of one meter 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.

2.2.3.1. 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.

3. Methods

3.1. Data sources

3.1.1. Base-line bioacoustics data

The collection and pre-processing of the data was conducted within the framework of the EIA studies for Horns Rev 1 Offshore Wind Farm. A detailed description of the acoustic methodology can be found in Teilmann et al. (2002a) and Tougaard et al. (2003b, 2004, 2005). An overview of the T-PODs and the T-POD-software, including a manual for data-acquisition and analysis, can be found at http://www.chelonia.co.uk/html/pod.html. The following section is limited to a general description of the methods.

Underwater acoustic has become an important tool for long-term monitoring of cetaceans in the wild. Fixed hydrophone installations at strategic sites can provide a means of remotely monitoring the presence of a particular species throughout the year, day and night and in all weather conditions. Recently, a variety of automated click-detectors have been developed that hold great potential for acoustically monitoring the distribution and movements of harbour porpoises; reviews in Evans & Hammond, 2004; Gordon & Tyack, 2002. One such device is the T-POD (porpoise-detector; Chelonia Marine Research), which has been used in several field studies (e.g. Teilmann et al., 2002a; Verfuss et al., 2004; Carlström, 2005; Tougaard et al., 2003a, 2004, 2005; Thomsen & Piper, 2004, 2006). Previous studies have looked at seasonal patterns in click activity in the Horns Rev area in different years and correlations of click activity with tide (Tougaard et al., 2003a, 2004, 2005). The goal of the present study is to provide a more extensive overview over the acoustic activity of harbour porpoises in the Horns Reef area between 2002 – 2005, with a focus on data taken in the area where the Horns Rev 2 Offshore Wind Farm is planned. Another goal is to analyse the relationship between environmental variables and acoustic activity in order to identify which parameters govern the presence of porpoise in the western part of Horns Rev as a basis for determining the variability in the use of the wind farm area by harbour porpoises.

The T-POD is a self-contained and fully automated system for the detection of echolocation clicks from harbour porpoises and other cetaceans. It is programmable via specialized software. The T-POD consists of a hydrophone, an analogue click detector, a digital timer and a duration logger (Figure 3.1).

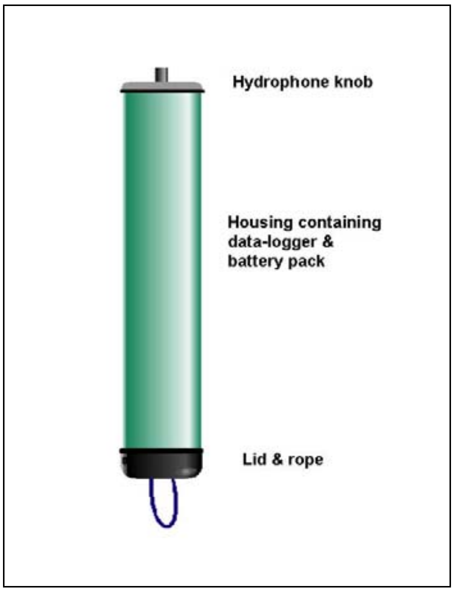


Figure 3.1. The T-POD.

Sonar clicks from porpoises are detected by the comparison of the outputs of two band-pass filters. One filter is set to the peak spectral frequency of clicks of the target species, in harbour porpoises 130 kHz (Verboom & Kastelein, 1995; Au et al., 1999a; Teilmann et al., 2002b). The other filter is set away from the centre-frequency at around 90 kHz. Any signal containing more energy in the high filter relative to the low one and with a duration shorter than 200 microseconds is highly likely to be either a porpoise or man-made sound (boat sonar, echo sounder). Boat sonar and echo sounders are filtered out by the software by analysing intervals between clicks. The T-POD hardware settings can be re-configured six times each minute. In each of these six ‘scans’ the T-POD logs for 9.3 seconds using the selected values for high and low filters and 3 additional parameters (Thomsen et al., 2005). The hydrophone of the T-POD is omni-directional in the horizontal plane and has a detection range for porpoise clicks of around 300 m (http://www.chelonia.co.uk/html/pod.html). There are different versions of T-PODs. The first version, termed V1, is equipped with 8 MB RAM, version V3 with 32 MB and V4 with 128 MB. All 3 types are powered by standard or lithium batteries. Logging stops when the voltage drops to 5.2 volts. Running time depends on voltage input, memory and settings and is usually about 60 days.

Data can be downloaded from the T-POD to a PC via parallel or USB port. The analysis is done with the T-POD-software. Through an algorithm, the T-POD software identifies click trains (clusters of clicks) using an estimate of their probability of arising by chance if the prevailing rate of arrival of clicks was from random or non-train producing sources. Based on this principle, the software classifies all trains in different classes according to their probability of coming from porpoises: 1) CET HI: trains with a high probability of coming from porpoises, 2) CET LO: less distinctive trains that may be unreliable in noisy places, 3) DOUBTFUL: these are often porpoise trains but are unreliable in noisy environments; 4) Very DOUBTFUL: these include trains resembling chance sequences arising from random sources or regular sequences from boat sonar; and 5) FIXED RATE / BOAT SONAR: these are trains showing very little drift in click rate, often containing long clicks and having a strong resemblance to a boat sonar. The T-POD-software offers three display options: duration of clicks and trains (Figure 3.2), interclick-intervals (ICI) and pulse-repetition-frequencies between clicks of a train. It can be set to 'high-resolution' from 10 µs to 100 ms per pixel along the x-axis. The 'low resolution' mode shows click counts over periods from 1 min. to 12 hours. Clicks of different categories are counted by the software over the entire logging period.

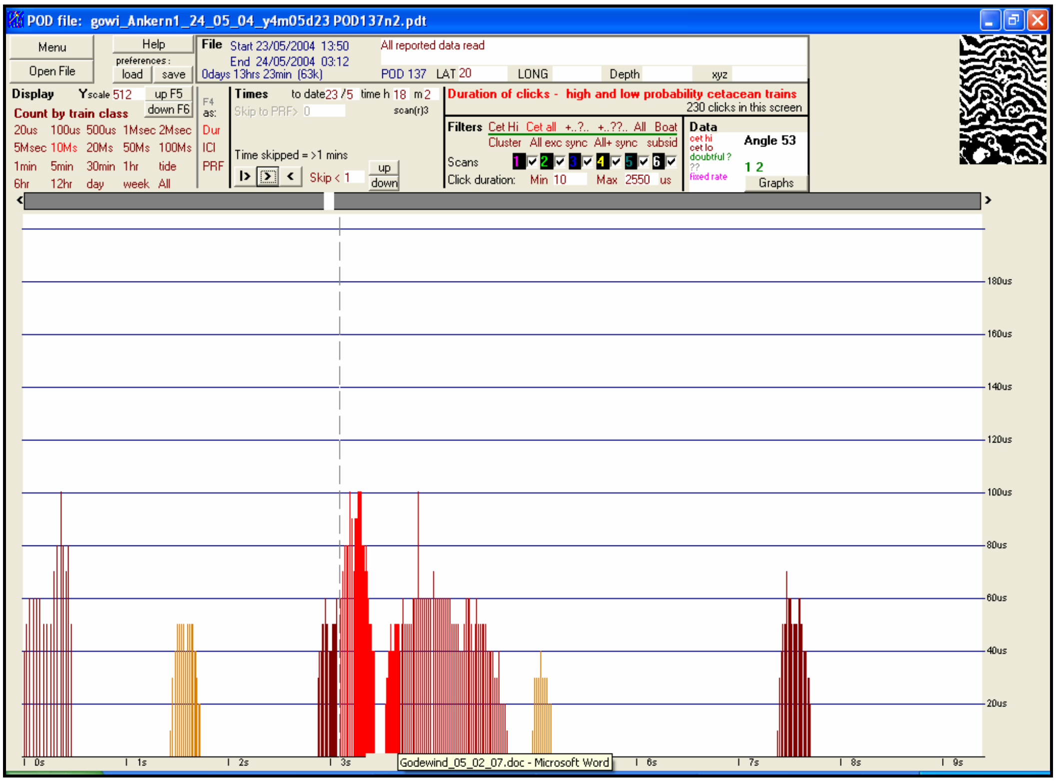


Figure 3.2. Example diagram from the T-POD software showing clicks and trains of different probability (x-axis = time (s); y-axis = duration (µs); red = CET-HI clicks, brown / yellow = CET-LO clicks).

After visual inspection, data can be processed and exported for statistical analysis using various export-functions.

Data used in this analysis was collected between 2002-2005 in the area 5-20 km west of Esbjerg. T-PODs were deployed in four sub-areas comprising two stations each (termed Horns Rev 1 –8; short = HR; Figure 3.3). The description of the method for deployment can be found in Tougaard et al. (2003b, 2005).

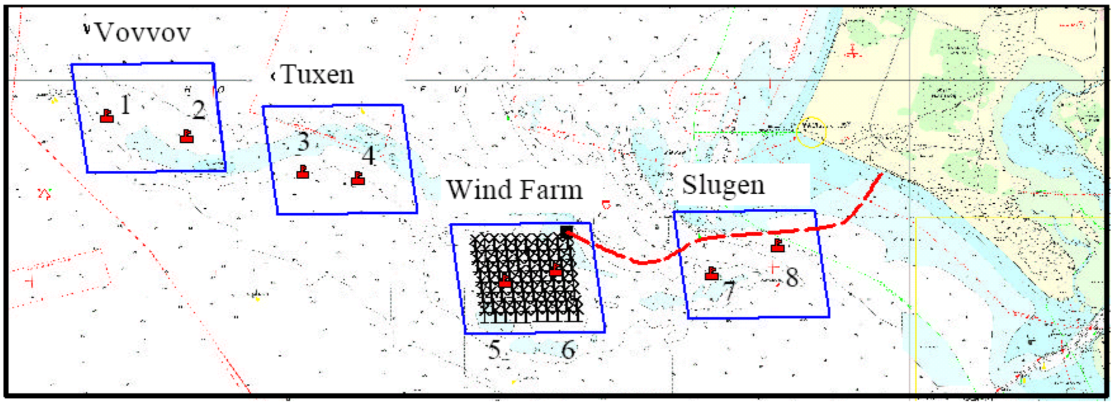


Figure 3.3. Overview of the T-POD study design for Horns Rev 1 Offshore Wind Farm. The four sub-areas are indicated by blue lines; stations are numbered flags.

Technical problems and loss of equipment prevented the inclusion of data from HR 2, HR 4 and HR 8 for further analysis. In the remaining stations (1, 3, 5, 6 and 7), 16 T-PODs were used including different versions (V1, V3 and V4; Table 3.1). The T-PODs differed in sensitivity, ranging from ‘sensitivity code’ 0.5 to 8. This scale is a sensitivity measured as SPL with the difference between two sensitivity values (A,B) in dB being 20 * log (A/B) (Tregenza, personal communication).

*Table 3.1. T-PODs used in the study (1/3, 3/1: Version 1 house / hydrophone and version 3 electronics and vice versa; * : re-evaluated by Nick Tregenza, personal communication).*

T-POD number	Station	Version	Sensitivity code
11	7	1/ 3	0.5*
15	1	1	0.5*
20	3	1	0.5*
37	1. 3	1	0.5*
38	3	1	0.5*
39	5. 6	1	0.5*
45	7	1	0.5*
161	6	3	8
224	1	3	4
226	5	3	4
270	5	3	4
282	7	3/1	4
334	3	4	4
335	5	4	4
341	1	4	4
342	6	4	4

Due to the above-mentioned problems, data was collected discontinuously within and across the 5 stations. A total of 1,891 data-days were used in the analysis with most days derived from station 7, followed by station 5, 3, 1 and 6. The 16 different T-PODs were used within and between stations with version 4 T-PODs introduced in 2005 in all stations, except 7 (Table 3.2). Station 1 was used to describe the baseline for the wind farm sites as it is located in the western part of the southern site.

Table 3.2. Overview over the months where data was recorded at the different stations (indicated in orange) and the T-PODs used in each station (numbers). Data-days are given below each station.

	HR 1	HR 3	HR 5	HR 6	HR 7
Jan 02		38			
Feb 02					
Mar 02	37				45
Apr 02	37				45
May 02	37				45
Jun 02	37			39	45
Jul 02				39	45
Aug 02			39	39	45
Sep 02	15	20			
Oct 02	15	20			
Nov 02					
Dec 02					
Jan 03		20			
Feb 03					11
Mar 03					11
Apr 03					11
May 03					11
Jun 03	224		226	161	11
Jul 03	224		226	161	11
Aug 03			226		11
Sep 03			226		11
Oct 03	224		226 / 270		11
Nov 03	224		270		
Dec 03	224		270	161	11
Jan 04	37 / 224		270		11
Feb 04	37 / 224				
Mar 04	37				
Apr 04		37	270		11
May 04		37	270		11 / 282
Jun 04		37	270		11 / 282
Jul 04			270		11 / 282
Aug 04					
Sep 04					
Oct 04					
Nov 04					
Dec 04					
Jan 05					
Feb 05		334	335	342	
Mar 05	341	334	335	161 / 342	282
Apr 05	341	334	335		282
May 05	341	334	335	161	282
Jun 05	341	334	335	161	
Jul 05		334	335		282
Aug 05		334	335		282
Sep 05		334	335		
Oct 05		334	335		
Nov 05			335		
Data-days	**304**	**349**	**525**	**97**	**616**

The T-PODs of one type were set identical (Table 3.3). Settings between versions were adjusted in a way to correct for inter-type variation (Tougaard et al., 2004). Shown in Table 3.3 are the settings for the V1 and V3 versions. V4 settings follow a different coding scheme.

Table 3.3. T-POD filter setting used at Horns Rev 1 Offshore Wind Farm for the T-POD-versions V1 and V3.

Settings	V1	V3
A filter (kHz)	130	130
B filter (kHz)	90	90
Ratio A/B	5	5
A filter sharpness	10	Low
B filter sharpness	18	High
Min. intensity/threshold	0	6
Min. duration (µs)	50	50

3.1.2. Base-line survey and telemetry data

Between April 1999 and December 2005, a total of 51 dedicated ship-based line-transect surveys for harbour porpoises were carried out during the biological monitoring of Horns Rev 1 Offshore Wind Farm (Table 3.4). These surveys comprised the basis for modelling the habitat quality of the two species of marine mammals at Horns Rev. In addition, incidental sightings of harbour porpoises were obtained from the following non-dedicated surveys: the 35 aerial line-transect seabird surveys made during Horns Rev 1 Offshore Wind Farm, the European Seabirds at Sea Database (ESAS) version 4 and other ship-based seabird data held by DHI Water & Environment. Data collected during the 1994 SCANS survey for small cetaceans in the North Sea were also made available for the assessment.

Details of the survey methodology operated during the targeted harbour porpoise surveys are given in Tougaard et al. (2003b). The animals were recorded using standard line-transect methods along a minimum of 10 east-west running transect lines covering approximately 400 km (Figure 3.4). Additional survey lines were surveyed to the north of Horns Rev when weather permitted. The distance between the seven transect lines was 2.5 km, while the distance between the lines in the northern part was 5 km. One line crossed the southern part of both Horns Rev 2 Offshore Wind Farm sites, one transect crossed the northern part of the northern wind farm site, and one line crossed the area just south of the sites. Due to the draught of the survey ships the shallowest parts of the reef were not crossed during the transects.

Three observers were running observations simultaneously; two observers using binoculars to improve detection of porpoises ahead of the survey ship, while the third observer was making recordings. All data was collected at a spatial resolution between 450 and 650 m. All three observers searched an area of 500 m within a 180 degree search area in front of the ship and used angle-boards and distance calipers determine distances and angles to first sightings.

Table 3.4. List of harbour porpoise surveys carried out at Horns Rev 1 Offshore Wind Farm.

1999: 5/3, 24/4, 25/4, 30/4, 23/8, 24/8, 29/8, 30/8
2000: 23/2, 23/7, 24/7, 25/7, 12/8, 13/8, 14/8
2001: 15/8, 16/8, 17/8, 18/8, 21/8, 22/8
2002: 12/3, 23/3, 24/3, 20/4, 21/4, 8/6, 9/6, 28/7, 29/7, 30/7, 31/7, 1/8, 2/8, 8/8
2003: 13/2, 18/3, 8/6, 8/7, 23/7, 24/7, 8/9, 8/10, 17/10, 18/10, 2/12
2004: 19/2, 20/2, 26/4, 27/4, 2/8, 3/8
2005: 23/6, 24/6, 30/6, 1/7, 18/8, 20/8, 21/8, 15/10, 16/10, 22/11, 23/11

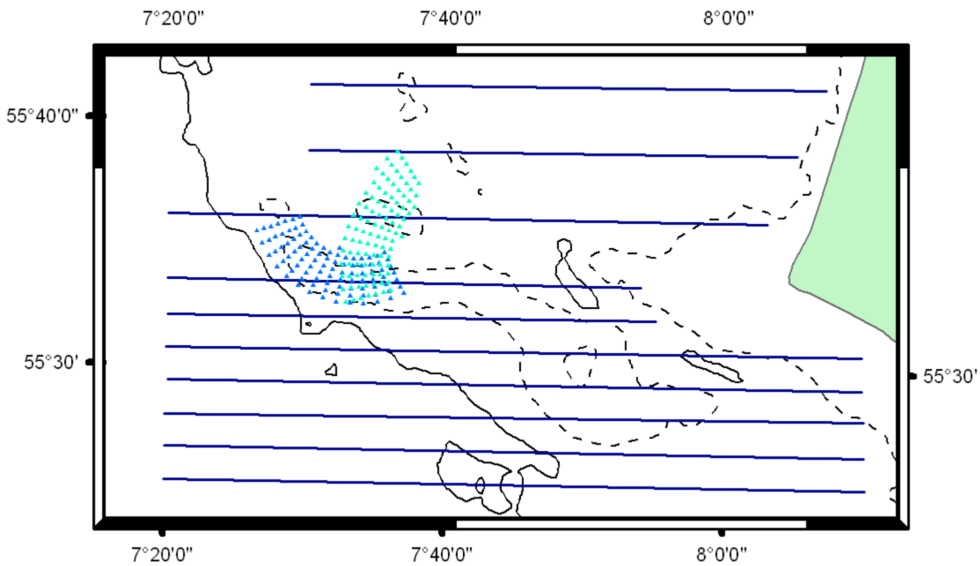


Figure 3.4. Survey design for the dedicated ship-based surveys of harbour porpoises associated with the Horns Rev 1Offshore Windfarm (minimum number of lines covered).

The additional (non-dedicated) survey data provided more observations and coverage of the planned wind farm sites during spring and autumn periods (figures 3.5 – 3.8).

The Argos satellite telemetry data cover two datasets. The first dataset was collected on five animals using SDR-T16 transmitters in 2002, the second dataset was collected during 2003-2005 using one SDR-T16, 4 SPOT2 and 6 SPOT6 transmitters.

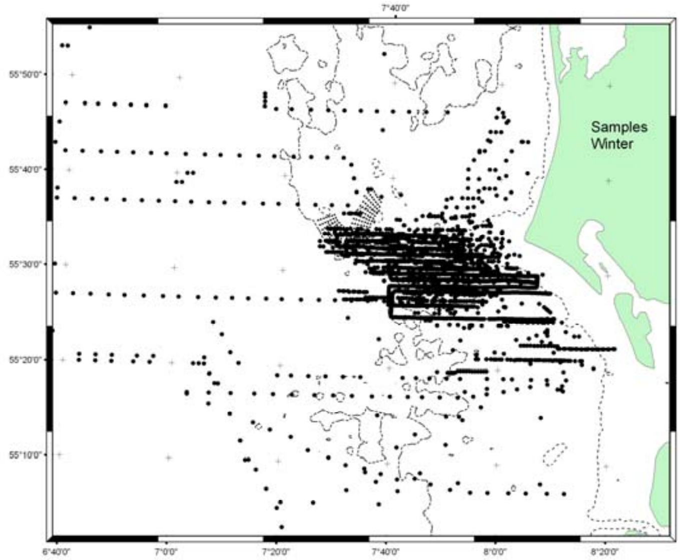


Figure 3.5. Distribution of total ship-based line-transect survey effort (dedicated and non-dedicated) available for the assessment in the area around Horns Rev for the winter period (December-February).

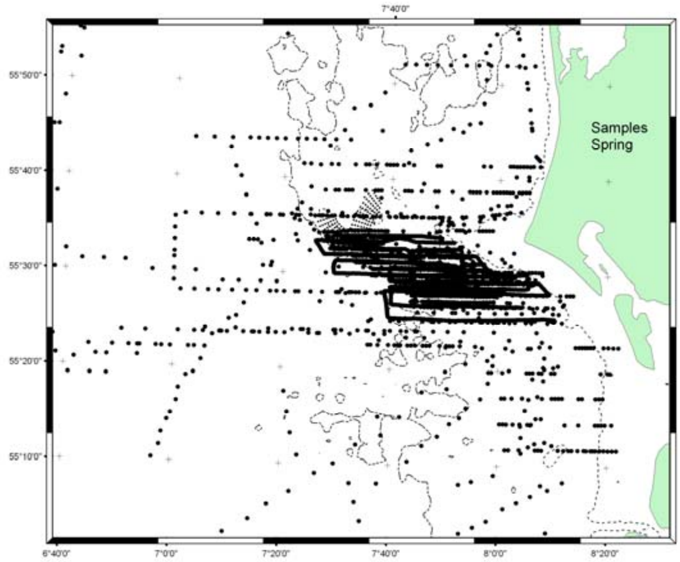


Figure 3.6. Distribution of total ship-based line-transect survey effort (dedicated and non-dedicated) available for the assessment in the area around Horns Rev for the spring period (March-May).

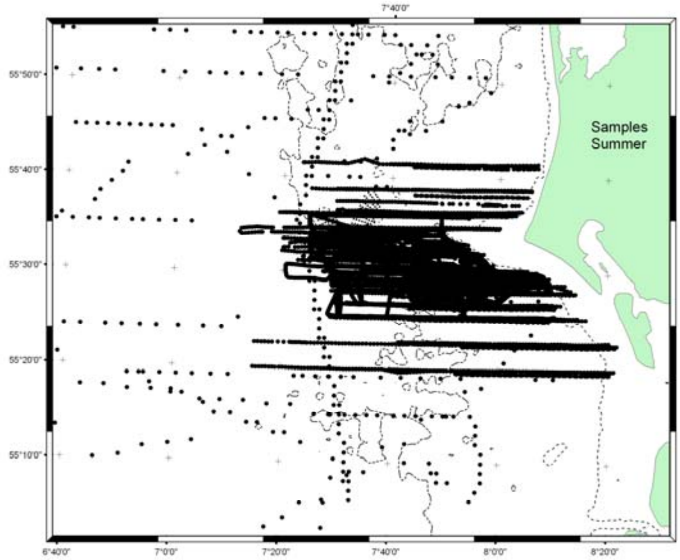


Figure 3.7. Distribution of total ship-based line-transect survey effort (dedicated and non-dedicated) available for the assessment in the area around Horns Rev for the summer period (June-August).

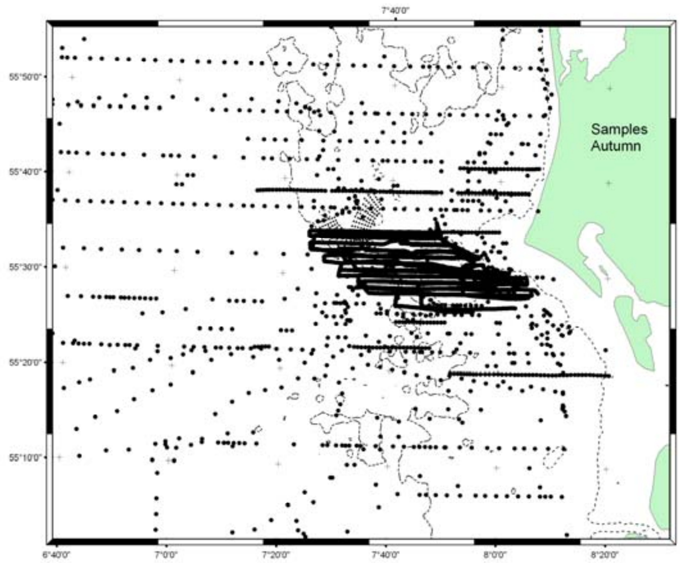


Figure 3.8. Distribution of total ship-based line-transect survey effort (dedicated and non-dedicated) available for the assessment in the area around Horns Rev for the autumn period (September-November).

