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Horns Rev 3 Offshore Wind Farm

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MARINE MAMMALS

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SUMMARY

The construction of a third offshore wind farm is planned for the Horns Rev area about 20-30 km northwest of the westernmost point of Denmark, Blåvands Huk. 40 to 136 turbines (range of 3.0 to 10.0 MW) with an overall capacity of maximal 400 MW shall be erected in an area of approximately 160 km^2.

The aim of this study is an environmental impact assessment on possible effects on the three marine mammal species harbour porpoise (*Phocoena phocoena*), harbour seal (*Phoca vitulina*) and grey seal (*Halichoerus grypus*) present in the Danish Wadden Sea. For this the abundance and distribution of harbour porpoise was assessed using aerial surveys and