3.2. Determination of the temporal variation of harbour porpoise

3.2.1. Data processing – indicators for acoustic activity of porpoises

The processing of the data was undertaken with the T-POD software. The data for later analysis contained clicks of the first two classes of trains (CET-HI, CET-LO). Three indicators of acoustic activity were extracted from the T-POD-signals:

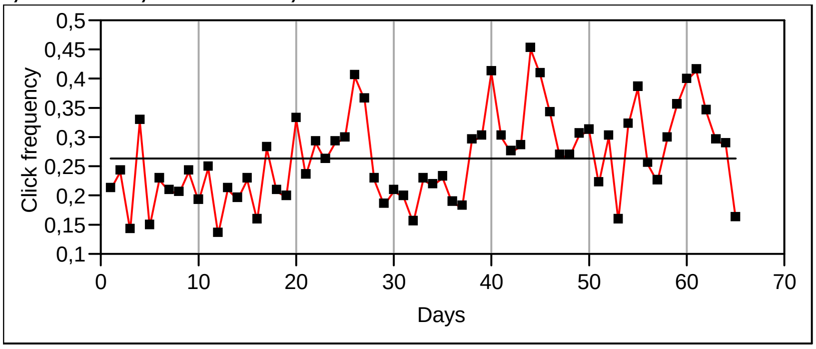
1) Daily click frequency: the proportion of minutes with clicks per day.
2) Waiting times: number of minutes in a silent period lasting more than 10 minutes
3) Encounter duration: Number of minutes between two silent periods lasting more than 10 minutes.

The click-frequency, also termed 'porpoise positive minutes per day' and the waiting times are a measure of porpoise abundance in an area. Higher click-frequencies and lower waiting times compared to another T-POD recording, indicate a higher presence of porpoises. Encounter duration provides information on the acoustic behaviour of porpoises when they are present.

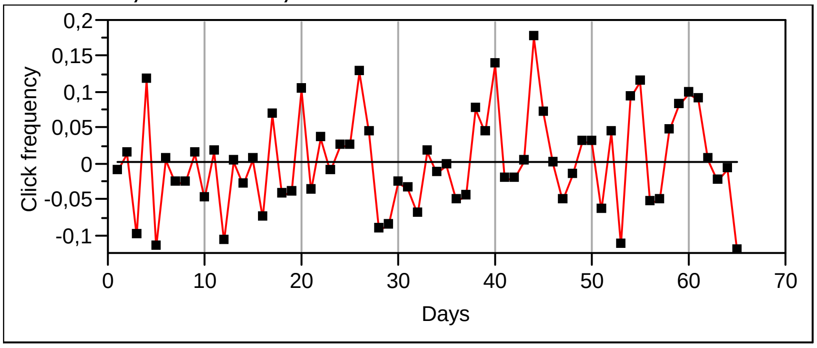
3.2.2. Data transformation and correction for serial autocorrelation

All three indicators were given as daily values. Click frequency was calculated as the proportion of minutes with porpoise clicks relative to the logging period (min) per day. Waiting times and encounter durations (min) were summarized per day. The three indicators were transformed to arrive at a normal-distribution (daily frequencies = arcsine; waiting times and encounter durations = log (y); see Tougaard et al. (2005) for a detailed description of the transformation process and Zar (1996) for most commonly used transformations). The time series of daily indicators (= periods of successive logging days per pod per station) were tested with a Durbin-Watson-Test for autocorrelation. Time series of daily click frequencies were found to be autocorrelated. In order to correct for this, every time-series was modelled using an ARMAM (1, 0, 1) process, resulting in non-autocorrelated residuals. To preserve the original differences across deployments, the mean of each time series was added to the residuals. This resulted in time series of daily frequencies that were not autocorrelated but still showed the trends of the original data. An example of this procedure can be found in Figure 3.9. It can be seen that the series of the transformed data is highly autocorrelated whereas the residual series derived after the ARMAM-modelling is not.

Time Series A, Station 7, T-POD 282, 10.03 – 13.05.05 - transformed

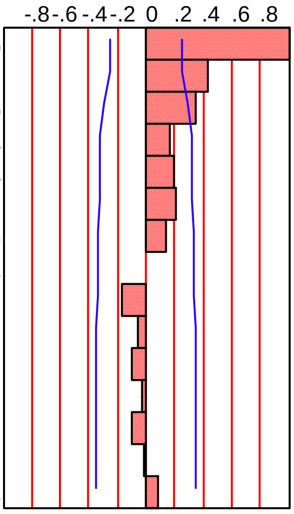


Time Series B Station 7, T-POD 282, 10.03 – 13.05.05 - residuals



Time Series A

Lag	AutoCorr
0	1,0000
1	0,4337
2	0,3450
3	0,1634
4	0,2024
5	0,2097
6	0,1329
7	0,0038
8	-0,1724
9	-0,0533
10	-0,1001
11	-0,0262
12	-0,0923
13	-0,0145
14	0,0906



Time Series B

Lag	AutoCorr
0	1,0000
1	-0,0147
2	0,0468
3	-0,1275
4	0,0228
5	0,1194
6	0,0728
7	-0,0312
8	-0,2687
9	0,0173
10	-0,0837
11	0,0209
12	-0,1407
13	-0,0392
14	0,0680

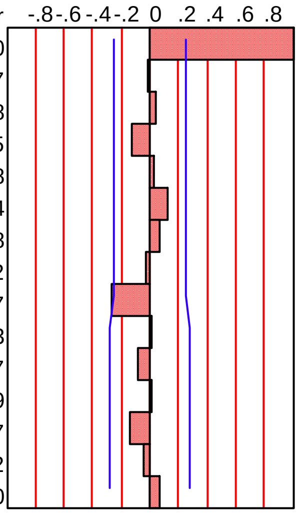


Figure 3.9. Time series of daily click frequencies and the residual series from a station 7 deployment in 2005. The autocorrelation graph is shown below, indicating lag 1 and lag 2 autocorrelation (left graph) for the transformed frequencies and no autocorrelation in the residuals (right graph) .

3.2.3. Analysis of variation in the indicators

All three indicators were assumed to be affected by the following factors: *Station*, *T-POD-number*, *year*, *season* and *month*. The factor area was not accounted for since, despite area 3, only one station was analysed per area. T-POD versions (V1, V3, V4) were originally tested but due to low degrees of freedom T-POD-number was introduced as a main factor since individual PODs were used in different stations, which would result in a mixture of nested and crossed designs. Therefore, the influence of the different factors was tested with a factorial design by the equation:

μ = station + year + season (year) month(season, year) + date(season, year, month) + T-POD-number

The analysis of environmental factors as predictors for indicators of acoustic activity was carried out using a combined factorial and polynomial model design in PLS regression analysis. PLS regression is an extension of the multiple linear regression model and enables the prediction of environmental factors underlying responses on the species from factors underlying the levels of the predictor variables extracted from cross-product matrices involving both the predictor and response variables. Ten dynamic environmental parameters were extracted as daily means from the hydrodynamic model data and added to the existing database (see details of the methodology in chapter 3.3, modelling of habitat quality).

As HR 1 is the only station in the vicinity of the planned wind farm, the analysis was mainly concentrated on data from this station. For a comparative approach, data from HR 7 was also used. Since porpoise activity differed strongly between seasons (see below). environmental parameters also differing with season would confound the analysis. As can be seen in Figure 3.10, density was negatively correlated with temperature, which is in turn affected by season. Both parameters were removed from the analysis.

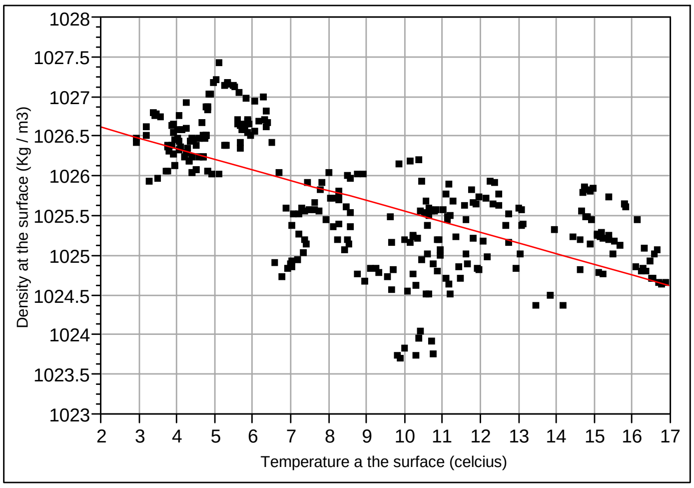


Figure 3.10. Bivariate fit of density at the surface by temperature at the surface (station HR 1).

It became further evident that the T-POD version used had a strong influence on data with most differences between V4 and the other two versions. Therefore, it was decided to run the analysis based on data recorded by T-PODs of version 1 for which the largest amount of data was available.

3.3. Modelling of habitat quality

3.3.1. Hydrodynamic modelling

Modelling of habitat suitability or quality of marine animals typically requires the computation of synoptic, dynamic variables (Doniol-Valcroze, 2005; Skov et al., 2005). We constructed a local 3-dimensional model for the Horns Rev area covering the entire period 2002-2005. The model was set up using DHI's model system MIKE 3, which is a fully dynamic, barotropic and baroclinic 3-D model. We used a finite difference grid, in which the hydrodynamic conditions are described in quadratic elements. The size of elements varied horizontally from 500 m in the core model area to 1500 m in the surrounding boundary area, which extended southwards to the north Frisian Islands (Figure 3.11). The vertical resolution was 2 m except for the surface layer, which has a depth of 5 m to take into account the tidal amplitude.

The hydrodynamic model, which was geo-referenced to WGS84, UTM zone 32, calculated the water levels (relative DVR90 datum), currents (3 components), temperature and salinity at half-hour intervals. The meteorologic forcings for the model have been delivered from Vejr2 in a resolution of 0.15º and a temporal resolution of 1 hour. The following data was interpolated at 1,500 m resolution and taken from the sea surface:

- Air pressure (hPa)
- Air temperature (ºC)
- Air speed and direction (10 minute means, m/s, radians)

The model has two open boundaries, which are forced with salinity, temperature and water levels derived from DHI operational waterforecast service for the North Sea (www.vandudsigten.dk). To obtain precise distributions of density differences time series data from seven sources of major freshwater discharges into the area were included (Figure 3.12). For the three German rivers Elbe, Weser and Ems, the actual daily discharge rates from Bundesanstalt für Gewässerkunde were used (http://www.bafg.de). For the four Danish sources, climatic discharge data was used.

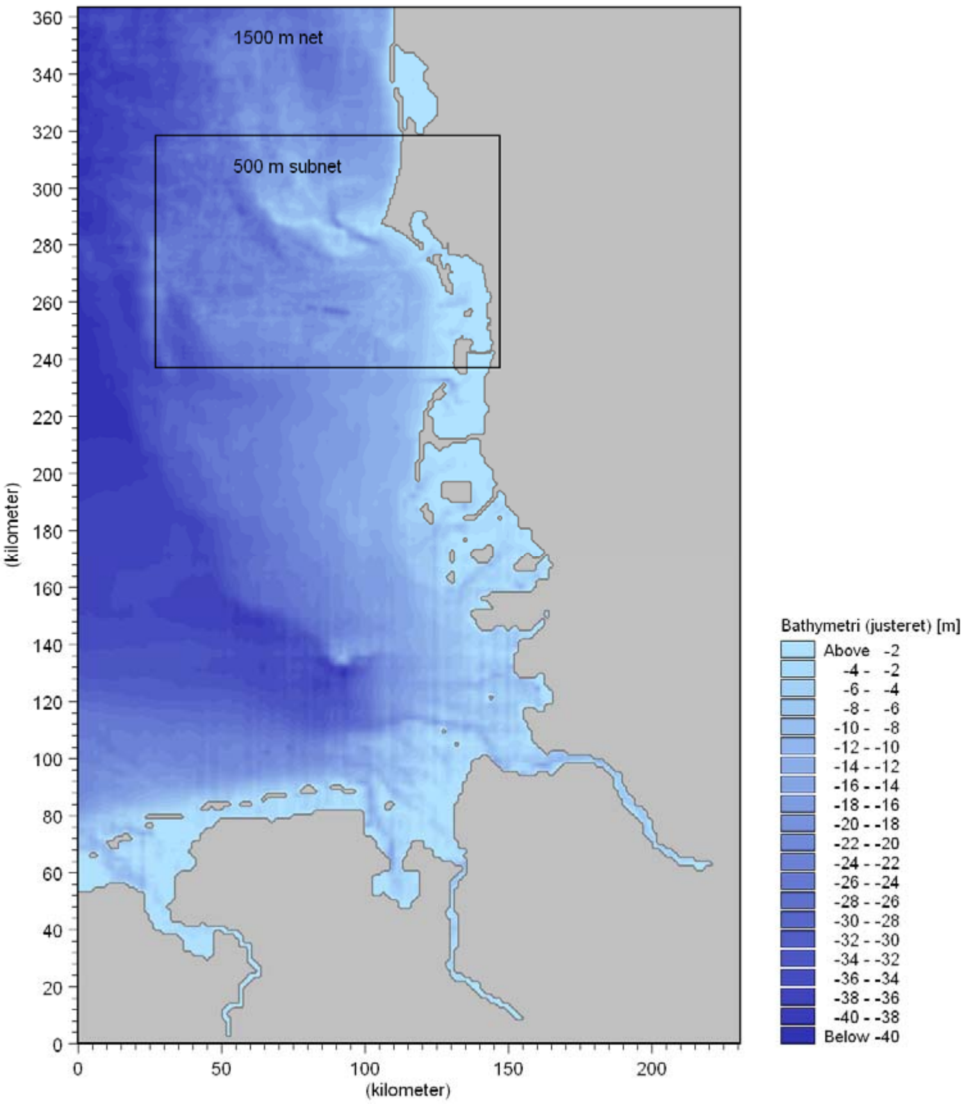


Figure 3.11. Hydrodynamic bathymetry model showing the core fine-scale area around Horns Rev nested into a larger-scale area.

Table 3.5. Specifications for the hydrodynamic model.

Area	**Horizontal resolution**	**Origo and angle**	**East-west range**	**North-south range**	**Vertikal range: max depth, resolution and layers**
West coast	1500 m	6º 33’ 23’’ E 52º 56’ 60’’ N -1.951 º	232.5 km 0-154 points	364.5 km 0-242 points	48 m 2 m 1-25 layers
Horns Rev	500 m	6º 51’ 03’’ E 55º 05’ 10’’ N -1.763 º	120.5 km 0-240 points	81.5 km 0-162 points	36 m 2 m 1-25 layers

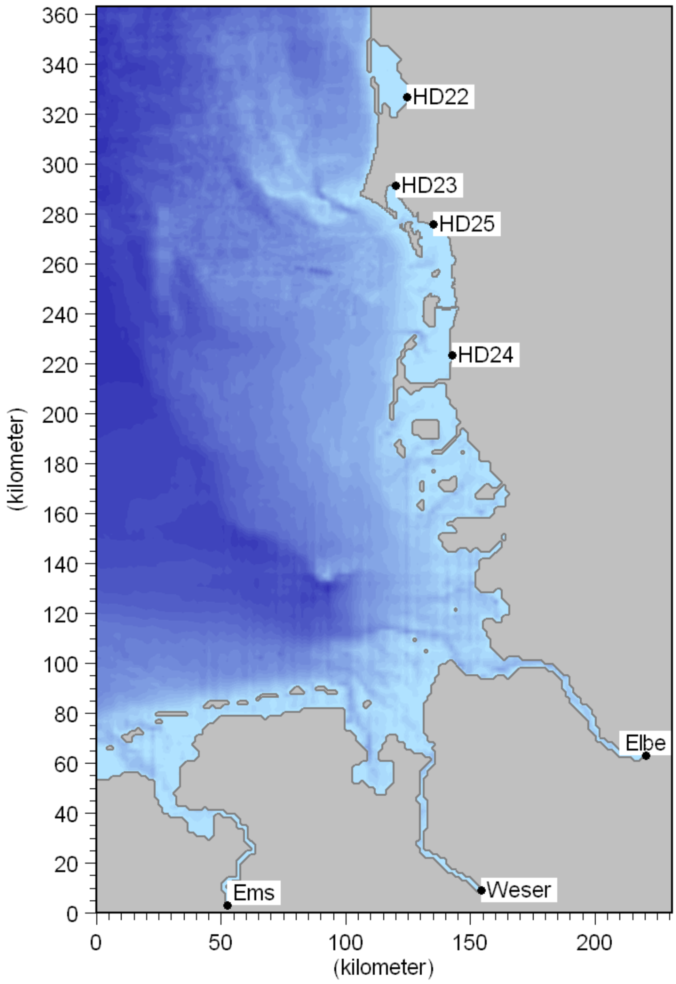


Figure 3.12. Sources of freshwater discharges, included in the model.

3.3.2. Analysis of environmental drivers and spatial modelling

The key environmental drivers behind the spatial dynamics of harbour porpoises at the Horns Rev 1 Offshore Wind Farm were analysed by carrying out a combined factorial and polynomial model design in PLS regression parallel to the analysis of drivers in acoustic activity (see Section 3.2.3 for details). Data from four surveys were analysed based on the criteria of large sample sizes (> 100 animals observed), temporal overlap with model data and different frontal positions of the large-scale density front: 28/7 2002, 8/8 2002, 6-7/8 2003 and 20-21/8 2005. During the four surveys the position of the density front changed between west, south, just east and east of the planned wind farm site. For each survey, the dynamic habitat variables were averaged for each tidal phase and collated in a raster GIS environment (Idrisi Version Kilimanjaro, ArcGIS Version 9.1) using UTM32 N Projection with WGS84 Datum at a spatial resolution of 500 m. The initial version of the PLS model included more than 200 variables, the original variables and their cross-products and second- and third-order polynomials, while the final version was limited to the variables, which best reflected the distinct auto-correlation scale of the harbour porpoise survey data and showed the most significant regression coefficients.

A total of 23 potential original potential habitat variables were computed by post-processing the Horns Rev hydrodynamic model data and local bathymetry data:

1. Stability of the water column: Richardson Number, which is defined as

$$Ri = \frac{g\beta}{(\partial u / \partial z)2}$$

where g is the acceleration of gravity, β a representative vertical stability (commonly θ/ z, where θ is potential temperature), and u/ z is a characteristic vertical shear of the wind.

2. U = On-shore current vector at the surface (m/s)
3. V = Long-shore current vector at the surface (m/s)
4. Relative vorticity (or local eddy potential): dV/dx - dU/dy
5. W = Vertical (upward) current vector at the surface
6. D = Density at the surface (Kg / m^3)
7. S = Salinity at the surface (psu)
8. T = Temperature at the surface (Celsius)
9. Water level (meters)
10. Gradient in U, measured as the slope of each grid cell based on the cell resolution and the values of the immediate neighbouring cells to the top, bottom, left and right of the cell in question using the following formula:

$$Tangent = \sqrt{\left(\left((right - left)/(res \bullet 2)\right)^2 + \left((top - bottom)(res \bullet 2)\right)^2\right)}$$

which measures the tangent of the angle that has the maximum downhill slope; *left*, *right*, *top*, *bottom* are the attributes of the neighbouring cells and *res* is the cell resolution

11. Gradient in V, same GIS method as 10
12. Gradient in W, same GIS method as 10
13. Gradient in surface density, same GIS method as 10
14. Gradient in surface salinity, same GIS method as 10
15. Gradient in surface temperature, same GIS method as 10
16. Bathymetry: negative values
17. Bottom relief: slope same GIS method as 10
18. Northern aspect of sea floor: Sine of the direction of the maximum slope values.
19. Eastern aspect of sea floor: Cosine of the direction of the maximum slope values.
20. Bottom complexity (F) calculated for 5x5 kernel: F = (n-1)/(c-1) Where n = number of different classes present in the kernel, c = number of cells
21. Distance to shallow areas (< 8 m water depth): Euclidean distance in m from each cell.
22. Distance to shallow area at Søren Jessens Sand (< 8 m water depth): Euclidean distance in m from each cell.
23. Distance to shallow area on Horns Rev (< 8 m water depth): Euclidean distance in m from each cell.

Spatial modeling techniques are increasingly recognized as important tools for extrapolating observations of marine animals to obtain spatial predictions of abundance or habitat suitability across large areas of ocean surface. We used the predictive presence-only model ENFA (Ecological Niche Factor Analysis) for developing models of habitat quality for harbour porpoises and harbour seals on Horns Rev. ENFA has been successfully applied to presence-only data in terrestrial (Zimmerman, 2004; Hortal et al.,

2005) and marine ecology (Leverette, 2004). The outputs of ENFA show two key aspects of the investigated species' habitat: marginality and specialization. The principle of the analysis is the mathematical comparison between the environmental space represented by the species distribution and the global distribution in the Horns Rev area. Like the Principal Component Analysis, the ENFA summarizes environmental data into a few uncorrelated factors retaining most of the information. Habitat marginality can be defined as the direction on which the species habitat differs the most from the available conditions in the Horns Rev area. It is computed by drawing a straight line between the centroids of the ellipsoids of the global distribution and the species distribution. Habitat specialization is defined as the ratio of the standard deviation of the global distribution to that of the species distribution.

For harbour porpoises, ENFA was applied to the tidal phase scenarios of each of the four selected surveys using BioMapper Version 3 (University of Lausanne, 2005). The initial version of the habitat model included all 23 variables, yet in the final version we limited the variables to those with a clear impact on habitat marginality and specialization. For the visual surveys and satellite telemetry data for harbour seals, ENFA was applied to summarised sightings from all surveys and analysed only with the topographic variables.

3.4. Assessment methodology

3.4.1. Assessment of noise-related disturbance

3.4.1.1. Introduction

Richardson et al. (1995) defined four zones of noise influence depending on the distance between the source and receiver. The zone of *audibility* is defined as the area within which the animal is able to detect the sound. The zone of *responsiveness* is the region with which the animal reacts behaviourally or physiologically. This zone is usually smaller than the zone of audibility. The zone of *masking* is highly variable, usually somewhere between audibility and responsiveness and defines the region within which noise is strong enough to interfere with detection of other sounds, such as communication signals or echolocation clicks. The zone of *hearing loss* is the area near the noise source where the received sound level is high enough to cause tissue damage resulting in either temporary threshold shift (TTS) or permanent threshold shift (PTS) or even more severe damage as acoustic trauma. The different zones are illustrated in Figure 3.13.

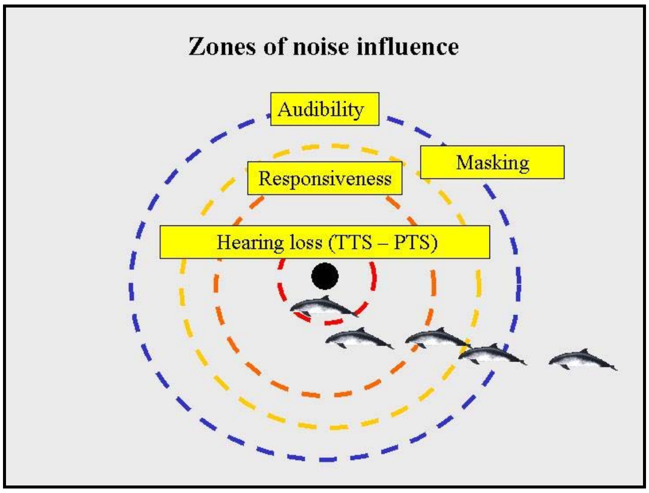


Figure 3.13. Zones of noise influence (after Richardson et al., 1995).

As sound usually spreads omni-directionally from the source, the zones of noise influences are given as the distance from the source indicating a radius rather than a straight line from the source. For example, a radius (r) of 10 km results in a zone of audibility of $A = \pi * r^2$; $3.1416 * 10\ km^2 = 314.16\ km^2$. In the following, knowledge of noise-related disturbance in harbour porpoises and harbour seals will be reviewed with the aim to identify the most reliable methodology for estimating noise influence radii for Horns Rev 2 Offshore Wind Farm. The noise influence radii will be combined with the results of the spatial modelling to estimate impacts on the two species and assess their importance according to specific criteria shown in Table 3.6. In determining the significance of an impact, 'magnitude' is assessed against 'importance' by ranging significance from 'negligible' to 'major' as shown in Table 3.7.

Table 3.6. 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 3.7. 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

3.4.1.2. Construction noise

Most construction of offshore wind farms involve a relatively high amount of ship-traffic for carrying parts of the pile and rotor, maintenance of construction platforms, etc (Tech-Wise / ELSAM 2003). Sound levels and frequency characteristics are broadly depending on ship size and speed with variation among vessels of similar classes. Medium sized support and supply ships generate frequencies mainly between 20 Hz and 10 kHz with source levels between 130 and 160 dB re 1 µPa at 1m (Richardson et al., 1995). For the following calculations a broadband source level of 160 dB_{rms} @ 1m was used.

Pile-driving activities are of special concern as they generate very high sound pressure levels and are relatively broad-banded (Nedwell & Howell, 2004; Madsen et al., 2006). Foundation piles are usually placed into the seabed by impact-pile-driving or vibration with the former being the most commonly used method (Tougaard et al., 2004; Nedwell & Howell, 2004). The single pulses are between 50 and 100 ms in duration with approximately one beat per second (ITAP, 2005; Madsen et al. 2006; Figure. 3.14).

To date, no measurements or behavioural observations have been made with respect to gravity foundations (Nedwell & Howell, 2004).

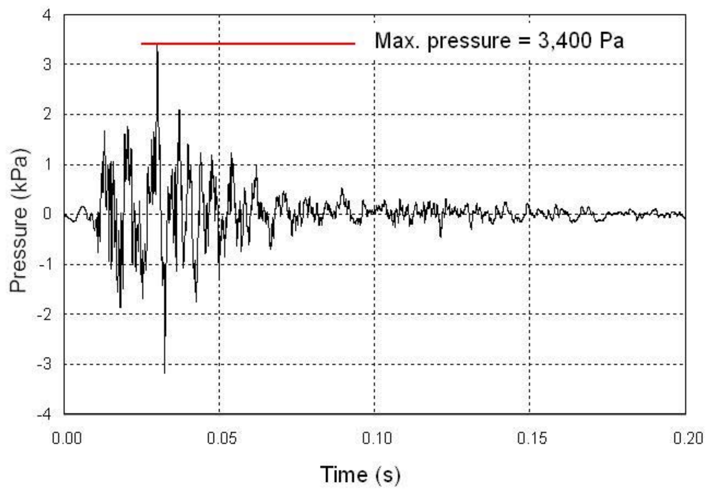


Figure 3.14. Waveform of a impact-pile pulse (after ITAP, 2005).

Degn (2000) measured 205 dB re 1 µPa at 30 m distances from the source during pile-driving at Utgrunden, Sweden. Nedwell et al. (2003) estimated a peak source level of 262 $dB_{p\text{-}p}$ re 1 µPa @ 1 m during the construction of the North-Hoyle offshore wind farm. However, the transmission loss used to calculate the source level was relatively high with the substrate being rocky. Therefore the results might not be applicable for the relatively sandy substrate at Horns Rev. The most detailed measurements to date were obtained by ITAP (2005) during the construction of the FINO-1 research platform off Eastern Frisia (Jacket-pile construction, diameter = 1.5 m per pile, sandy bottom, water depth ~ 30 m). They estimated a broadband peak source level of 228 $dB_{0\text{-}p}$ re 1 µPa @ 1 m. More importantly, ITAP measured third-octave-sound pressure levels as peak and sound exposure levels directly at 400 m from the source. These values were back-calculated using a formula by Thiele (2002) resulting in the spectrum shown in Figure 3.15. It can be seen that the sound pressure level was highest at the 315 centre frequency (Lpeak = $218_{0\text{-}p}$ dB re 1 µPa @ 1 m) with additional peaks at 125 Hz and 1 kHz with considerable pressures above 2 kHz.

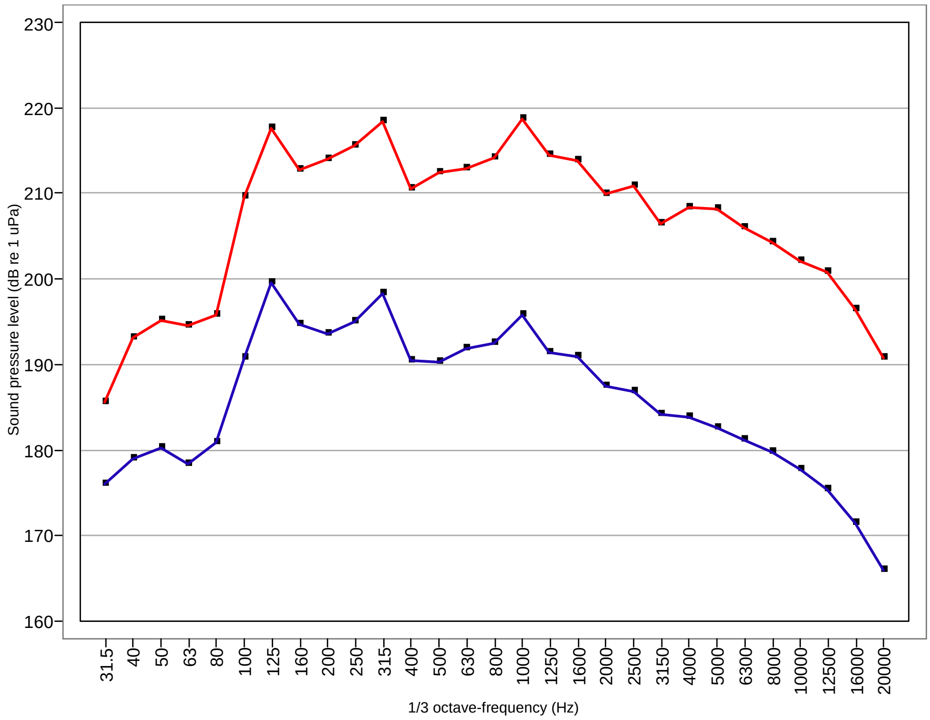


Figure 3.15. Frequency spectrum (Third octave band sound pressure level) of ramming pulses (FINO 1-platform) back-calculated to 1 m (red = $dB_{0\text{-}p}$ re 1 µPa, blue = dB_E re 1 µPa from ITAP, 2005).

Sound pressure levels in impact pile-driving are dependant on the length and diameter of the pile and the impact energy (Nedwell et al. 2003). Betke (pers. comm.) and ITAP (2005) measured 1/3 octave-band sound pressure levels during impact pile-driving in an adjacent region to FINO-1 (Amrumbank-West). The pile had a diameter of 3.5 m and the impact-energy therefore was considerably higher than at FINO-1. The increase in sound pressure levels was approximately 10 dB for every 1/3 octave-band (ITAP, 2005; Betke, pers. comm.). Since Horns Rev 2 Offshore Wind Farm may use monopiles of a comparable diameter, 10 dB have to be added to every 1/3 octave band to derive a meaningful model of sound pressure levels during construction.

3.4.1.3. Operational noise

Noise during operation has been measured from single piles (maximum power 2 MW) in Sweden, Denmark and Germany and has been found to be of much lower intensity than the noise during construction (review in Madsen et al., 2006). Again, the most detailed measurements have been obtained by ITAP (2005) during the operation of an offshore turbine in Sweden (1.5 MW) at moderate-strong wind speeds of 12 m/s. 1/3 octave sound pressure levels ranged between 120 and 145 dB_{Leq} re 1 µPa @ 1 m with most energy at 50, 160 and 200 Hz (Figure 3.16). Noise levels of more powerful and hence larger (~ 4-5 MW) turbines are probably greater (Madsen et al., 2006). However, it is currently unknown to what extent noise levels will be elevated and if this would account for frequencies relevant to the hearing of harbour porpoises and seals. Since the measurements of ITAP (2005) are the most detailed to date, they will be used as inputs in assessments of influence of operational noise.

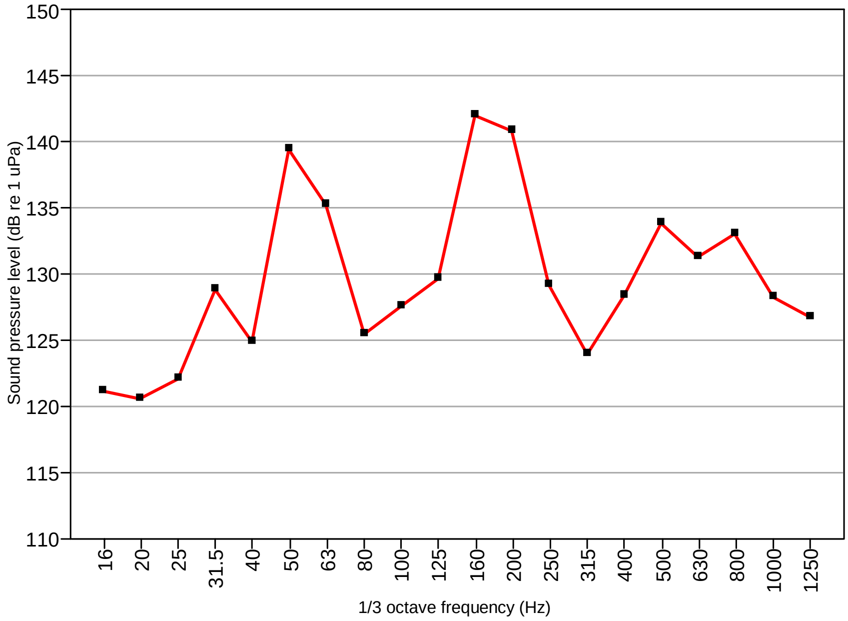


Figure 3.16. Operational source level noise in dB_{Leq} of an offshore wind turbine measured at a 110 m distance and back-calculated to 1 m (from ITAP, 2005).

3.4.1.4. Transmission-loss calculations

As wind turbines are currently planned in relatively shallow waters below 50 m transmission loss might be described by cylindrical spreading, 10 log *R* (Richardson et al., 1995). However, several field studies indicated a higher transmission loss in shallow waters, depending on local conditions (Nedwell et al., 2003; Nedwell and Howell, 2004; Madsen et al., 2006; Verboom, personal communication). Thiele (2002) developed a formula that is applicable for coastal North Sea waters with a sandy bottom and wind-speeds up to 20 kn:

$$TL = (16.07 + 0.185\ FL)\ (\log (r/1.000\ m) + 3) + (0.174 + 0.046\ FL + 0.005\ FL^2)\ r$$

(FL = 10 log (f / 1 kHz; 1 m - 80 km, Frequencies f in kHz (100 Hz - > 10 kHz))

The advantage of this particular formula is that it takes frequency dependent attenuation into account. Control measurements in the field showed that this transmission loss model is quite feasible for waters with a similar bathymetry as Horns Rev. The assessment of noise influences based on this formula can therefore be viewed as quite realistic and hence reliable.

The formula predicts sound levels at different distances from the source. As distance from the source increases, sound levels decrease up to a point where the animal can’t detect the noise. The ability to detect noise is depending on the hearing sensitivity of the species in question, which we will deal with in the next section.

3.4.1.5. Hearing in harbour porpoises

To date, four studies investigated hearing in harbour porpoises with different methods. Hearing thresholds were derived either through auditory-brainstem-responses (ABR) or behaviourally. Table 3.5 gives an overview over the results of the different studies.

Table 3.5. Overview of the results of hearing studies in harbour porpoises.

Reference	**Lucke et al. (2004)**	**Popov & Supin (1990)**	**Andersen (1970)**	**Kastelein et al. (2002)**
Method	**ABR's**		**Behavioural audiogram**	
Stimulus	**Sinus-tone 10 – 25 ms**	**Clicks broadband 5µs**	**Sinus-tone 1.5 s**	**Sinus-tone 2 s**
Stimulus frequency (kHz)	**Hörschwelle (dB_{rms} re 1µPa)**			
0.25				115
0.3	117			
0.5	119			92
0.7	109			
1	105		82	80
1.4	97			
2	90-95		65	72
2.8	78			
4	91		53	57
5.6	71			
8	85		49	59
10	59	87		
11.2	90			
16	53		52	44
20		81		
30		62		
32			47	37
50		78		36
70		74		
100		71	60	32
125		55		
160		102		91

It can be seen that the results differed markedly between the studies, probably due to inter-individual differences in sensitivity. However, another factor affecting the results might have been the method used. Central-nervous-processing might lead to a relatively better perception of acoustic stimuli in behavioural studies compared to ABR-methods (Lucke et al., 2004). Therefore the results of the behavioural studies, especially the ones derived by Kastelein et al. (2002) from a subadult male, seem to be better suited for the following calculations. Figure 3.17 shows the harbour porpoise audiograms measured by Kastelein et al. (2002) and Andersen (1970) along with ambient noise levels and one audiogram of a bottlenose dolphin for comparison (Johnson, 1967).

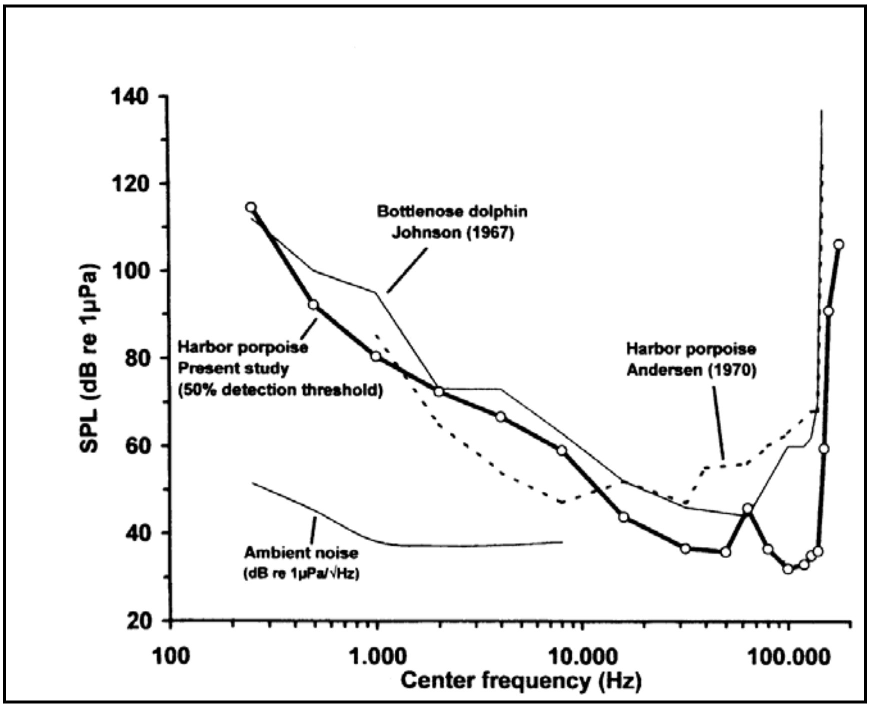


Figure 3.17. Audiograms of harbour porpoise and bottlenose dolphin (from Kastelein et al., 2002)

After Kastelein et al. (2002), harbour porpoises exhibit a very wide hearing range with relatively high hearing thresholds of 92 – 115 dB_{rms} re 1 µPa below 1 kHz, good hearing with thresholds of 60 – 80 dB_{rms} re 1 µPa between 1 and 8 kHz, and excellent hearing abilities (threshold = 32 – 46 dB_{rms} re 1 µPa) from 16 – 140 kHz. The reported hearing abilities closely match the sounds emitted, which can be divided after Verboom & Kastelein (1995) into four classes:

1. Low frequency sounds at 1.4 – 2.5 kHz for communication
2. Sonar-clicks (echolocation) at 110 – 140 kHz
3. Low-energy sounds at 30 – 60 kHz
4. Broadband signals at 13 – 100 kHz

Most of the energy of acoustic emissions is exhibited in sonar clicks (Verboom & Kastelein, 1995). This is probably due to high absorption of ultrasounds underwater (Urick, 1983). Looking at Figure 3.17, it is also evident that the hearing system in harbour porpoises is well adapted for detecting these essentially short-range sonar-clicks. However, it can also be seen that the hearing system covers a wide range of frequencies, including those associated with offshore-wind farm construction and operational noise (see above). Since the audiogram of Kastelein et al. (2002) is the most detailed and, compared to the ones taken with ABR-methodology, most reliable one, it will be used in the impact assessment.

3.4.1.6. Hearing in harbour seals

Harbour seals have an underwater hearing range of 0.07 – 60 kHz and are most sensitive between 8 – 30 kHz (threshold = 60 – 70 dB re 1 µPa (Møhl, 1968). Hearing thresholds in lower frequencies at and below 1 kHz are reported to range between 70 and 80 dB dB re 1 µPa (Møhl 1968; Terhune & Turnbull, 1995). Kastak & Schusterman (1998) measured underwater hearing in one individual to frequencies of 6 kHz and derived thresholds between 63-102 dB_{rms} re 1 µPa (Figure 3.18 Table 3.6).

The relatively good sensitivity in lower frequencies match closely the frequencies of sounds used in underwater communication that range between 0.5 - 3.5 kHz (Richardson et al., 1995). Very similar to harbour porpoises, harbour seals are most sensitive in those frequencies were biologically relevant signals are emitted.

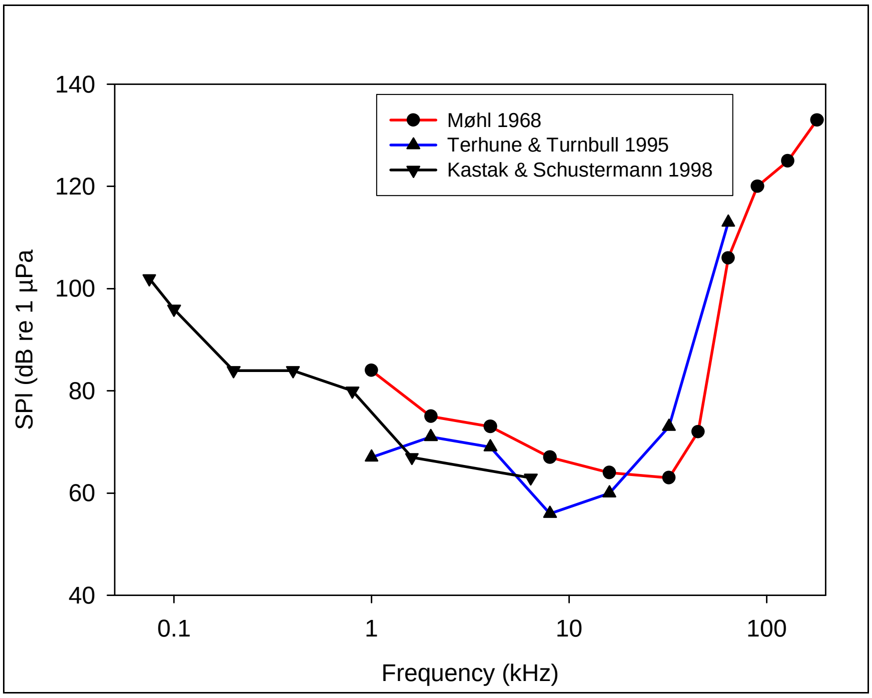


Figure 3.18 Underwater audiograms of harbour seals

Table 3.6. Underwater hearing threshold of a harbour seal (after Kastak & Schustermann, 1998).

Frequency [kHz]	Hearing threshold (dB_{rms} re 1µPa)
0.075	102
0.1	96
0.2	84
0.4	84
0.8	80
1.6	67
3.2	-
6.3	-
6.4	63

3.4.2. Assessment of other impacts

Other possible impacts than noise-related disturbances, such as indirect effects during construction from sedimentation processes, collisions with boats, barrier effects on migratory routes, indirect habitat alterations and increases in the abundance of prey due to the presence of scour protection and electromagnetic fields along the cables, will be discussed from experiences drawn from the Horns Rev 1 Offshore Wind Farm and Nysted offshore Wind Farm.

3.4.3. Assessment of cumulative effects

Horns Rev 2 Offshore Wind Farm will be situated 10-12 km from Horns Rev 1 Offshore Wind Farm, depending on which of the two mentioned areas is selected. Cumulative effects may occur due to the presence of Horns Rev 1 Offshore Wind Farm being close to the planned Horns Rev 2 Offshore Wind Farm area.

Although the impacts from Horns Rev 2 Offshore Wind Farm are primarily assessed on its individual merits, it is also clear that due to the presence of a similar wind farm only a few kilometres away, impacts from the latter cannot be disregarded, but must be taken into consideration as cumulative impacts. Similarly, cumulative impacts and effects can be generated by the joint impacts from various activities in the lifetime of the Horns Rev 2 Offshore Wind Farm.

4. Status and distribution of harbour seal and harbour porpoise at the Horns Rev 2 Offshore Wind Farm

In the following the results of the statistical analyses of acoustic and visual data are reviewed in order to provide an overview of the importance of the Horns Rev 2 Offshore Wind Farm to harbour porpoise and harbour seal.

4.1. Acoustic activity of harbour porpoise

Statistics on the mean patterns of acoustic activity recorded during the monitoring programme for Horns Rev 1 are given below. All factors, except date for daily click frequency, significantly accounted for the variation in the three indicators (Table 4.1).

Table 4.1. Analysis of variation for the three indicators. Shown are the p-values for the different factors.

Indicator	***Station***	***Year***	***Season***	***Month***	***Date***	***T-POD r***
Click frequency	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.347*	*<0.0001*
Waiting time	*0.0081*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Encounter duration	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*

Figures 4.1 – 4.6 show the variation in daily click frequency with spatial, temporal and instrumental factors. Daily click frequency was selected since it best describes the presence of porpoises in the study area. The graphs show daily click frequency (as original data in %) across stations, year, month, T-POD number and T-POD version from all recordings. The highest click frequencies were recorded in station 3, followed by 6, 5, 7 and 1 (Figure 4.1). Mean daily click frequencies did not differ much from 2002-2004. However, in 2005 click frequencies were much higher than in the previous years (Figure 4.2). Daily click frequencies were highest in autumn, followed by summer spring and only low rates in winter (Figure 4.3). The daily click frequencies across all stations showed peaks in September 2002, June, July and November 2003, July 2004 and from August to October 2005 (Figure 4.4). Mean click frequencies differed markedly between T-POD versions with T-PODs of version 4 recording much higher frequencies than those of version 1 and 3 (Figure 4.5). T-POD 334 (version 4) recorded by far the highest daily click frequencies, followed by 335, 282, 161 and 20 (Figure 4.6).

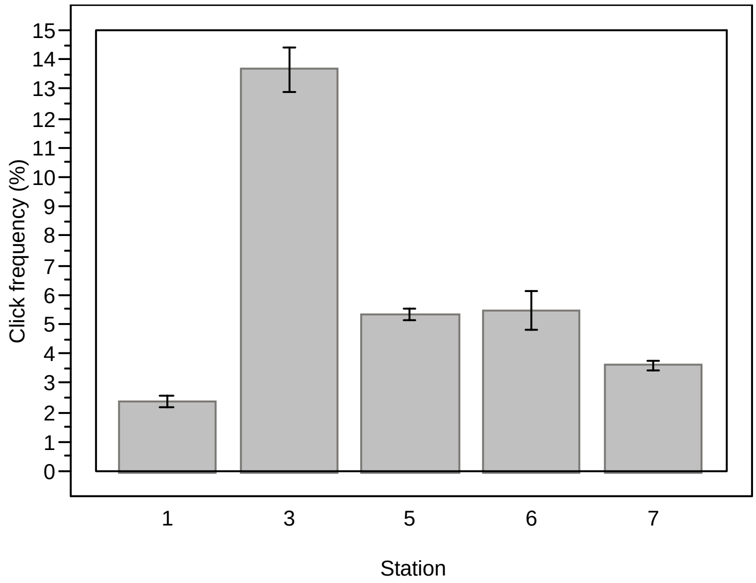


Figure 4.1. Mean click frequency by station (all data; error bars = SE).

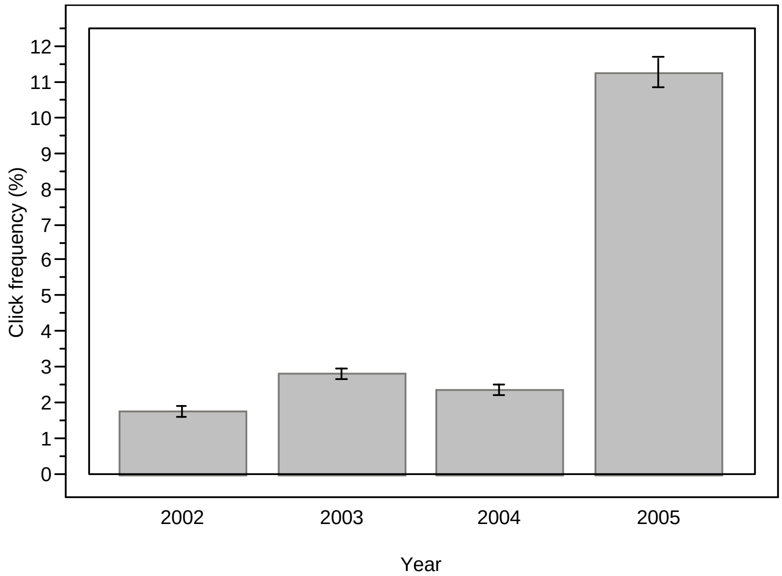


Figure 4.2. Mean click frequency by year (all data; error bars = SE).

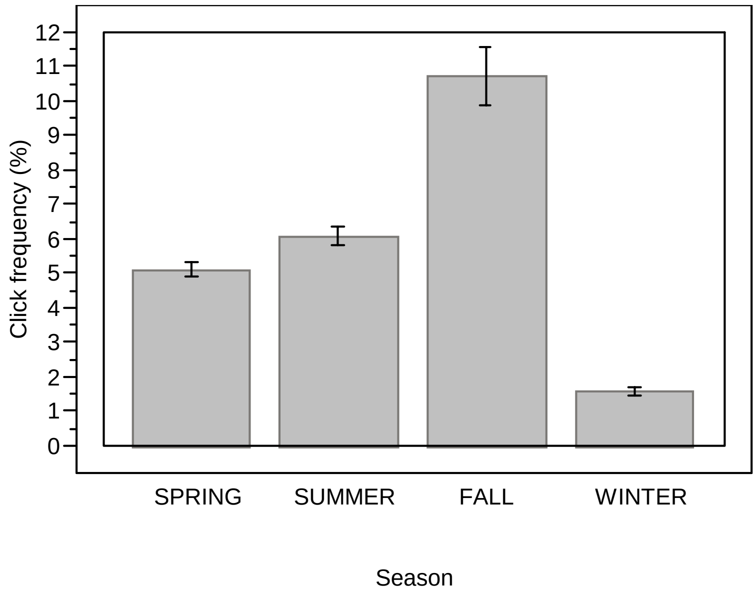


Figure 4.3. Mean click frequency by season (all data; error bars = SE).

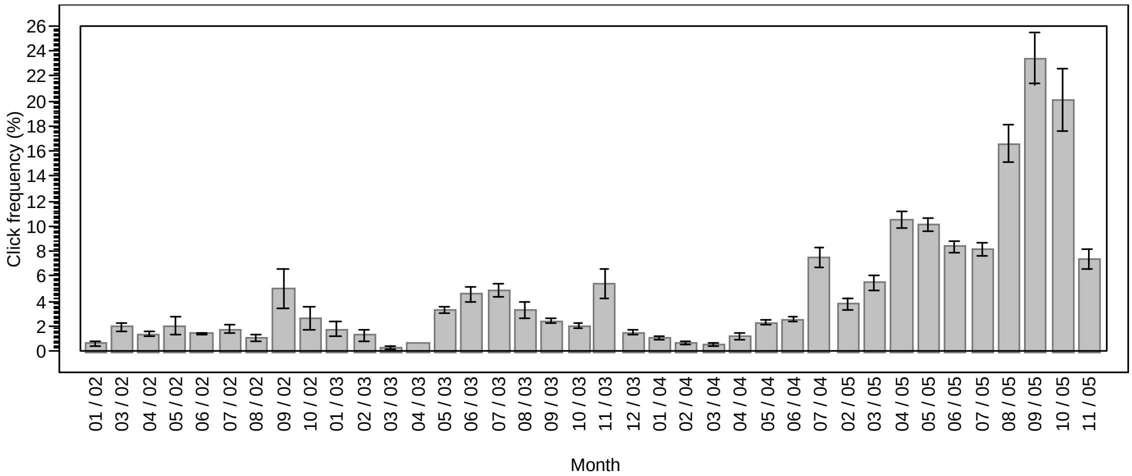


Figure 4.4. Mean click frequency by month (all data; error bars = SE).

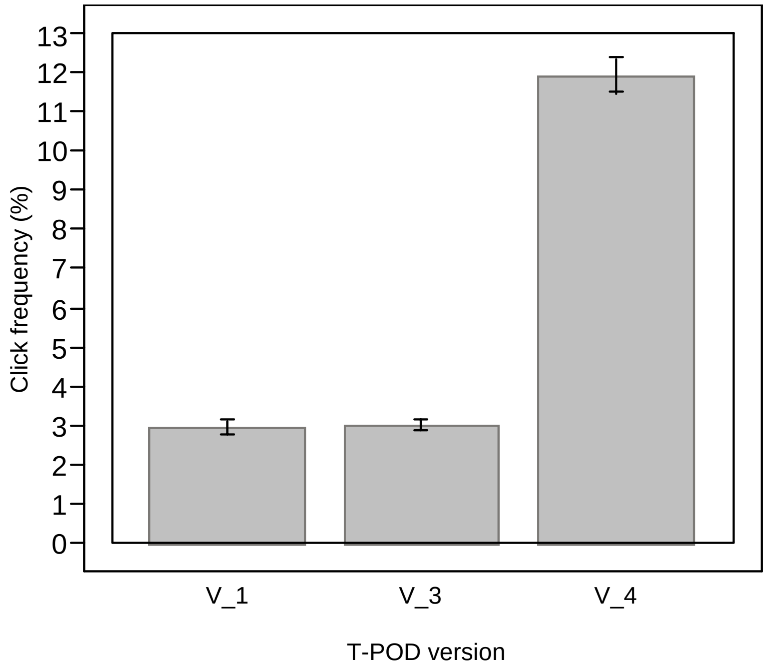


Figure 4.5. Mean click frequency by T-POD version (all data; error bars = SE).

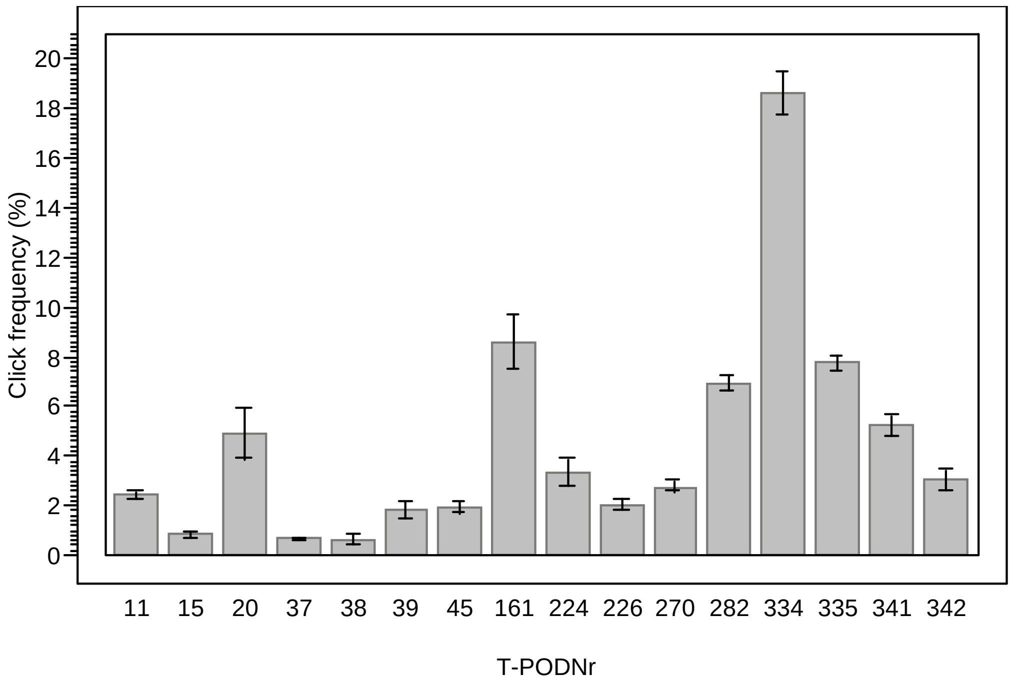


Figure 4.6. Mean click frequency by T-POD number (all data; error bars = SE).

4.1.1. Temporal variation within stations 1 - 7

This chapter provides a more detailed break-down of the variability in acoustic indicators and key factors. Figures 4.7 – 4.12 show the mean click frequency per month for each station with bar colours indicating which T-POD-version was used. It is evident that variation existed in the temporal pattern within as well as across stations. For example, in station 1, where T-PODs of all three versions were used in succession, a spring and summer peak in click frequencies was evident in the years 2004 and 2005. This was not the case in station 3, where click frequencies peaked in September 2002, April 2005 and again from August to October 2005. Click frequencies were also much higher in 2005, the time of introduction of the V4 version, than in the previous years and also higher than in every other station. A rather irregular pattern could be found in station 5 with one peak in July 2004 and a drastic increase in click frequencies in 2005, especially during spring and September. Again, this pattern was found with the introduction of version 4 T-POD. Click frequencies were highest in summer 2003 in station 6, low at the beginning of 2005 and increased drastically during May and June 2005. Here, version 4 was only used for a short period of time. The clearest trends were found in station 7. Click frequencies in station 7 showed two rather distinct maxima, one from May to October 2003, the other from May to August 2005. One additional single peak was found in July 2004. Note that in station 7 only T-PODs 11 and 282 were used with versions 1 and 3, respectively. To summarize: despite considerable variation, click frequencies were relatively high in spring and summer compared to other seasons and sometimes extended into early autumn. The trend of higher click frequencies extending into autumn became stronger in the later stages of deployment (2005).

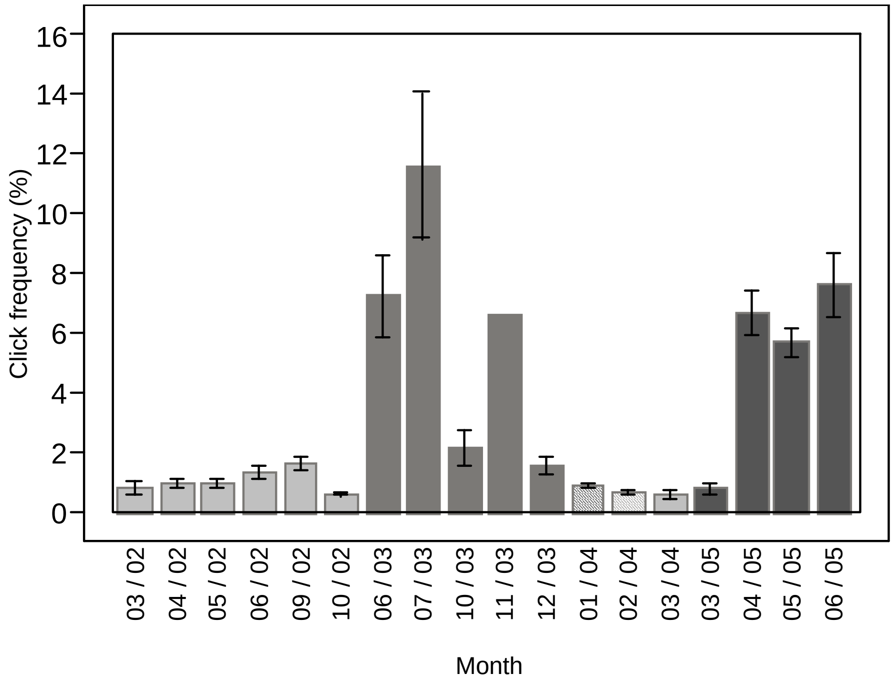


Figure 4.7. Mean click frequency per month in station 1 (+/-SE; light grey = V1, medium grey = V3, dark grey = V4, patterned = V1/V3).

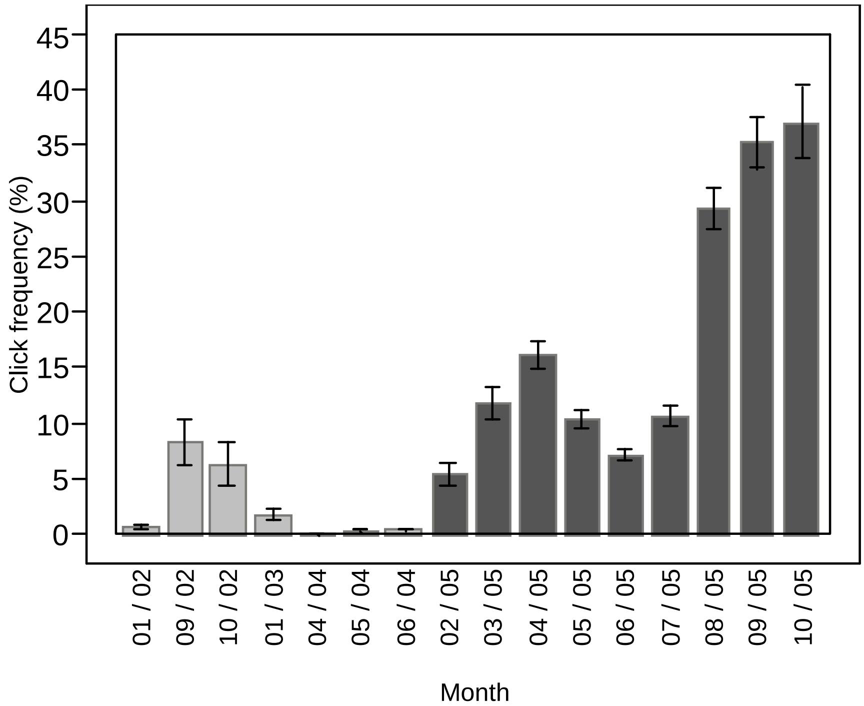


Figure 4.8. *Mean click frequency per month in station 3 (+/-SE; light grey = V1, medium grey = V3, dark grey = V4).*

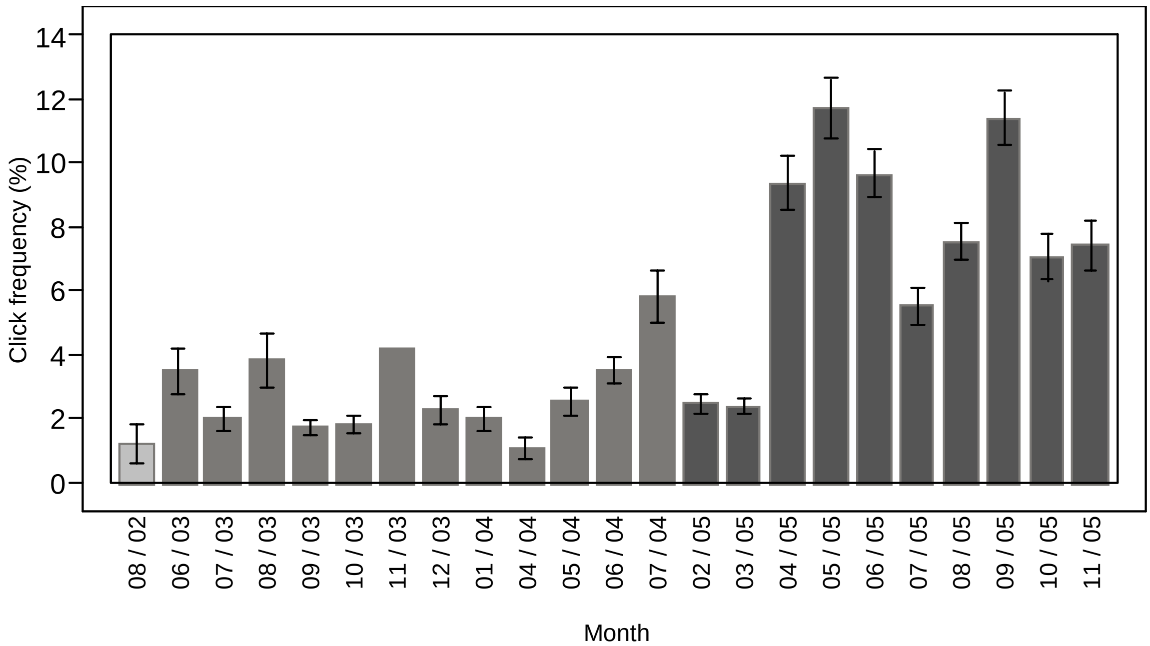


Figure 4.9. *Mean click frequency per month in station 5 (+/-SE; light grey = V1, medium grey = V3, dark grey = V4).*

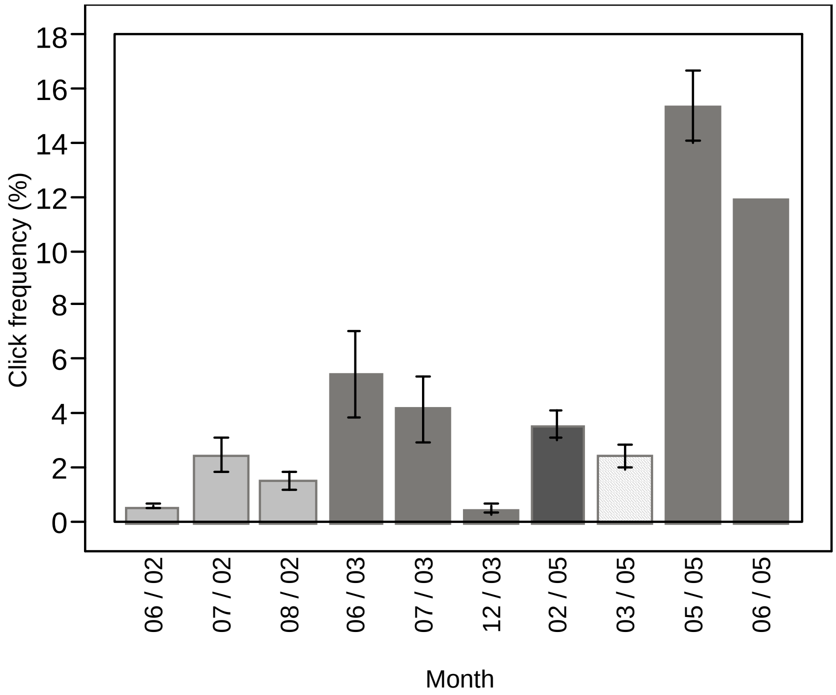


Figure 4.10. Mean click frequency per month in station 6 (+/-SE; light grey = V1, medium grey = V3, dark grey = V4, patterned = V3/V4).

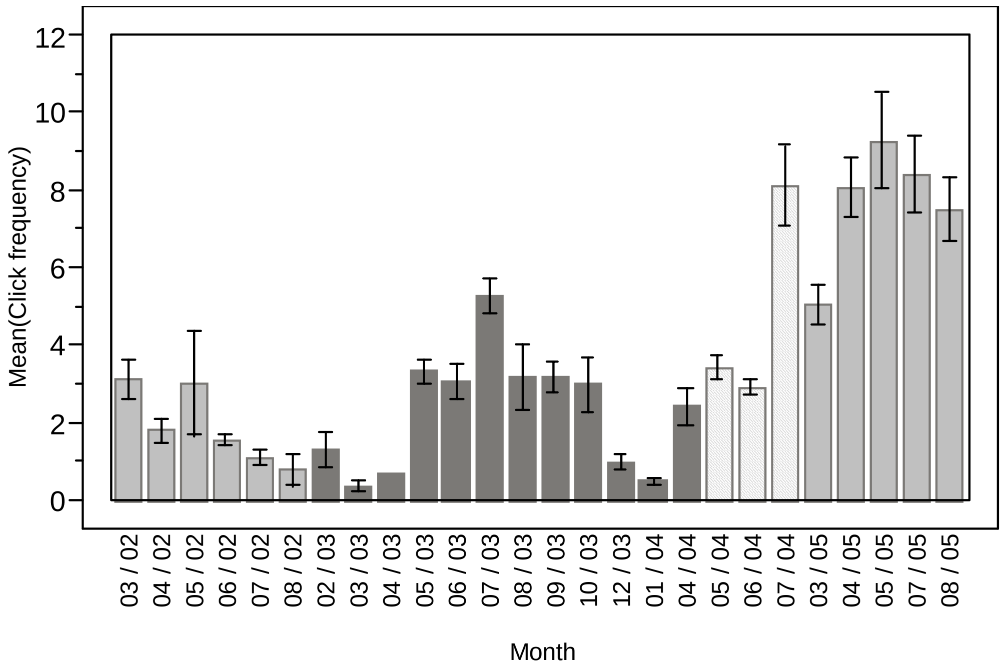


Figure 4.11. Mean click frequency per month in station 7 (+/-SE; light grey = V1, medium grey = V3, dark grey = V4, patterned = V1/V3).

Daily click frequencies varied considerably with days. An example of a time series taken from station 1 is shown in Figure 4.12. The mean click frequency during this particular period (spring and early summer) was 6.2% with a range between 2.0% and 14.0%.

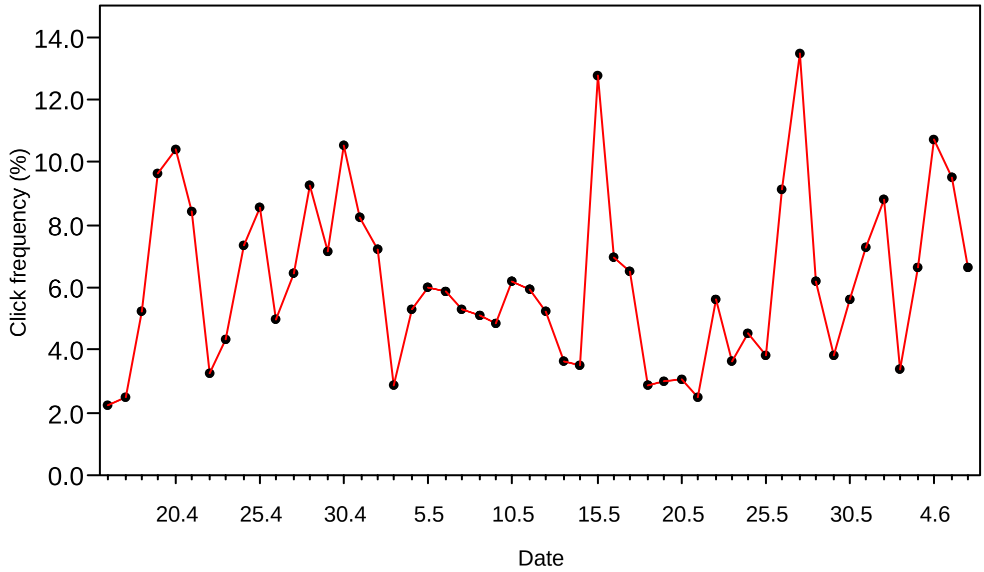


Figure 4.12. Daily click frequency from 16.04.05 – 06.06.05 recorded at station 1.

The results show that many factors contribute to the variation in indicators of acoustic activity, including T-POD version and T-POD number, which is consistent with previous investigations (Tougaard et al., 2003b, 2005). Attempts to calibrate T-PODs in order to account for inter and intra type variation have only been recently undertaken. It is challenging since variation between individual T-PODs and versions might be caused not only by differences in sensitivity but also by other rather unknown variations, for example the directionality of the hydrophone (Verfuss et al., 2004; Thomsen & Piper, 2004; Thomsen et al., 2005). A general point of concern is the ongoing introduction of new T-POD versions that differ markedly in recording characteristics from previous versions. For example, the drastic increase in daily click frequencies in 2005 compared to the previous years might be attributed to the introduction of the new V4 version, which is much more effective in recording porpoise clicks than previous ones (Tregenza, pers. comm.). Figure 4.16 indicates that much of the increase in click frequencies in 2005 might be attributed to one T-POD (334, version 4), which recorded a steady number of clicks. This might have influenced all other results such as variation of click frequency across stations, seasons and months. On the other hand, the increase in click frequency in 2005 was also apparent in stations 6 and 7, where no V4 T-PODs were used. This indicates that variation in click frequencies between years can not be attributed solely to version-specific variation.

When looking at each station separately and periods within which T-PODs of only one version were used gives a better picture of seasonal variation that is probably biologically relevant and not caused by methodology (Figures 4.8 – 4.12). Daily click frequencies varied with season in most stations with spring, summer and occasionally autumn exhibiting much higher acoustic activity than late autumn and winter (years 2003-2005). This matches the results of visual surveys in 2003 and 2004 with higher densities of porpoises in spring, summer and mid-October (2003) compared to February (Tougaard et al., 2003b, 2005). The mid-October peak can not be shown with the T-POD data since harbour porpoises were almost exclusively seen in the western part of the survey area with the corresponding stations (1, 3) not or only temporarily logging data during the survey.

The seasonal variation in click frequencies has been found in other studies as well, (2004; Northern Frisia: Diederichs et al., 2005; Eastern Frisia: Thomsen et al., 2006b; Thomsen & Piper, 2006). T-PODs however, can provide additional data that is not readily available from visual surveys since they monitor the presence of porpoises for extended periods of time, day and night and in all weather conditions. As can be seen from Figure 4.16, click frequencies varied considerably between days, perhaps reflecting fine scale shifts in occurrence of porpoises in the area.

We did not look into the diurnal variation in acoustic activity. Carlström (Scotland; 2005) and Thomsen & Piper (Eastern-Frisia; 2006) found a higher proportion of clicks during nighttimes compared to daylight hours. Diederichs et al. (Northern-Frisia; 2005) reported the opposite. However, these patterns have to be interpreted with caution as it is unclear if they reflect a higher number of porpoises present or behavioural changes. It is also possible that diurnal patterns are caused by artefacts. For example, Tougaard et al. (2005) found acoustic activity positively correlated to rising tides. It is very likely that under high tide conditions the effective search area of the T-POD increases as water masses above mooring increase too. Such clear correlations as presented by Tougaard et al. (2005) therefore have to be interpreted with caution. Finally, a more detailed analysis of click train structure might give some insights on the activity of the porpoises since short interclick intervals (ICI) are associated with prey capture, whereas longer and more regular ICI’s are associated with orientation in spacial orientation (Verfuss et al., 2005).

4.1.2. Environmental parameters

In the following, the results of the analyses of key drivers behind the variability of acoustic activity in porpoises at Horns Rev are given. Several trends could be identified in the responses of the acoustic indices to the environmental parameters, but overall the major responses were related to parameters, especially higher order levels and interactions between dynamic parameters, that represent short-term processes: currents, winds and water levels. All three indicators showed almost the same responses with waiting times giving the clearest results. The results of the PLS regression for waiting times are shown in Figure 4.13. Short waiting times (negative regression coefficients) showed the strongest responses to vertical current velocities in combination with winds (longshore as well as onshore velocities) and vertical current velocities. Negative responses can be seen to currents and no response to winds alone.

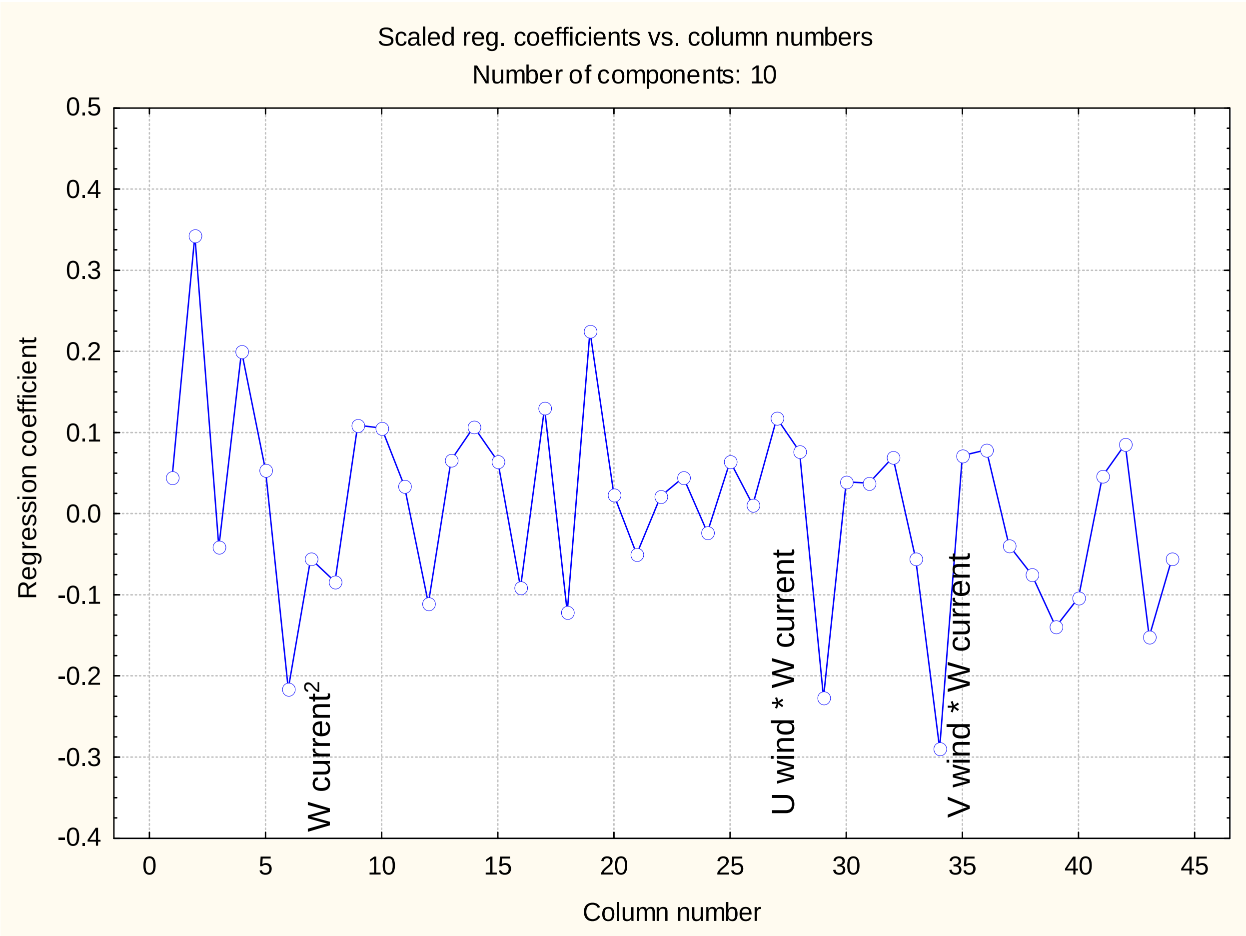


Figure 4.13. Results of the PLS regression showing regression coefficients vs environmental variables for waiting times at station HR 1.

Compared to station 1, the positive responses at station 7 were more related to vertical current velocities alone than in combination with wind. Negative responses were less clear to strong horizontal current velocities. There was also a strong negative response if currents were combined with strong onshore winds (Figure 4.14).

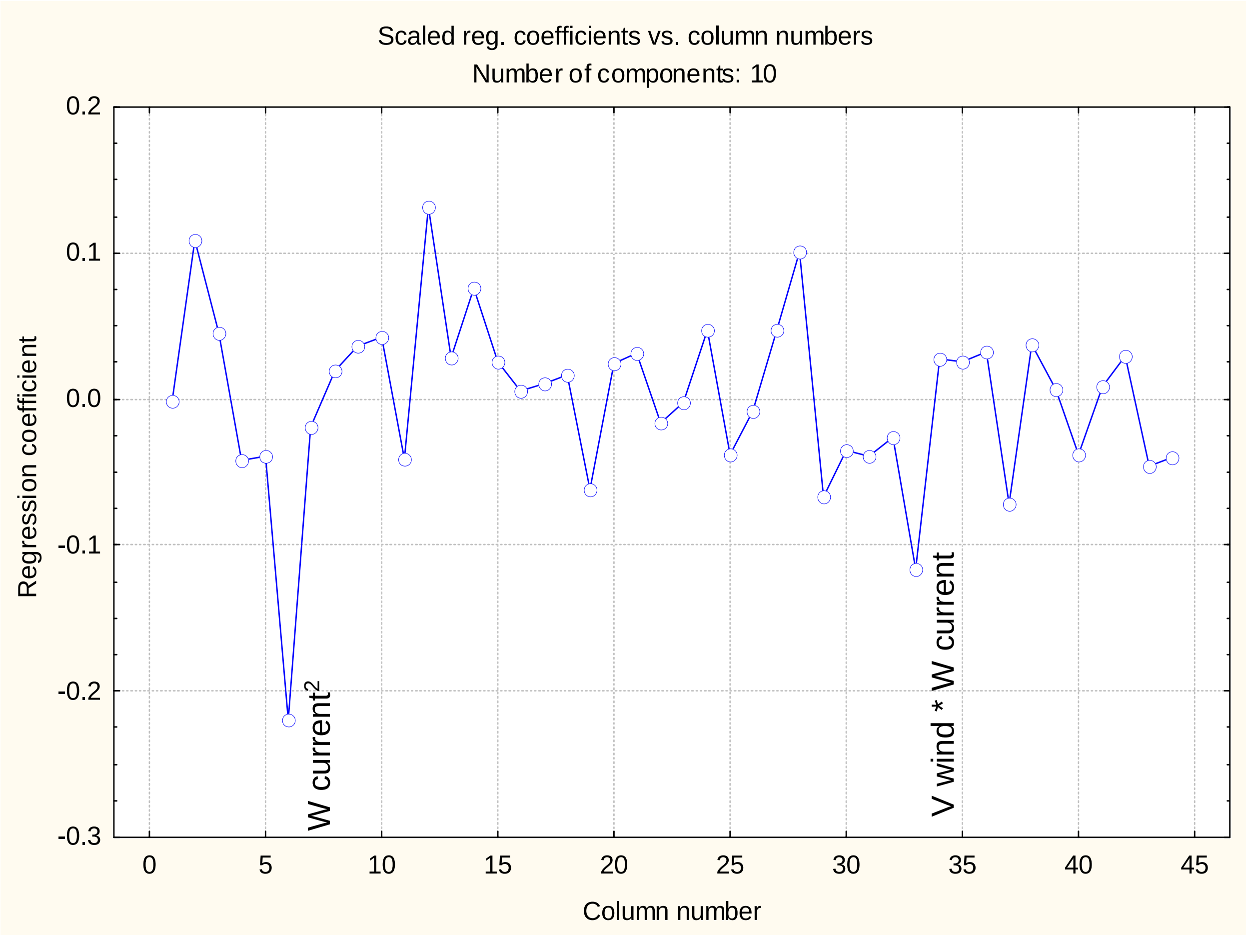


Figure 4.14. Results of the PLS regression showing regression coefficients vs. environmental variables for waiting times at station HR 7.

Looking at the daily click frequency at station 1, there were positive responses to winds and vertical current velocities and to onshore currents if accompanied by strong winds or vertical current velocities. There were negative responses to strong currents, with and without high water levels, vertical current velocities and winds (Figure 4.15).

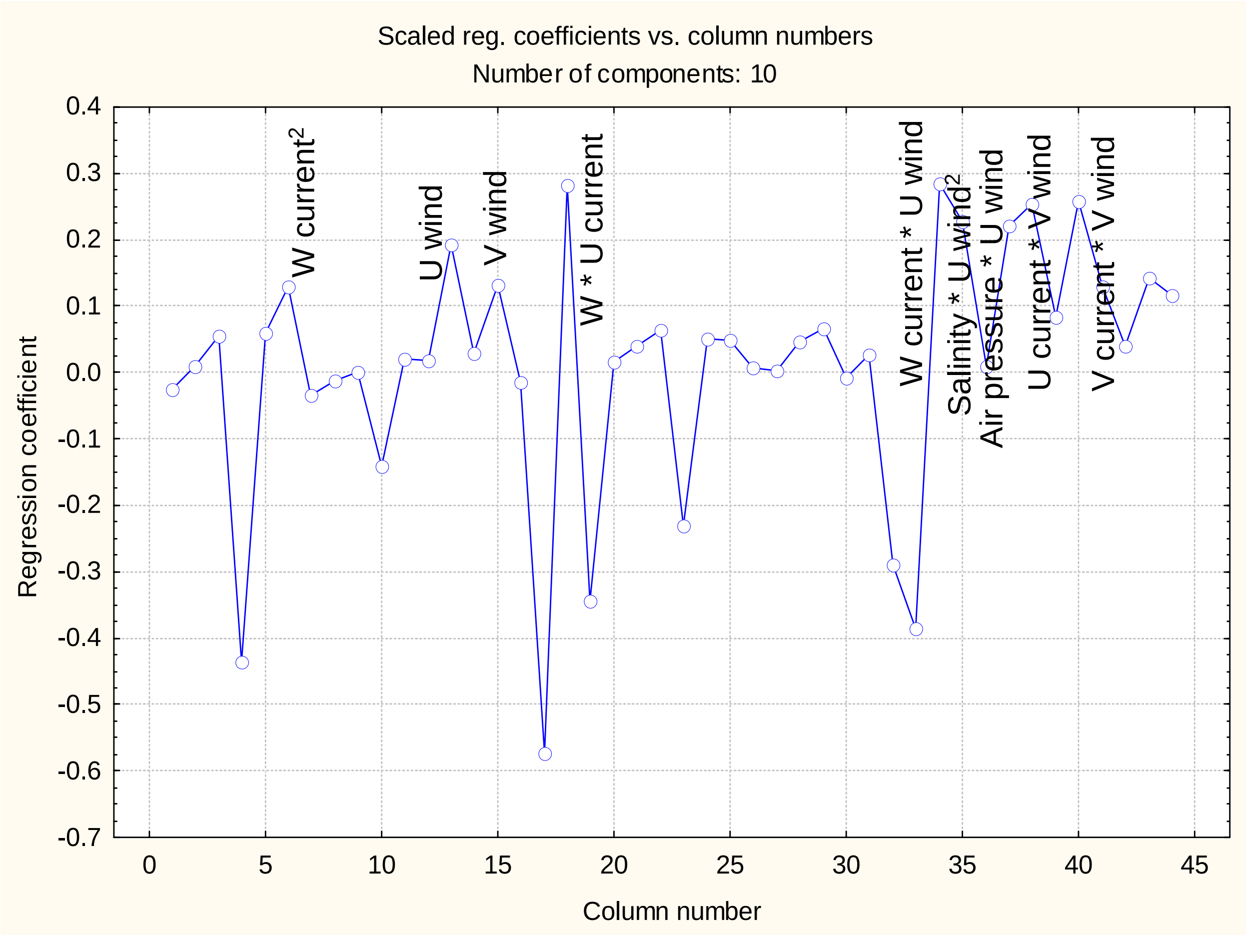


Figure 4.15. Results of the PLS regression showing regression coefficients vs environmental variables for daily click frequency at station HR 1.

These results provide measures for interpreting the usage of the Horns Rev 2 Offshore Wind Farm area by porpoises on a long-term basis. The statistical analysis of responses in acoustic and environmental data gave strong indications that vertical velocities and hence local up-welling is a main driver for acoustic activity at Horns Rev station 1 in the western part of the southern wind farm site. It should be mentioned, however, that our analysis was restricted to averaged daily values. Finer resolution data might have given more insights into coupling between up-welling and acoustic activity at the wind farm.

4.2. Distribution of harbour porpoise and harbour seal

Both harbour porpoises and harbour seals are seen throughout the year in the area of Horns Rev, including the planned site of the Horns Rev 2 Offshore Wind Farm. Although there are indications of less frequent observations of large numbers of harbour porpoises during the winter months and more frequent observations during the late summer, these patterns are obscured by the lower number of surveys carried out during the winter months. In fact, the second largest count of harbour porpoises around Horns Rev was made on February 23 2000 when 410 animals were sighted. Although the harbour porpoise can be seen in large numbers throughout the year, it is considered most likely that the area is used by animals from a large regional population using wider areas of the North Sea. Both the tagging of harbour porpoises and harbour seals support the idea that the animals use most of the North Sea for feeding. Population estimates of harbour porpoises for the Horns Rev 1 Offshore Wind Farm surveys indicate that the number of animals using the area is somewhere between 500 and 1000 (Skov et al. 2002, Tougaard et al. 2003b). The relatively high abundance of harbour porpoises is also illustrated by the fact that more than 100 animals were sighted during half of the ship-based surveys.

The PLS-analysis of environmental drivers behind the spatial dynamics of the harbour porpoise at Horns Rev stressed the importance of small-scale structures and processes reflected by the interactions between frontal and up-welling parameters, higher-order versions of current vectors and fine-scale topography (Table 4.2). No single parameter stands out, and the relative importance and interactions between parameters changed between tidal periods, indicating dynamic coupling to discrete processes. Large coefficients during north-flowing tidal currents were mainly related to frontal and up-welling parameters at large distances from land (Søren Jessens Sand), while the dynamic parameters and their interactions with topography seemed to play a larger role throughout the Horns Rev area during south-flowing tidal currents.

Table 4.2. Main environmental drivers behind the spatial dynamics of the harbour porpoise during the selected surveys as determined by the results of the PLS regression analysis. Regression coefficients are shown for the three most important factors for northward and southward tidal currents. Tidal currents are noted as flowing either northward (N) or southward (S).

Dato	*Tidal current*	*Factor*	*Coefficient*
28th July 2002	*S*	*V^2*Bottom slope*	*0.35*
	S	*ΔU*Bottom slope*	*0.34*
	S	*$\Delta W * W^2$*	*0.33*
	S	*ΔW*Bottom slope*	*-0.41*
	S	*V^3*	*-0.22*
	S	*$\Delta W * V^2$*	*-0.21*
	N	*$U^2 * V^2$*	*0.36*
	N	*Distance Jessen*ΔU*	*0.32*
	N	*Jessen*W*	*0.23*
	N	*$\Delta W * V^2$*	*-0.33*
	N	*Vsq*W*	*-0.29*
	N	*Complex sq*	*-0.17*
8th August 2002	*S*	*V^3*	*0.32*
	S	*ΔW^2*	*0.3*
	S	*ΔW* Distance Horns Rev*	*0.24*
	S	*$\Delta W * U^2$*	*-0.41*
	S	*ΔU^2*	*-0.37*
	S	*Distance Jessen Sand*W*	*-0.37*
	N	*$\Delta U * \Delta V$*	*0.31*
	N	*Distance Horns Rev* Bottom slope*	*0.3*
	N	*Distance Jessen Sand*W*	*0.28*
	N	*ΔV* Distance Horns Rev*	*-0.29*
	N	*Distance Jessen Sand *U^2*	*-0.25*
	N	*U^2*Distance Horns Rev*	*-0.25*

6-7th August 2003	*S*	ΔV	*0.22*
	S	U^2*V^2	*0.14*
	S	*Distance Jessen Sand*Bottom slope*	*0.14*
	S	$\Delta U*\Delta V$	*-0.16*
	S	U^2	*-0.2*
	S	*Distance Jessen Sand*V^2	*-0.24*
	N	V^3	*0.43*
	N	V^2	*0.3*
	N	$\Delta V*U^2$	*0.3*
	N	U^2*V^2	*-0.58*
	N	V^2* *Distance Horns Rev*	*-0.34*
	N	$\Delta V*W$	*-0.31*
20-21th August 2005	*S*	V^3	*0.36*
	S	*Bottom slope*^{2}	*0.29*
	S	$\Delta W*V^2$	*0.27*
	S	V^2*Bottom slope*	*-0.35*
	S	W^2*Bottom complexity*	*-0.33*
	S	V^2*Bottom complexity*	*-0.27*
	N	*Distance Jessen Sand*W*	*0.28*
	N	U^2*Distance Horns Rev*	*0.15*
	N	V^2*W	*0.14*
	N	U^3	*-0.29*
	N	W^3	*-0.22*
	N	$\Delta U*W$	*-0.22*

The spatial modelling results corroborated the results of the analysis of acoustic data and the PLS-analysis of survey data and they provided a clear overview of the habitat use by porpoises. The modelled habitat suitability of all ship-based sightings of harbour porpoises evaluated with topographic variables indicated areas of high use throughout the shallower part of the area, notably with high values in the western part of the reef (Figure 4.16). However, following the results of the PLS analysis it was clear that topographic variables alone were unlikely to summarise the main habitat features for the species. The modelled habitat suitability for harbour porpoises evaluated for different frontal scenarios and evaluated for south-flowing and north-flowing tidal phases displayed discrete areas of concentrated use and obvious variability in the general pattern of habitat use (Tables 4.3 and 4.4, Figures 4.17, 4.18, 4.19 and 4.20). The northeastern slope of Horns Rev as well as the eastern slope in general are mainly used during south-flowing tidal currents, while the southwestern slope overlapping the southern parts of the two wind farm sites is mainly important to porpoises during north-flowing tidal currents. The southwestern slope area during north-flowing tidal current seems to be the overall main habitat for porpoises at Horns Rev. The coefficients of the habitat variables differ between the two tidal phases as illustrated in Table 4.3 and 4.4. During south-flowing tidal currents the topographic key variables slope and bottom complexity are more important than up-welling as indicated by vertical current velocities, which are very important during north-flowing tidal currents. Accordingly, the modelling results indicate that the gradient in habitat use in the southern parts of the wind farm sites is largest during north-flowing tidal currents.

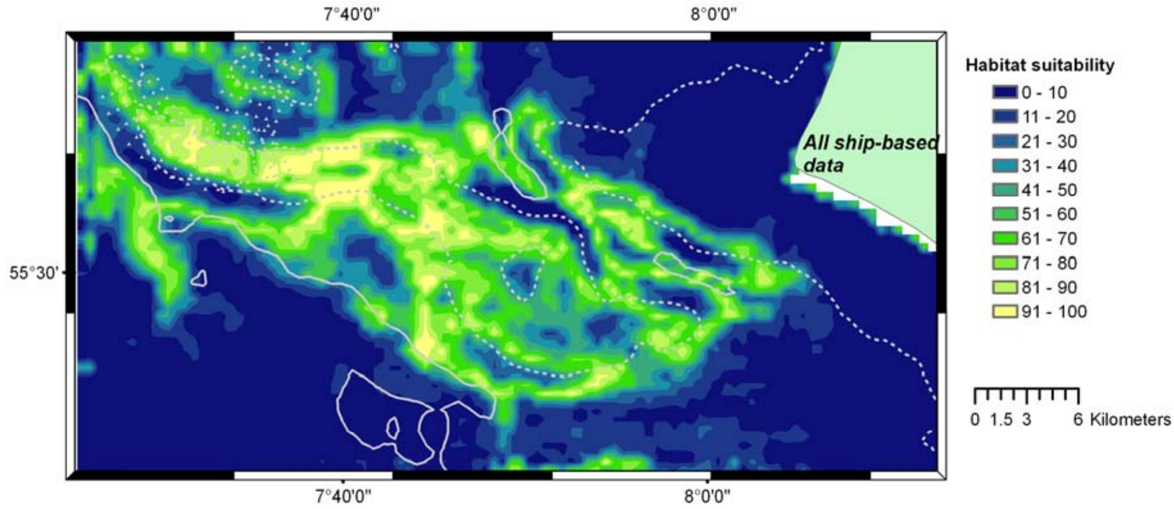


Figure 4.16. The modelled habitat suitability of harbour porpoise from all ship-based sightings of harbour porpoise..

Table 4.3. Example of results of the ecological niche factor analysis for observations of harbour porpoises during south-flowing tide (July 28, 2002). Coefficient values for the marginality factor are given. Positive/negative values mean that porpoises prefer location with higher/lower values than average for the modelled area.

Variable	*Marginality*
Distance Søren Jessens Sand	*0.161*
Distance Horns Rev	*-0.498*
Eastern aspect of seafloor	*0.156*
Northern aspect of seafloor	*0.025*
Bathymetry	*0.221*
Complexity of seafloor	*0.509*
Slope of seafloor	*0.397*
Salinity	*-0.412*
Onshore current velocity	*-0.055*
Long-shore current velocity	*0.209*
Vertical current velocity	*-0.135*

Table 4.4. Example of results of the ecological niche factor analysis for observations of harbour porpoise during north-flowing tide (August 6-7, 2003). Coefficient values for the marginality factor are given.

Variable	*Marginality*
Distance Søren Jessens Sand	*0.206*
Distance Horns Rev	*-0.613*
Eastern aspect of seafloor	*-0.285*
Northern aspect of seafloor	*-0.058*
Bathymetry	*0.165*
Complexity of seafloor	*0.235*
Slope of seafloor	*0.219*
Salinity	*0.002*
Onshore current velocity	*-0.148*
Long-shore current velocity	*0.349*
Vertical current velocity	*0.458*

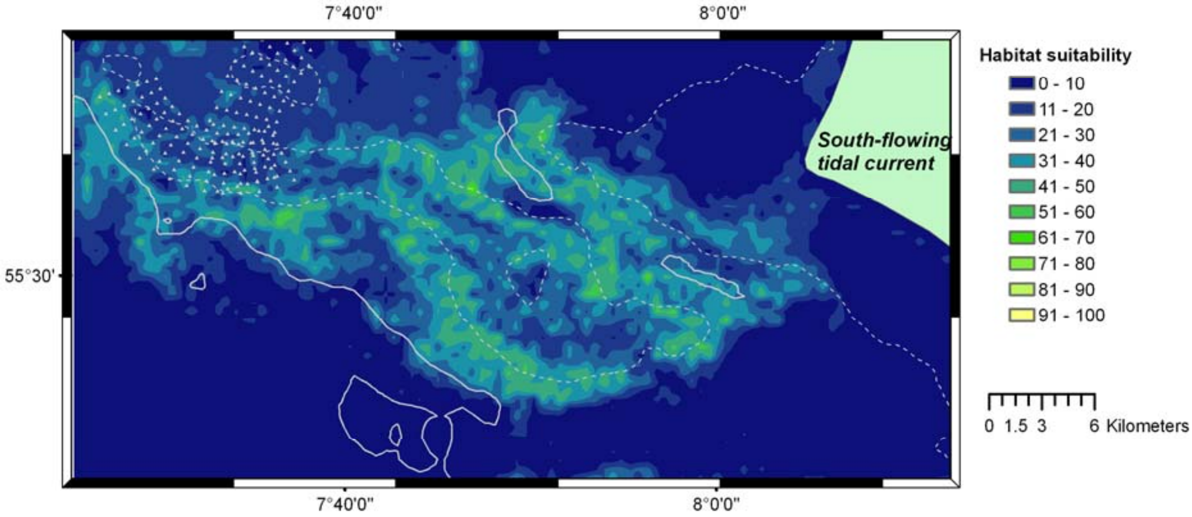


Figure 4.17. The modelled habitat suitability of harbour porpoise during periods of south-flowing tidal currents (selected surveys) .

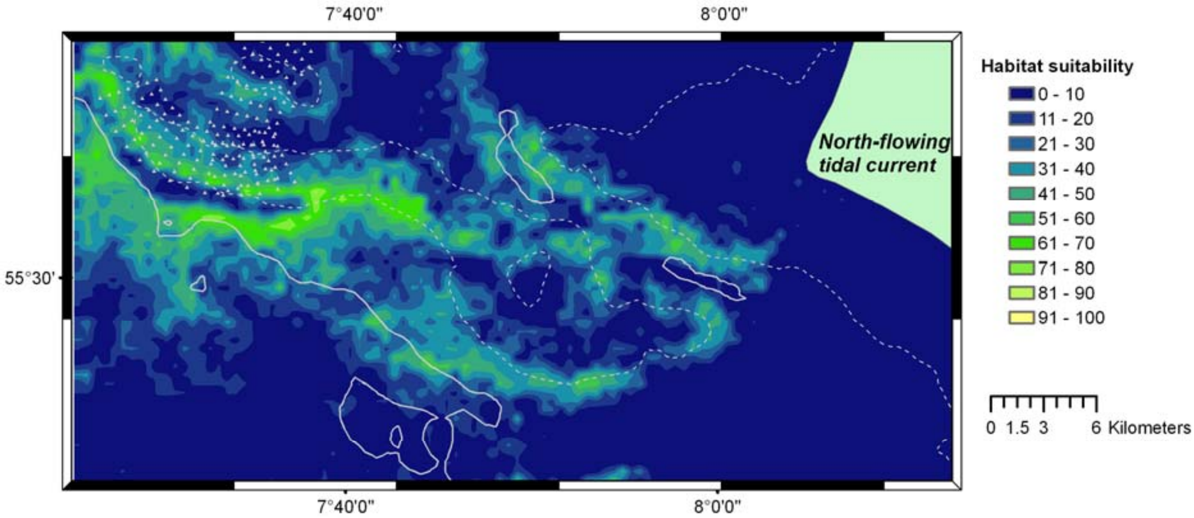


Figure 4.18. The modelled habitat suitability of harbour porpoise during periods of north-flowing tidal currents (selected surveys).

Gradients in the modelled habitat quality parameters, i.e. the marginality factor, across the wind farm area during the four selected surveys (north-flowing tide) are shown in Figures 4.21 and 4.22. In spite of the fact that the position of the density front changed markedly between the surveys, the gradients are very similar. The area of high habitat use mainly overlaps with the southern site and a profile running centrally through this site from east to west show high values over approximately 25% of the length of the profile. The scale of the peak habitat values is around 10 km and this scale is clearly reflected in the spatial structure of the survey encounter rates of all harbour porpoises (Figure 4.23 and 4.24).

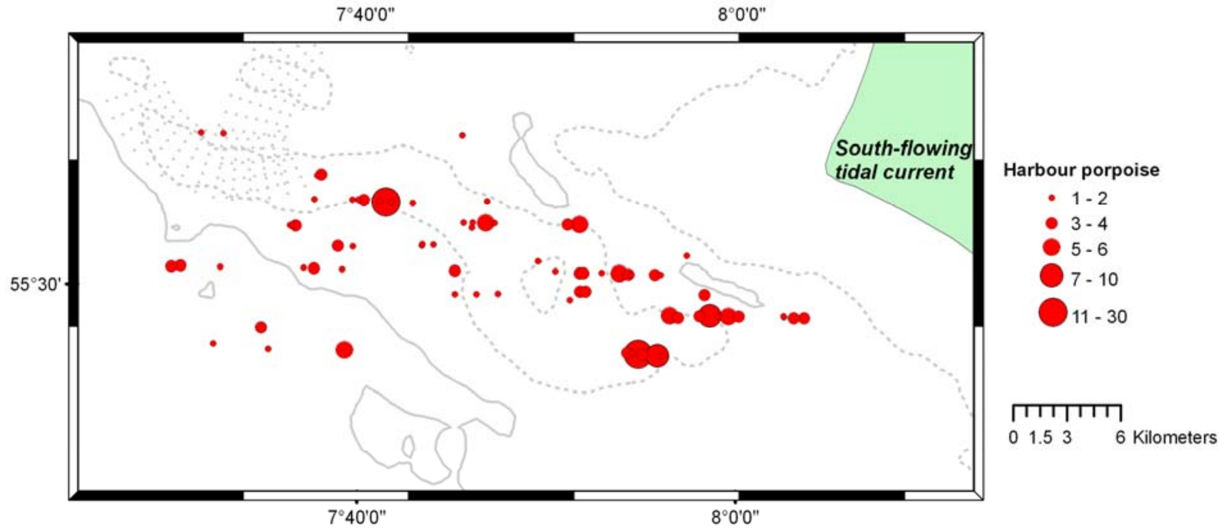


Figure 4.19. Observations of harbour porpoise during periods of south-flowing tidal currents (selected surveys) .

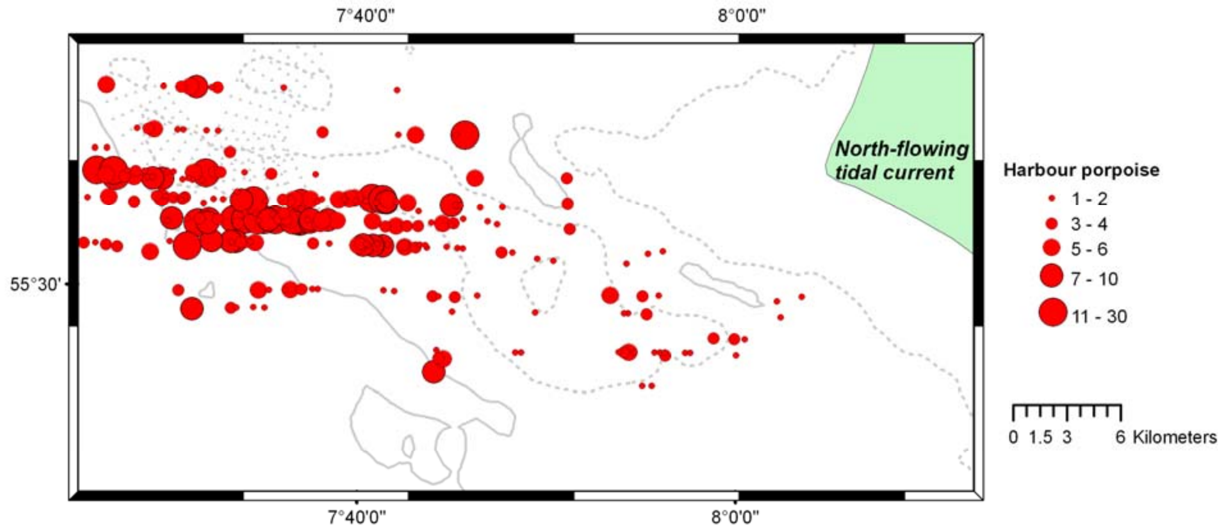


Figure 4.20. Observations of harbour porpoise during periods of north-flowing tidal currents (selected surveys) .

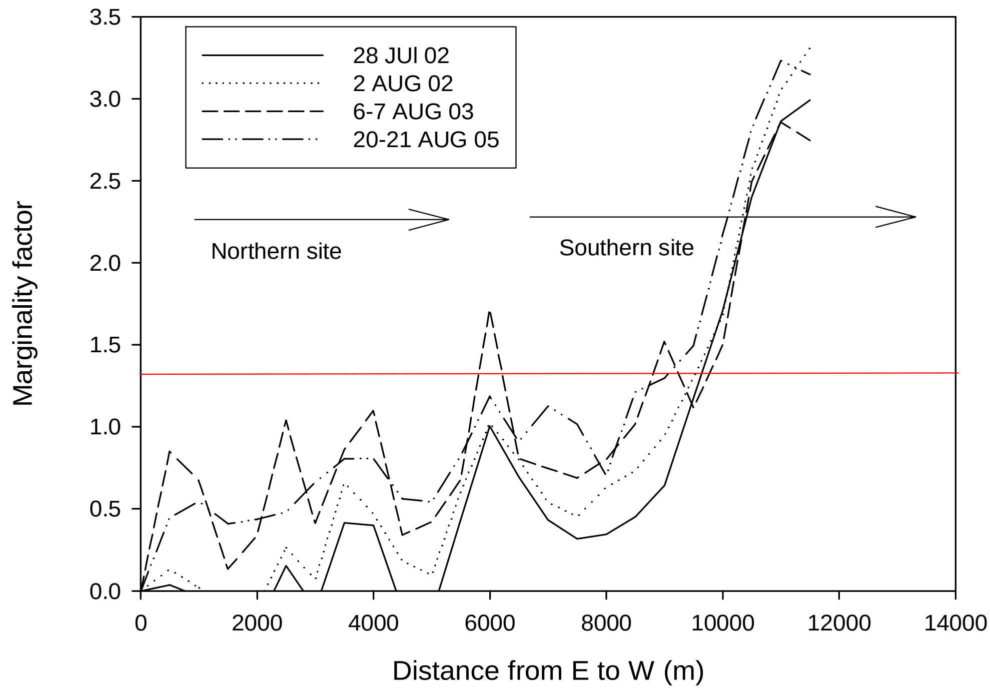


Figure 4.21. Variation in ecological marginality factor for harbour porpoise during north-flowing tidal currents on the four selected surveys along an east-west profile passing through the centre of both the northern and the southern wind farm sites. The red line marks the threshold for significance (mean value plus one standard deviation).

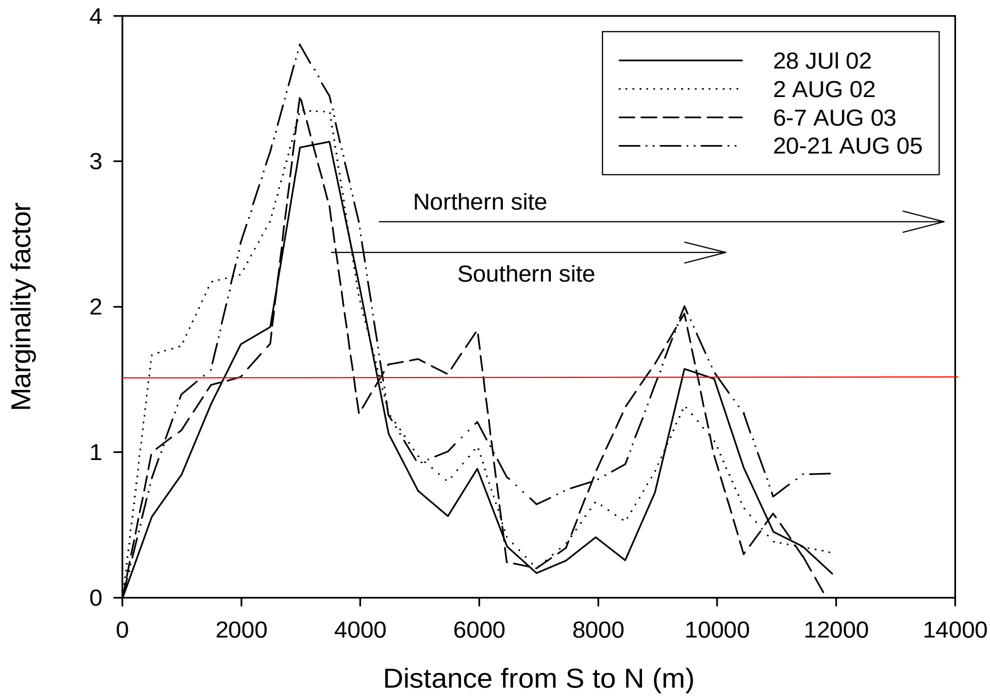


Figure 4.22. Variation in ecological marginality factor for harbour porpoises during north-flowing tidal currents on the four selected surveys along a south-north profile passing through the centre of both the northern and southern wind farm sites. The red line marks the threshold for significance (mean value plus one standard deviation).

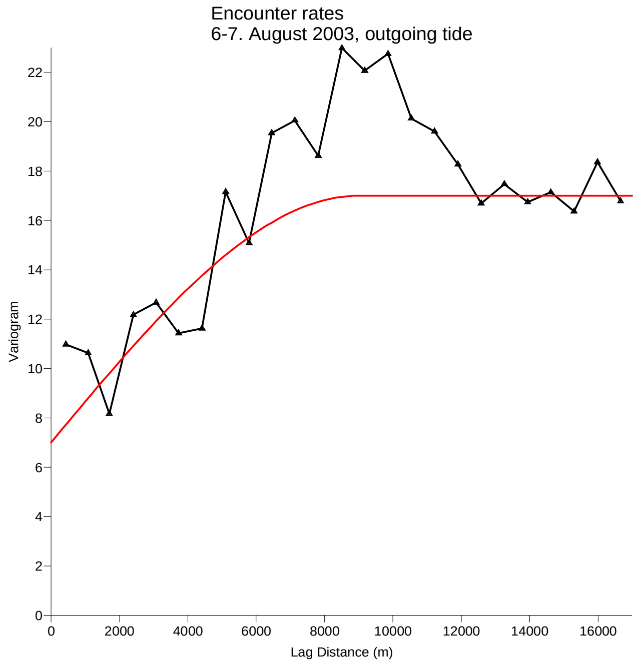


Figure 4.23. Empirical and experimental variograms of encounter rates of harbour porpoises during August 6-7, 2003.

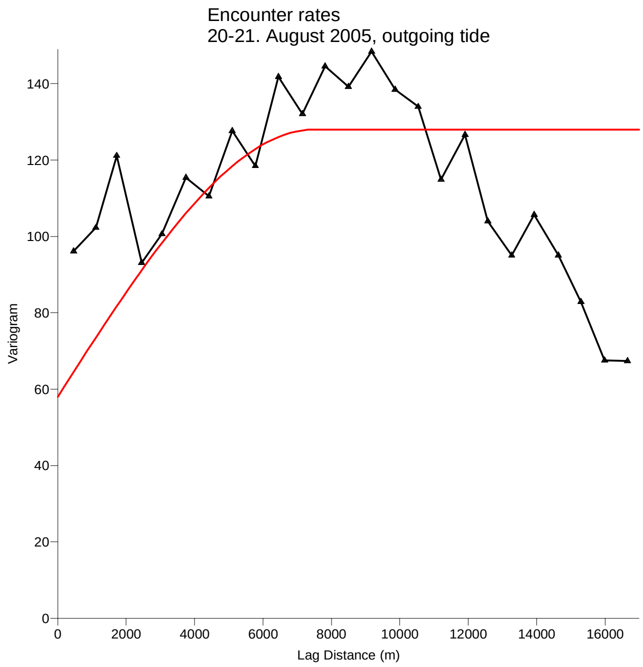


Figure 4.24. Empirical and experimental variograms of encounter rates of harbour porpoises during August 20-21, 2005.

The modelled habitat suitability of harbour seal sightings from the ship-based surveys evaluated by topographic variables showed that harbour seals displayed more or less identical overall habitat trends to harbour porpoises, although with a larger area of high habitat use over the central part of the reef, Figure 4.26. The habitat suitability of harbour seal modelled from the satellite telemetry data, Figure 4.27, underlines the general importance of the central parts of the reef to this species. However, the two data sets provide different trends of habitat use across the planned area of the Horns Rev 2 Offshore Wind Farm. Combining the trends depicted in both graphs it may be concluded that the area of high habitat suitability for seals overlaps the southern site and the southern part of the northern site.

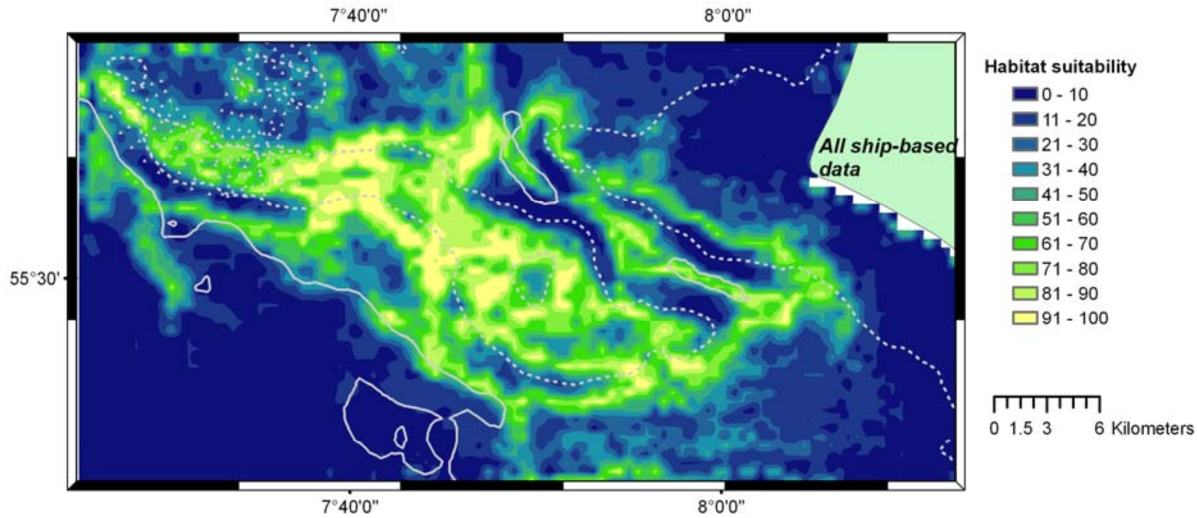


Figure 4.26. The modelled habitat suitability of harbour seals from observations obtained during ship-based surveys

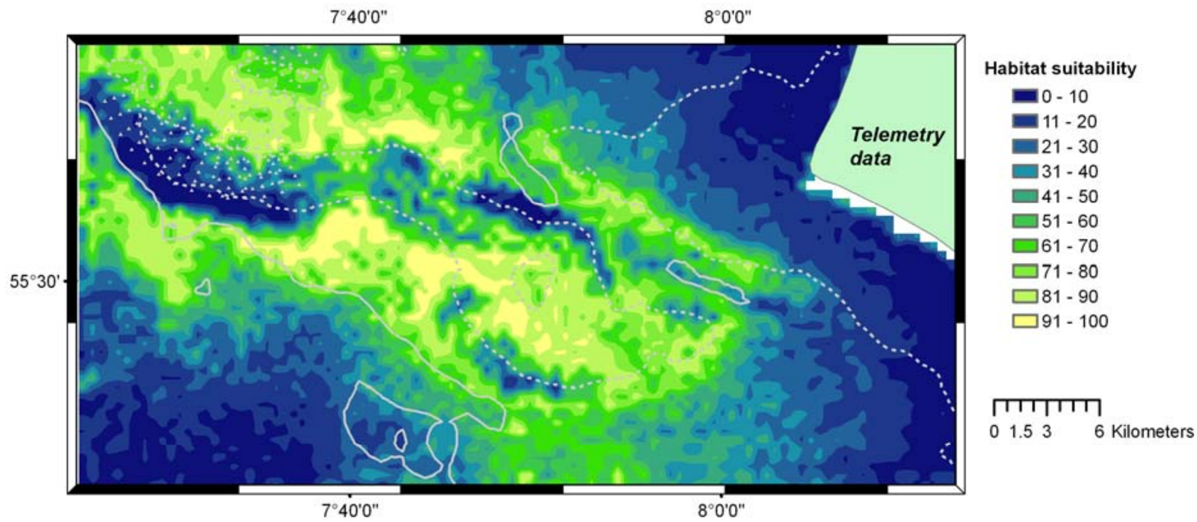


Figure 4.27. The modelled habitat suitability of harbour seals from recordings obtained from satellite telemetry

5. Sources of impact

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

Each of these 4 phases are associated with various impacts or impacts of different strength on the site of location of the wind farm and the associated fauna, resulting in a number of effects that will be reviewed and assessed in chapter 7.

5.1. 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 5.1:

Table 5.1. Overview over the main sources of impacts associated with the different phases or life stages of an offshore wind farm.

Source of impact	Phase			
	Pre-construction	Construction	Operation	Decommissioning
Noise and vibrations	X	X	X	X
Suspension 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. These other sources of impacts which include the physical loss of natural habitats and the physical introduction of new habitats deserve special mentioning potentially negative/positive impacts.

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 assessment of impacts and effects of Horns Rev 2 Offshore Wind Farm need also to include the cumulative effects derived from the presence of a wind farm that is only approximately 10 km away.

5.1.1. Noise and vibrations

The background noise levels in the sea are produced by different natural and man-made oceanic noise sources. The natural noise originates from mainly physical and biologic processes. Physically generated noise in the Horns Rev area includes wind, wave and rain generated noise. The biological noise includes vocalization by marine mammals and communication among individuals of various fish species, e.g. Atlantic cod. Noise generated by the wind is primarily related to wave action and is a product of speed, duration, water depth and proximity to the nearest coast. Wind introduced noise typically lies within the frequency band 0.001 - >30 KHz 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 with sound produced during the construction and decommission phase expected to be more intense than the sound created during both the pre-construction and the operation phases. However, in terms of duration, all but the operation phase 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. The sounds created in the construction phase originate from various sources. The most intense and thus most significant noise is generated during piling of foundations (Table 5.2). 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 5.2.

*Table 5.2. Noise generated during construction activities associated with the establishment of an offshore wind farm. For comparison a number of other common sources of noise at sea are listed. * (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

6. Assessments of effects

The following assessment of effects of the planned Horns Rev2 Offshore Wind Farm on harbour porpoise and harbour seal has been based mainly on the acoustic assessment methodology mentioned in chapter 3.4.1. and on the key habitats identified by the spatial modelling techniques outlined in chapter 3.3. The assessment covers the following issues: suspension of sediments, noise and vibrations, traffic, reef effect and cumulative effects for the pre-construction, construction, operation and decommissioning phases.

6.1. 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, seismic surveys (noise) and core sampling of the sediment (suspension of sediment), all of which will generate disturbances to the environment and thus impact the biological communities.

6.1.1. 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 two species of marine mammals and their prey in the area.

6.1.2. Noise and vibrations

During the pre-construction phase noise and vibrations will occur as a result of the vessel traffic and the seismic investigations. Noise generated by the pre-construction vessel activities are of the same magnitude as noise generated by fishing vessels, the seismic air gun surveys have a higher impact level and approach the impact level during driving of monopiles. A detailed assessment of noise and vibration impacts from traffic and monopile installations is given in the following chapter.

6.1.3. Traffic

During the pre-construction phase, an increased traffic level is expected in the area, resulting in an increase in short-term disturbance reactions of harbour porpoises. However, no significant effects are expected and the most likely scenario will be movements of animals in and out of the site in response to traffic intensity.

6.1.4. Reef effect

Apart from the possible establishment 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.

6.1.5. Cumulative effects

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

6.2. Construction phase

6.2.1. Overview

Establishment of a marine wind farm is associated with a number of construction activities primarily including: 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.

6.2.2. Suspension of sediments

Various disturbances to the sediment in the wind farm area will invariably take place in the construction phase. These include the digging operations needed for construction of foundations and scour protection and for sluicing down the cables. The affected area amounts to 0.2-0.3% of the total wind farm area depending 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 6.1.

At present, two types of foundations are under consideration for Horns Rev 2 Offshore Wind Farm (monopile or gravitation foundations). Table 6.1 shows the magnitudes and duration of important elements of work in the construction phase for each of the two types of foundations mentioned.

Table 6.1. Example of the magnitude and duration of important work elements related to the construction of one foundation for each of the two types of foundations mentioned for Horns Rev 2 Offshore Wind Farm (from Engell-Sørensen & Skyt, 2001).

	Gravitation	***Mono-pile***
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 6.1 indicates that the sediment works are much more comprehensive for the gravitation foundation than for the mono pile foundation. This is due to the amounts of foundation material to be laid out 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 the sediment plumes generated from the gravitation foundation are expected to be greater than sediment plumes generated from the monopile foundations (Engell-Sørensen & Skyt, 2001).

Sediment plumes are not expected to cause any direct impact on seals and porpoises, but may reduce the availability of prey, especially juvenile fish. However, since the affected areas are expected to be very small compared to the total wind farm area and the duration of the impact is short, no significant negative effects are expected. ´

6.2.3. Noise and vibrations

6.2.3.1. Pile driving

Attenuation of pile driving noise

Figure 6.1 shows the attenuation of pile-driving noise at different distances from the source calculated with the transmission loss formula by Thiele (2002) and background noise at moderate wind speeds of 3 bft. Pile driving noise decreases with distance and higher frequencies are more rapidly attenuated than lower ones. However, even at an 80 km distance, which represents the upper limit for the transmission loss formula used here, the sound pressure levels at frequencies <4 kHz are well above background noise. Maximum sound pressure levels at 80 km distance are 144 dB_{0-p} re 1 µPa (125 Hz), 146 dB_{0-p} re 1 µPa (250 Hz) and 148 dB_{0-p} re 1 µPa (315 Hz). These levels are approximately 70 dB above background noise. However, since background noise levels are given in a different dB unit than pile driving noise levels, this has to be considered as a rough estimate. RMS values that are directly comparable to LEQ-levels are difficult to derive for transient signals such as pile driving noise. They can provisionally be calculated from the sound-exposure levels with the formula:

$dB_{rms} = dB_E + 10 \log (T1/T2)$ (Au, pers. comm.)

where T1 = 1 s and T2 = duration of the signal. If T2 is defined as 50 ms, a difference of + 13 dB for any given SEL value is reached. This results in differences between peak and RMS of 6-12 dB, which could be provisionally defined as the error for this model. In other words, at an 80 km distance, pile-driving noise levels at frequencies below 4 kHz are between 60 – 70 dB above background noise levels under moderate conditions.

Audibility

Figure 6.2 shows the pile driving noise levels at different distances along with the audiograms of harbour porpoises and harbour seals. Since audiogram values are given as RMS, dB-values can not be compared 1:1. The error would be approximately between 6-12 dB. If we further consider that hearing was tested against a 2 s sine-wave tone (harbour porpoises) and a 500 ms sine-wave (harbour seals) and that one pile-driving pulse has a duration of only approximately 50 ms, then the figure represents an illustration rather than a quantitative measure.

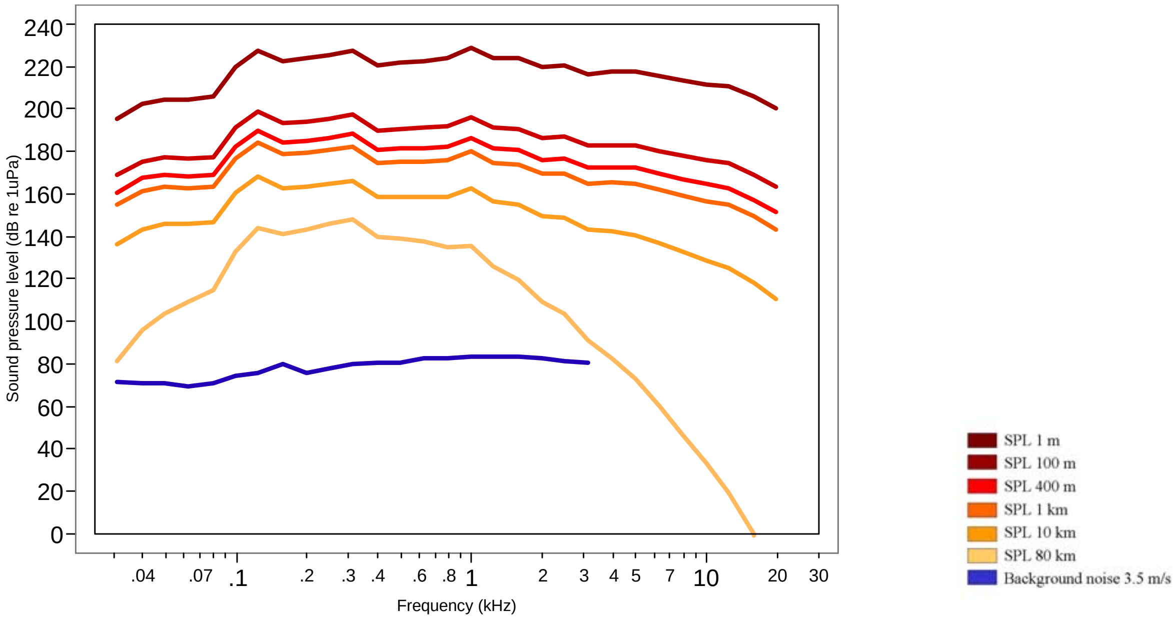


Figure 6.1. Attenuation of pile-driving noise at different distances from the source and background noise levels at moderate wind-speeds (Pile-driving noise after ITAP (2005) and Betke, pers. Comm; values as dB_{0-p} re 1 µPa in 1/3 octave-bands; TL-calculations after Thiele (2002); ackground noise levels as 1/3 octave-bands in dB_{Leq} re 1 µPa after Betke et al., 2004).

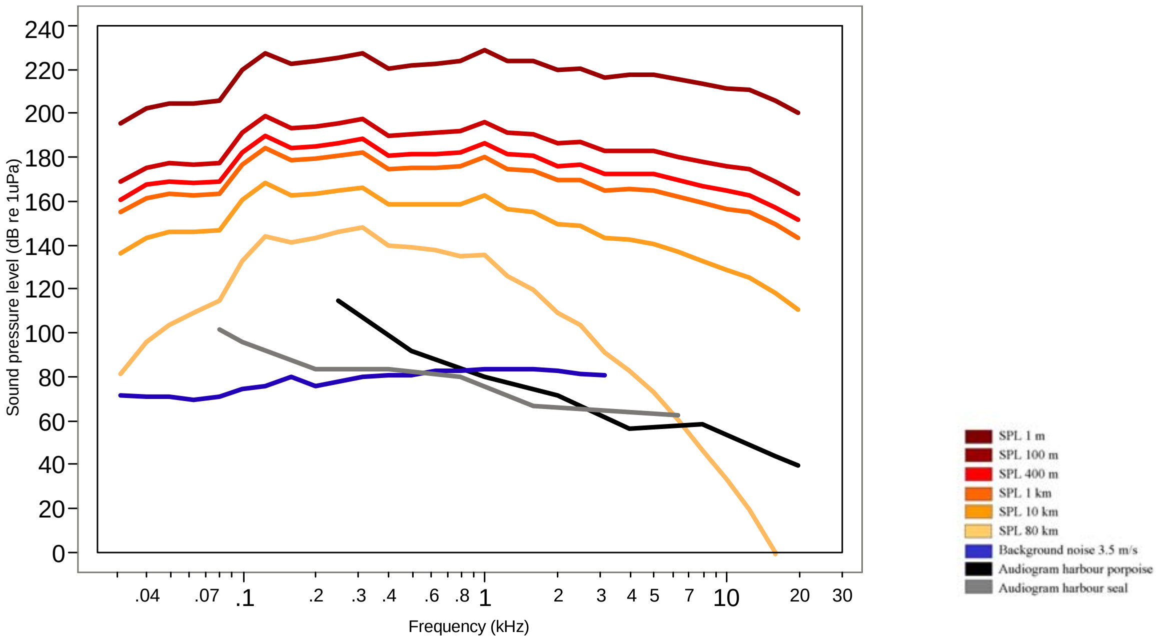


Figure 6.2. Pile-driving noise and background noise (see Figure. 6) compared to the audiogram of harbour porpoises and harbour seals (audiogram values as dB_{rms} re 1 µPa; after Kastelein et al., 2002 and Kastak & Schusterman, 1998).

However, in the present example, sound pressure levels are up to 56 - 59 dB above the hearing threshold of porpoises and seals. Taking all possible uncertainties into account, it can be conclude that the zone of audibility extends at least 80 km from the source for both species. Especially at frequencies below 600 Hz (seals) and 800 Hz (porpoises), audibility is solely dependant on the hearing threshold since, under moderate conditions, background noise levels are below threshold. At higher frequencies, background noise levels are above threshold and audibility is depending on the width of the critical band that ranges from 1/3 to 1/12 of an octave in cetaceans. (Richardson et al., 1995; Erbe & Famer, 2002; Erbe, 2002; Frisk et al., 2003; Wahlberg & Westerberg, 2005). Therefore, both pile-driving noise and background noise values were estimated in 1/3 octave bands. A sound is detected if the received noise is above background noise. In our case, background noise under calm to moderate conditions is 83 dB $_{rms}$ at 2 kHz (1/3 octave band see Figure 6.2). It can be seen that the pile-driving noise at this frequency is well above background noise and therefore audible. However, due to frequency dependant absorption, the range of detection will be smaller than for the lower frequency part of the ramming pulse. Frequencies higher than app. 2 kHz will be at or below background noise and it is therefore questionable, porpoises and seals will detect them (Figure 6.2).

Responsiveness

Many factors affect responsiveness in marine mammals, some of them are shown in Figure 6.3. Therefore, the zone of behavioural response is particularly difficult to assess (Richardson et al., 1995; Gordon, 2002; Madsen et al., 2006).

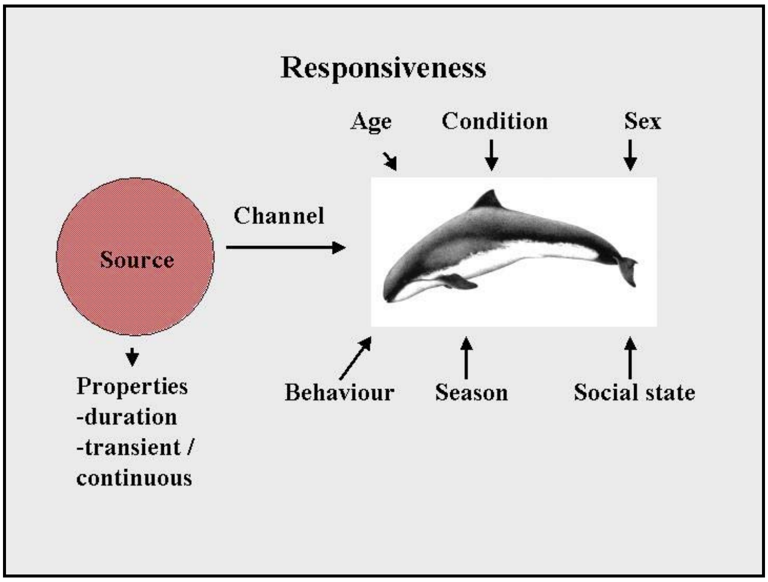


Figure 6.3. Factors affecting responsiveness in marine mammals (Harbour porpoise drawing by D. Bürkel, Hamburg).

It is important to note that pile driving pulses are transient stimuli and that at certain frequencies (see above) impact-pulses are probably the only signals the animals hear. Therefore, harbour porpoises should react strongly to them (Kastelein et al., 2005). On the other hand, pulses are of short duration, probably well below the time where full detection of signals is possible in porpoises (Cummings, 2003; SCAR, 2004; Madsen, 2005). It is therefore possible that there is a trade-off between transition and duration that will lead to an intermediate behavioural reaction.

Theoretical assumptions and some empirical data suggest a wide zone of responsiveness for pile-driving noise. McCauley et al. (2004) found strong behavioural reactions in humpback whales to air gun sounds at a received broad-band level of 172-180 dB_{p-p} (duration = 60 ms; frequency range = 0.1 – 2 kHz). This would correspond to an approximate threshold of 166 dB_{0-p}. If the model pile driving noise is assumed to be broadband with 238 $dB_{0\text{-}p}$ and calculate transmission loss to be 16 log (r) – the lowest transmission loss reported so far for pile-driving noise (Madsen et al., 2006) – a **25 km** radius is calculated for behavioural reaction.

Nedwell et al. (2003) defined a dB_{ht} (ht = hearing threshold) value at which behavioural reactions should occur in cetaceans. They postulate that sound pressure levels between 75 and 90 dB above hearing threshold should lead to mild and strong behavioural reactions in cetaceans. The way this value is calculated is not exactly explained. The authors also admit that the dB_{ht} values are derived from studies on other taxa, mostly fish, and need further evaluation. The advantage of this method is that impacts are calibrated against the hearing abilities of any species. If a 75 dB value is added to the audiogram by Kastelein et al. (2002), different reaction-thresholds are calculated and shown in Table 6.3. The problem of calculating RMS for transients (Madsen 2005) arises again, so both dB-values should be considered here. If for the sake of a worst case scenario, the peak values are used, a zone of 20 km is calculated. Here, the 1 kHz frequency Peak-SPL is above the threshold. The RMS value is well below threshold. To summarise, using the dB_{ht} scale by Nedwell et al. (2003), the radius for behavioural reaction would be between **10 and 20 km**.

Table 6.3. Behavioural reaction thresholds for harbour porpoises after Nedwell et al. (2003) and received sound pressure levels at 20 km distance from an impact pile-driver (Transmission loss calculated after Thiele (2002)).

Frequency (kHz)	Reaction Threshold (dB_{rms} re 1µPa)	Received SPL at 20 km ($dB_{0\text{-}p}$ re 1µPa)	Received SPL at 20 km (dB_{rms} re 1µPa)
0.25	190	160	152
0.5	167	154	145
1	155	156	146
2	147	141	132
4	142	131	120
8	134	118	107
16	119	98	87
20	115	89	77

In a recently published experiment, Kastelein et al. (2005) tested the reaction of harbour porpoises in a pool to different signals with main frequencies around 12 kHz. They found aversive responses at received levels of 97 – 111 dB_{Leq} re 1 µPa. The only signal resembling pile-driving noise was the test sound S2 (1.0 s pulse duration; 0.7 interval between pulses), which induced aversive responses at a received level of 103 dB_{Leq} re 1µPa. To compare the Leq-value with other dB-values, the interval has to be considered. A sound pressure level of 103 dB_{Leq} re 1 µPa would correspond to a sound exposure level (integration time = 1.0 s) of 10 log (1.7 / 1) = 105 dB_{SEL}. This value can be defined as a threshold for behavioural reaction for this particular signal at 12 kHz. For pile driving signal model, the 1/3 octave sound exposure level at the source was 185 dB_{SEL} re 1 µPa. Using the transmission loss model, the threshold for behavioural reaction would be reached at an approximately **7.5 km** distance from the source.

Empirical studies at the Horns Rev 1 Offshore Wind Farm by Teilmann et al. (2004) and Tougaard et al. (2003b, 2004) have shown that harbour porpoises reacted to impact pile driving sounds at ranges of at least 15 km. However, the effects were of short duration. It should also be noted that both pingers and seal-scarers were used before ramming. The seal scarers might have caused avoidance response since the source levels used were high (189 dB_{p-p} re 1 µPa) with frequencies of 13 – 15 kHz, where harbour porpoises have very acute hearing (Lofitech, Norway, pers. comm.). Therefore it cannot be ruled out that some of the observed effects were caused by the mitigation measures employed rather than by the construction activity.

For harbour seals, the zone of responsiveness of impact-pile-driving is even more difficult to assess than for porpoises. After Richardson et al. (1995) and Gordon et al. (2004), impulsive sounds have less negative impact on seals than on cetaceans. Using satellite telemetry, Tougaard et al. (2003b) could show that harbour seals transited Horns Rev during pile driving. On the other hand, Edren et al. (2004) found a 10 – 60% decrease in the number of hauled out harbour seals on a sandbank 10 km away from the construction during days of ramming activity compared to days were no pile-driving took place. However, this effect was of short duration since the overall number of seals remained the same during the whole construction phase. As a conservative measure, the behavioural reaction radius of seals should be viewed as a similar dimension as in porpoises. The results of the different studies are summarised in Table 6.4.

Table 6.4. Summary of recent studies looking at behavioural response in cetaceans.

Reference	Method	Species studied	Stimulus	Reaction threshold	Estimated radius of response for harbour porpoises
McCauley et al. (2004)	Empirical	Humpback whales	Airgun-pulse (60 ms; 0.1 – 2kHz)	172 dB_{p-p} re 1µPa	25 km
Nedwell et al. (2003)	Theoretical	various	-	75 dB above hearing threshold	10 – 20 km
Kastelein et al. (2005)	Empirical	Harbour porpoise	Pulsed tone (12 kHz; 1.0 s)	103 dB_{Leq}	7.5 km
Tougaard et al. (2004)	Empirical	Harbour porpoises	Impact-pile-driving (> 220 dB_{p-p})	-	15 km

To summarise, the reported assumptions and empirical studies lead to a wide zone of responsiveness in harbour porpoises and harbour seals. As a conservative measure, the responsive radius can be defined as approximately 20 km from the construction site. For both the northern and the southern wind farm sites the range of 20 km will cover 75 % of the area of primary habitat to both harbour porpoises and harbour seals at Horns Rev. However, these effects should be of short duration, allowing the animals to return to the key areas following pile driving activities.

Masking

The zone of masking is defined by the range at which sounds levels from the noise source are received above threshold within the critical band centered on the signal (Frisk et al. 2003). In other words, masking starts when the sound level of the masking sound equals the ambient noise (Madsen et al. 2005).

It is quite possible, due to short signal duration and pulsation of the ramming signal (minimum of 1.0 s interval between pulses), that masking by impact pile-driving sounds is reduced. However, sound pressure levels are rather high and might cause stress, which might in turn also affect communication among harbour porpoises and harbour seals (Madsen et al. 2006).

Since the sonar of harbour porpoises operates in a frequency range of 120 – 150 kHz, where ramming pulses have probably very low intensities, masking of echo location is not an issue. Amundin (1991) and Verboom & Kastelein (1995, 1997) described low-frequency sounds from porpoises around 2 kHz emitted either as by-product of high-frequency clicks or independently and speculated about their possible function in communication, for example between mother and calf. However, to date, no investigation dealt directly with those signals and essential data to predict the zone of masking for them (e.g. source levels) are unknown. It should be emphasised that studies on the communicative significance of harbour porpoise sounds are urgently needed to derive meaningful conclusions considering masking.

Harbour seals use signals between 0.2 - 3.5 kHz for communication between mother and calf and as territorial signals among males (Richardson et al.,1995; Riedmann, 1990). After Southall et al. (2000), the 200 Hz component of a harbour seal call had a spectrum level of 105 dB re 1 μPa at 1 m resulting in a 1/3 octave sound pressure level of 121 dB_{rms} re 1 μPa at 1 m (see Madsen et al. 2006 for calculations). Since background noise levels at 200 Hz are below the hearing threshold under moderate conditions (see above), the masking threshold would be dependant on the hearing threshold (84 dB_{rms} re 1 μPa). The received 1/3 octave sound pressure level would be well above the hearing threshold so masking would occur at least at a radius of 80 km and probably much farther.

Hearing loss

Temporary threshold shift (TTS) – the temporal elevation of the hearing threshold due to noise exposure – has been measured in white whales (Delphinapterars leucas) and bottlenose dolphins (Tursiops truncatus). Noise stimuli varied greatly in the experiments and the results indicate a linear relationship between sound exposure level and duration of exposure; the longer an animal is exposed, the lower the level of TTS. For short signals, however, sound pressure levels had to be 90 – 120 dB above hearing threshold to induce TTS (Kastak & Schustermann 1999; Au et al., 1999b; Finneran et al., 2000; Schlundt et al., 2000; Nachtigall et al., 2003).

From a regulatory perspective, injury is a concern when the received broadband sound pressure level exceeds 180 dB_{rms} re 1 μPa for cetaceans and 190 dB_{rms} re 1 μPa for pinnipeds (NMFS, 2003). The model impact pile-driving broadband sound pressure level is 229 dB_{rms} re 1 μPa at 1 m. Using this value and calculating a TL of 16 log (r) (see Madsen et al., 2006), the resulting TTS-zones would be 1,000 m for harbour porpoises and 250 m for pinnipeds. Of course, this is only a first estimate, since RMS values are difficult to apply to impulsive sounds such as pile driving (Madsen et al., 2006).

Recent studies on fish, birds and terrestrial mammals indicate that the degree of TTS is linearly correlated with the hearing threshold with a greater degree of TTS (in dB) in frequencies of high sensitivity compared to low ones (Linear threshold shift hypothesis; Smith et al. 2004). Frequency-dependent TTS has not been studied in cetaceans to date but it might become an important issue for further impact assessment since TTS-thresholds might vary considerably with hearing sensitivity. In humans, exposure to continuous airborne noise, 90 – 100 dB above hearing threshold, will cause TTS. Permanent hearing impairment is induced if noise exposure is 80 dB above hearing threshold (8 h per day exposure for 10 years; Richardson et al. 1995). It is uncertain to what degree these ‘dB-above threshold criteria’ are applicable to cetaceans (Richardson et al. 1995; Ketten, 1999). However, looking at the TTS-studies so far, it is likely that the ‘theoretical threshold shift zone’ in cetaceans is of similar dimensions. For example, in bottlenose dolphins TTS is induced if noise exposure is 96 dB above hearing threshold for 30 min (Au et al., 1999b). After Nachtigall et al. (2004), broadband noise exposure between 4 - 11 kHz for 30 min causes TTS in a bottlenose dolphin at a received level of 160 dB_{rms} re 1 µPa. Looking at the hearing threshold at these frequencies (4 kHz = 70 dB_{rms} re 1 µPa; 11 kHz = 50 dB_{rms} re 1 µPa; Johnson, 1967), the received levels would be between 90 - 110 dB above threshold. As worst case scenario, a 90 dB above threshold criterion might be feasible to work with.

Figure 6.4 shows the result if frequency dependent TTS is taken into account. Again, the model sound is the impact pile-driving pulse in 1/3 octave sound pressure levels calculated at different distances from the source. The peak sound pressure levels are shown in Figure 6.4. The audiogram by Kastelein et al. (2002) and a theoretical threshold shift zone of 90 dB above it are plotted for comparison. Again, the model has to interpreted with caution since peak values and RMS values differ at about 6- 12 dB (see above) and RMS values can not readily be derived for transient signals (Madsen et al., 2006).

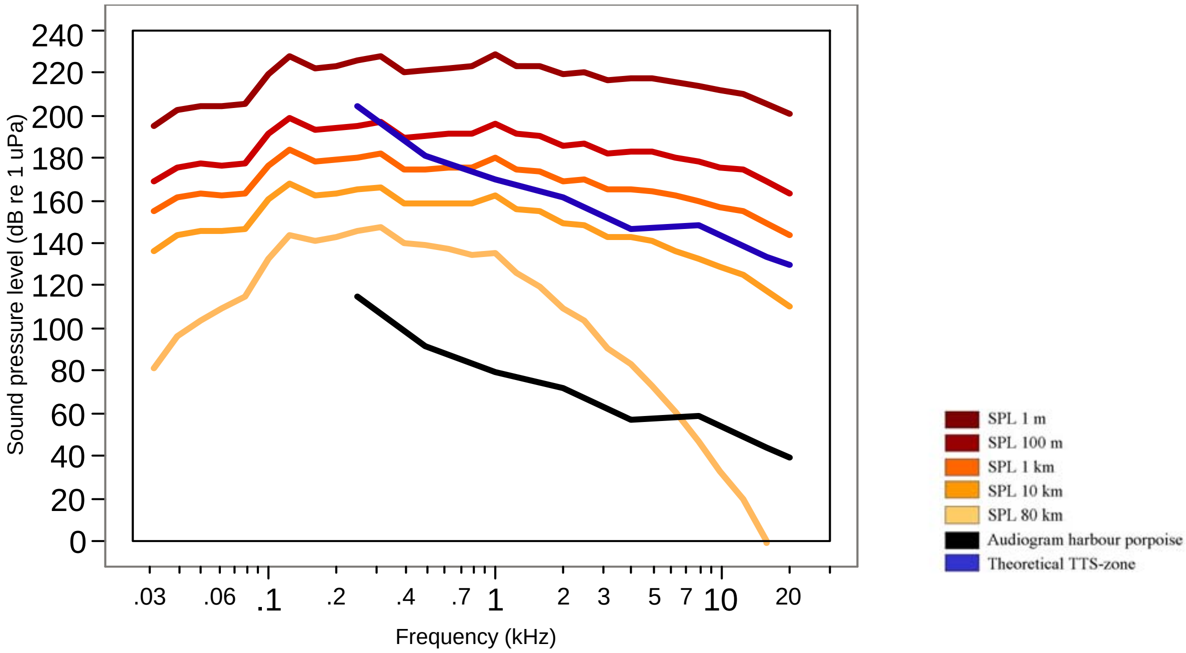


Figure 6.4. Attenuation of impact pile-driving noise at different distances from the source compared with the audiogram and a theoretical threshold shift zone of 90 dB above audiogram.

The radius of TTS in this example lies somewhere between 1 - 10 km and at 1 km, frequencies above 1 kHz are higher above TTS-threshold than those below 1 kHz. It should be emphasised that this is only an example that should show two things that might be important for future assessments. First, if frequency dependent TTS is taking into account, the radius for TTS might be wider as suggested by a regulatory approach. Of course, this depends solely on the thresholds used, but even elevating the threshold to 100 dB above audiogram would still result in an impact zone of more than 1,000 m as frequencies around 4-6 kHz would still be considerably above the TTS-zone at that distance. Second, the model implies that the higher frequency component of the signal would be more harmful than the lower one. If unmitigated, TTS impacts may be important, especially in the up-welling area used intensively by the marine mammals in the southern part of the wind farm sites.

Conclusions
To summarise, masking might occur in harbour seals over distances of 80 km from the source. Temporal hearing loss might occur at 1,000 m in harbour porpoises and 250 m in harbour seals from a regulatory perspective. If frequency dependant hearing loss is taken into account, temporal hearing loss might occur at greater distances as predicted by a regulatory approach.

6.2.3.2. Ship noise
Audibility
Table 6.5 shows sound pressure levels of ship noise at 0.25 kHz and 2 kHz at various distances from the source. Both frequencies were picked because most noise from construction / maintenance ships is exhibited in lower frequencies (Richardson et al. 1995). They are also applicable for harbour porpoises and harbour seals, since both species are suspected or known to communicate at low frequencies with acute hearing abilities around 2 kHz.

If detection thresholds for harbour porpoises are considered (115 dB_{rms} re 1 μPa at 0.25 kHz; 83 dB_{rms} re 1 μPa at 2 kHz) then it can be concluded that ship noise around 0.25 kHz will be detected by the species at distances of 1 km. Ship noise around 2 kHz will be at a distance of approximately 17 km. For harbour seals (detection thresholds = 84 and 83 dB_{rms} re 1μPa at 0.25 and 2 kHz respectively), the zone of audibility will be app. 15 km for the 0.25 content of ship noise and identical to the 2 kHz content (Table 6.5).

Table 6.5. Sound pressure levels of ship noise at different distances from the source calculated after Thiele (2002).

	Ship noise (dB_{rms} re 1 μPa)	
Distance to source	**0.25 kHz**	**2 kHz**
1 m	160	160
10 m	145	143
50 m	135	132
100 m	130	127
1 km	115	110
10 km	99	90
80 km	80	50

Responsiveness
As sound pressure levels from ships are considerably lower than those during pile driving, the zone of responsiveness to ship noise will be much smaller than for pile-driving noise. For porpoises, the lower frequency component of the ship noise will be

audible only at distances of 1 km. The 2 kHz component will be detected at ranges of 15 km. Richardson et al. (1995) defined a received level of 120 dB for continuous noise as a criterion for responsiveness in cetaceans. Looking at the results shown in Table 6.5, the zone of responsiveness should be limited to approximately 200 – 300 m.

Masking

As stated above, no information on the communicate significance of low-frequency sounds in harbour porpoises exist. Therefore, the zone of masking can't be determined. For seals, masking might occur up to the range of audibility (~ 17 km), depending on the exact characteristics of the boat-noise.

Hearing loss

Due to the much lower noise levels from construction ships compared to pile-driving, TTS would occur in both species only at very close distances to ships.

6.2.4. Traffic

The construction phase is associated with intense vessel traffic. Collisions involving small cetaceans and seals are normally limited to fast sailing boats like transport boats with service personnel. Collisions with harbour porpoises and seals are most likely to happen in the high-use zone in the southern parts of the wind farm sites. In general, knowledge of the migratory routes of porpoises and seals in the eastern North Sea is inadequate to evaluate to what degree the wind farm construction will potentially act as barriers to those routes.

6.2.5. 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).

6.2.5.1. Loss of existing habitats

Establishing turbine foundations and scour protections amounting to 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 habitat. This loss is considered insignificant in terms of total habitat availability to harbour porpoises and harbour seals at Horns Rev. Both species forage on fish in the water column. The main habitat area at the southwestern up-welling may house high densities of key prey fish like sandeel, yet these will aggregate in the frontal zone from a larger area of suitable sediment on Horns Rev. The digging and excavation 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. Likewise, the excavation operations are not expected to have any significant effect to the adult sandeels.

6.2.5.2. Reef effect

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 also likely to occur at Horns Rev 2 Offshore

Wind Farm. Although colonisation is fast, only the initial phases of the colonisation are expected to take place during the relatively short construction phase.

6.2.6. Cumulative effects

Since, to date, there are no published measurements of noise from larger wind turbines or larger wind farms, such as Horns Rev 1 Offshore Wind Farm, no reliable estimate can be made on the effects of operational noise from Horns Rev 1 Offshore Wind Farm on the construction phase of Horns Rev 2 Offshore Wind Farm. However, it is not very likely that operational noise from a wind farm 10 km away is audible to porpoises or seals under moderate conditions. The cumulative effects are therefore probably minimal. It has to be noted here that during the construction phase, noise will probably lead to a behavioural reaction of harbour porpoises and seals in a radius of 20 km from the construction site. The zone of behavioural response can therefore be expected to be approximately 1,250 km^2. Any possible effects of operation from a wind farm 10 km away will be negligible compared to the effects during the construction phase of Horns Rev 2 Offshore Wind Farm itself.

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

6.3. Operation phase

6.3.1. Suspension of sediments

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

6.3.2. Noise and vibrations

Figure 6.5 shows sound pressure levels of a 1.5 MW turbine in operation at wind-speeds of 12 m/s (bft = 6). Background noise levels were taken from Betke et al. (2004) and Madsen et al. (2006) to take account for wind-speeds of 12 m/s. At 110 m, - turbine noise would be audible to both harbour porpoises and harbour seals. At 1,000 m, the signal to noise ratio is too low for detection in harbour porpoises. In harbour seals detection might be possible at 1,000 m in the 125 – 160 Hz range since background noise is only barely above hearing threshold and detection would be limited solely by the hearing sensibility of the species. This wider zone of audibility for harbour seals compared to porpoises is consistent with previous studies (Henriksen et al., 2001; Madsen et al., 2006).

The calculations above depend on the signal to noise ratio of turbine and background noise. In calmer conditions, the detection range of the signal will probably increase. However, since turbine noise decreases, the overall ranges should remain constant. The results indicate a rather small zone of audibility and noise levels at 1,000 m are too low to induce responsiveness, masking or TTS in porpoises. Their might be masking of harbour seal sounds but this will happen at close ranges below 1 km. Experiences from the Horns Rev 1 Offshore Wind Farm indicate no negative behavioural response to the production noise. Both species are seen regularly within the wind farm. Koschinski et al. (2003) reported behavioural responses in both species to playback of simulated offshore turbine sounds. However, Madsen et al. (2006) point out, Koschinski et al. (2003) might have introduced artefacts at higher frequencies that were responsible for the reactions. It is unknown if and to what degree higher-powered turbines, as planned at Horns Rev 2 Offshore Wind Farm, noisier. However, it might be reasonable to conclude that elevation of noise levels will happen predominately in lower frequencies below 100 Hz (Betke, personal communication). Since both species are probably not very sensitive in this range, it is questionable if larger foundations would have a greater effect than smaller ones.

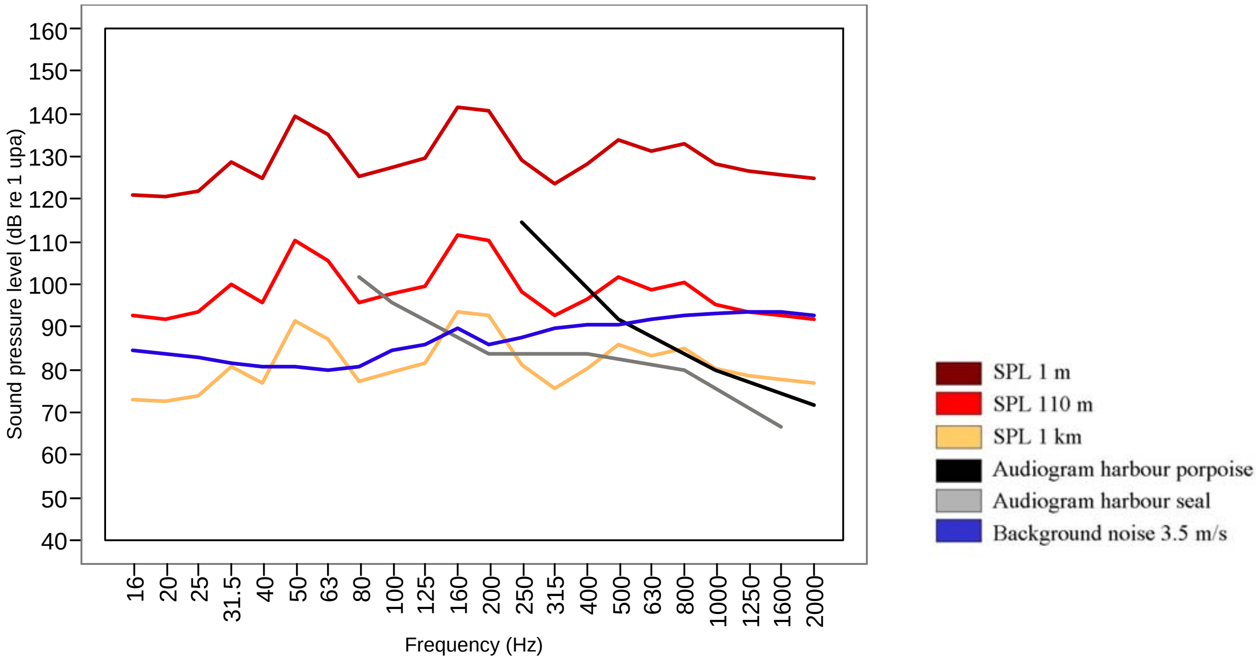


Figure 6.5. Sound pressure levels at an offshore wind farm in operation in at different distances from the source compared to the audiogram of harbour porpoises and harbour seals and background noise (SPL = Leq in 1/3 octave sound pressure levels; 110 m = measurement; 1 m = back-calculated after Thiele, 2002; 1,000 m calculated with 16 log (r); background noise after Betke et al., 2004 and Madsen et al., 2006; audiogram harbour porpoise by Kastelein et al., 2002; harbour seal by Kastak & Schusterman, 1998).

6.3.3. Traffic

Running maintenance of the turbines involves some vessel activities in the wind farm area. The traffic during the operational phase is restricted to smaller vessels participating in the maintenance operations and collision risks in relation to marine mammals will be limited to fast sailing boats.

6.3.4. Electromagnetic fields

During operation, the power cables connecting the wind farm to shore will generate a narrow zone of electromagnetism along the cables. Marine mammals are generally not regarded as sensitive to electromagnetic fields generated close to the cable (Gill et al. 2005), although the range of electromagnetism is detectable by electro-sensitive fish species (CMACS, 2003). Modelling, measurements and monitoring results show that the field of impact is narrow (< 1 m) and impacts on local fish stocks are non-significant (CMACS, 2003, Hvidt et al., 2003) with impacts on marine mammals deemed negligible.

6.3.5. *Reef effect*

Colonising of foundations and scour protections will continue during the operation phase. 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. The fish diversity is expected to increase during the operation phase. The increased availability of potential prey for porpoises and seals like cod (*Gadus morhua*) and whiting (*Merlangius merlangus*) within the wind farm may attract the animals to the wind farm site.

In addition to the reef effect, it deserves mentioning that construction 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 25 years (expected minimum life time of the wind farm). During this period (mainly the operation period) incidental catches and disturbance of harbour porpoises will be reduced in the area of the wind farm.

6.3.6. *Cumulative effects*

The effect of operational sounds can not be predicted for certain, since no measurements of source levels of an operating turbine > 2 MW or a whole wind farm in operation are available to date. However, it is unlikely that operational noise of either wind farm will affect the behaviour of marine mammals in the other.

6.4. Decommissioning phase

Impacts on harbour seals and harbour porpoises envisaged during decommissioning are similar to some of the disturbance impacts expected during construction, depending on the activities of pile removal and service boats. The potential disturbance effects will be smallest for decommissioning of gravity foundations. As decommissioning involves activities similar to construction, the cumulative effects will be the same as those mentioned in chapter 5.2.6.

6.5. Mitigative and preventive measures

Listed below are some proposals for mitigative measures in the four different phases of the life cycle of the wind farm related to the perceived moderate and major impacts.

6.5.1. *Pre-construction phase*

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

6.5.2. *Construction phase*

The construction phase contains the most intensive impacts regarding emission of noise and vibration. The potential major impacts related to the potential TTS zone during pile-driving operations can be mitigated, while the overall moderate impacts due to short-term responsive movements, may be impossible to mitigate. Mitigation measures during construction can focus on the source of noise as well as the receiver, in this case harbour porpoises and seals. Looking at the source, there are several mitigation options:

- Extending the duration of the impact during pile-driving (decrease of 10-15dB in SL; mostly at higher frequencies > 2 kHz)
- Mantling of the ramming pile with acoustically-isolated material (plastic etc.; decrease of 5 –25 dB in SL; higher frequencies better than lower ones)
- Air bubble curtain around the pile (decrease of ~ 10 dB; Würsig et al., 2000)
- Soft-start / ramp-up procedure (slowly increasing the energy of the emitted sound; Richardson et al., 1995)

The methods mentioned above have benefits and costs; extending the duration of the impact reduces source levels very efficiently but has biological implications since signals of longer duration would mask harbour seal and possibly harbour porpoise communication signals to a greater extent than shorter signals. The method is also limited technically, since shorter pulses are more effective in driving the pile into the bottom than longer ones. Mantling seems to be very promising but has so far only been tested in a relatively short pile. Air bubble curtains are very expensive and might only be effective in relatively shallow water (Knust et al., 2003). Soft-start procedures are theoretically promising but their effect has not been tested to a large degree. Ramping-up might also make it more difficult for cetaceans and seals localizing the sound source (Richardson et al., 1995).

Looking at the receiver, acoustic harassment devices have been used both for seals and harbour porpoises and have proven to be effective in scaring the animals away from the source (Yurk et al., 2000; Culik et al., 2001). Culik et al., (2001) reported a mean avoidance zone of 500 m around a ‘pinger’ for porpoises. Cox et al. (2001), reported a smaller avoidance response of approximately 208 m. At Horns Rev 1 Offshore Wind Farm, a seal scarer with an effective range of 300 m was used. Therefore, both systems seem to work at relatively short ranges, well below the potential TTS zone (see above). It might therefore be necessary to deploy several pingers at different distances from the construction site (see also the potential impact of seal-scarers on harbour porpoises under chapter 6.2.3.1).

To sum up, the recommended mitigation measures are the application of seal scarers and pingers in combination with ramp-up procedures during pile driving. The seal scarers are judged essential, as they have the most potential for effective mitigation against TTS impacts.

6.5.3. Operation phase

As there are no significant impacts expected for seals and porpoises during operation of wind farms, no mitigation measures are needed.

6.5.4. Decommissioning phase

As impacts of decommissioning are mainly the reverse of construction (except pile-driving), the use of seal-scarers and pingers might be an effective mitigation measure.

7. Conclusions

The impacts to the regularly occurring species of marine mammals at Horns Rev, harbour porpoise and harbour seal, are summarised in Tables 7.1 and 7.2.

The large amount of data available from the biological monitoring program at the Horns Rev 1 Offshore Wind Farm proved sufficient to describe the trends in acoustic activity and habitat quality at the two sites for the Horns Rev 2 Offshore Wind Farm. Time-series from five porpoise detectors (PODs) and 51 fine-scale ship-based surveys provided the basis for the analyses and combined with topographic and hydrodynamic model data key habitats and their variability were defined for the period 2002-2005. Constraints in the extrapolation of Horns Rev 1 Offshore Wind Farm monitoring data to the Horns Rev 2 Offshore Wind Farm sites were found in relation to the variance of acoustic data induced by different T-POD versions and in relation to seasonal biases in the visual data. With respect to the different T-POD versions, the issue was solved by limiting the gradient analysis in acoustic activities in relation to environmental variables to data collected by the T-POD version 1. With respect to seasonal biases, the monitoring data indicated a reduction in the recordings of harbour porpoises during the winter season.

Harbour porpoises are relatively abundant in the Horns Rev area with local population estimates in the range of 500 to 1000 animals. Harbour seals breed in the nearby Wadden Sea and pass Horns Rev on their movements to feeding grounds in deeper waters of the North Sea. Although harbour porpoises are recorded throughout the area, the trend analysis and statistical tests of both acoustic and visual data with physical oceanographical data showed that the species is linked to small-scale dynamics, especially localised up-welling driven by tidal currents, rather than to large-scale dynamics, driven by the estuarine front. The up-welling zones are associated with the slope areas, including the southwestern slope at the southern part of the Horns Rev 2 Offshore Wind Farm sites. The modelled habitat suitability of harbour porpoises at Horns Rev both showed discrete areas of high use in the southwestern slope area, the northeastern slope, the southern slopes in Slugen and the southeastern slope. The northeastern slope of Horns Rev seems mainly to be used during south-flowing tide, while the southwestern slope overlapping the southern parts of the two wind farm sites seems mainly to be used during north-flowing tidal currents. The southwestern slope area during north-flowing tidal current seems to be the overall main habitat for porpoises at Horns Rev. The scale of peak habitat use by harbour porpoises at Horns Rev is approximately 10 km and the area of high habitat quality measures approximately 15% of the total modelled area. Harbour seals displayed more or less identical overall habitat trends as harbour porpoises when evaluated against topographic features, with the shallower, central parts seemingly being used more intensively. For harbour porpoises a strong decreasing gradient in habitat quality was discovered from the southern to the northern parts of the proposed sites.

Impacts were assessed by linking the classified key habitats to detailed investigations of noise-related disturbance using *in situ* measurements together with a method of frequency-related impact assessment. The main focus of the assessment is added effects imposed by under water noise, especially pile driving noise during construction. Based on the integration of models for attenuation of pile driving noise and audiograms for the two species, a zone of audibility is estimated at approximately 80 km and a zone of responsiveness is estimated at 20 km. For both the northern and the southern wind farm site, the range of 20 km will cover 75% of the primary habitat area to both harbour porpoises and harbour seals at Horns Rev. However, these effects should be of short duration, allowing the animals to return to the key areas following pile driving activities. Impacts on marine mammal communication caused by the pile driving noise is probably of limited significance, and with the data at hand probably only of relevance to harbour seal with an estimated masking zone of 80 km. Temporary threshold shift (TTS) zones for porpoises and seals are estimated at 1,000 m and 250 m, respectively. However, the TTS range for harbour porpoises is uncertain and, if frequency dependent TTS is taken into account the impact zone for this species will extend beyond 1,000 m. If unmitigated, TTS impacts may be important, especially in the up-welling area used intensively by porpoises in the southern part of the wind farm sites.

Other impacts during construction are considered as minor. Noise from ships associated with the construction activity could lead to responsive reactions in harbour porpoises and at close range (2-300 m).

Impacts on marine mammals during operation will be limited. The net effect of the establishment of the Horns Rev 2 Offshore Wind Farm may be positive depending on the development of new habitats and hard-substrate communities and the attraction of prey fish to these communities. Underwater turbine noise emissions are estimated to be audible for harbour porpoises only at close range (1-200 m), while harbour seals will be able to detect the sound within 1,000 m. The low levels of noise at predominantly lower frequencies are too low to induce responsiveness, masking or TTS in porpoises. There might be masking of harbour seal sounds but this will happen at close ranges below 1 km.

Impacts on harbour seals and harbour porpoises envisaged during decommissioning are similar to some of the disturbance impacts expected during construction, depending on the activities of pile removal and service boats. The potential disturbance effects will be smallest for decommissioning of gravity foundations.

Cumulative local and regional effects will mainly be an issue in relation to pile driving activities at Horns Rev 2 Offshore Wind Farm. Any possible effects of operation from Horns Rev I will be negligible compared to the effects of the construction phase of Horns Rev 2 Offshore Wind Farm.

Recommended mitigation measures are described with the most promising and well-tested being the application of seal scarers and pingers in combination with ramp-up procedures during pile driving. The seal scarers are judged essential, as they have the most potential for effective mitigation against TTS impacts.

Tabel 7.1. Summarised impacts on marine mammals from construction and operation activities associated with the establishment of Horns Rev 2 Offshore Wind Farm – Monopiles.

Monopiles

Impact	Criteria	Preconstruction	Construction	Operation	Decommissioning
Noise and vibrations	Importance	Regional	Regional	Local	Local
	Magnitude	Minor	Moderate	Minor	Minor
	Persistence	Temporary-short	Temporary-short	Temporary	Temporary
	Likelihood	High	High	High	High
	Other	Direct	Direct	Direct	Direct
	Significance	Minor	Moderate	Minor	Minor
Suspension of sediments	Importance	Local	Local	Local	Local
	Magnitude	Negligible	Minor	Negligible	Minor
	Persistence	Temporary-short	Temporary	Permanent	Temporary
	Likelihood	Low	High	High	High
	Other	Direct/indirect	Direct/indirect	Direct/indirect	Direct/indirect
	Significance	Negligible	Negligible	Negligible	Negligible
Traffic	Importance	Local	Local	Local	Local
	Magnitude	Minor	Minor	Minor	Minor
	Persistence	Temporary-short	Temporary-long	Semi-permanent	Temporary-long
	Likelihood	High	High	High	High
	Other	Direct	Direct	Direct	Direct
	Significance	Minor	Minor	Minor	Minor
Electromagnetic fields	Importance			Local	
	Magnitude			Negligible	
	Persistence			Permanent	
	Likelihood			High	
	Other			-	
	Significance			Negligible	
Reef effect	Importance		Minor	Negligible	Minor
	Magnitude		Minor	Negligible	Minor
	Persistence		-	Permanent	-
	Likelihood		High	High	High
	Other		-	-	-
	Significance		Negligible	Minor - positive	Negligible
Cumulative effects	Importance	Local	Local	Local	Local
	Magnitude	Negligible	Minor	Negligible	Minor
	Persistence	Temporary-short	Temporary	Permanent	Temporary
	Likelihood	Low	Low	Low	Low
	Other	-	Direct	-	Direct
	Significance	Negligible	Negligible	Negligible	Negligible

Tabel 7.2. Summarised impacts on marine mammals from construction and operation activities associated with the establishment of Horns Rev 2 Offshore Wind Farm – Gravitation foundations.

Gravitation foundations

Impact	Criteria	Preconstruction	Construction	Operation	Decommissioning
Noise and vibrations	Importance	Regional	Local	Local	Local
	Magnitude	Negligible	Minor	Minor	Minor
	Persistence	Temporary-short	Temporary	Temporary	Temporary
	Likelihood	High	High	High	High
	Other	Other: Direct	Other: Direct	Other: Direct	Other: Direct
	Significance	Negligible	Minor	Minor	Minor
Suspension of sediments	Importance	Local	Local	Local	Local
	Magnitude	Negligible	Minor	Negligible	Minor
	Persistence	Temporary-short	Temporary	Permanent	Temporary
	Likelihood	Low	High	High	High
	Other	Other: Direct/indirect	Other: Direct/indirect	Other: Direct/indirect	Other: Direct/indirect
	Significance	Negligible	Negligible	Negligible	Negligible
Traffic	Importance	Local	Local	Local	Local
	Magnitude	Minor	Minor	Minor	Minor
	Persistence	Temporary-short	Temporary-long	Semi-permanent	Temporary-long
	Likelihood	High	High	High	High
	Other	Other: Direct	Other: Direct	Other: Direct	Other: Direct
	Significance	Minor	Minor	Minor	Minor
Electromagnetic fields	Importance			Local	
	Magnitude			Negligible	
	Persistence			Permanent	
	Likelihood			High	
	Other			Other: -	
	Significance			Negligible	
Reef effect	Importance		Minor	Negligible	Minor
	Magnitude		Minor	Negligible	Minor
	Persistence		-	Permanent	-
	Likelihood		High	High	High
	Other		Other: -	Other: -	Other: -
	Significance		Negligible	Minor - positive	Negligible
Cumulative effects	Importance	Local	Local	Local	Local
	Magnitude	Negligible	Minor	Negligible	Minor
	Persistence	Temporary-short	Temporary	Permanent	Temporary
	Likelihood	Low	Low	Low	Low
	Other	Other: -	Other: Direct	Other: -	Other: Direct
	Significance	Negligible	Negligible	Negligible	Negligible

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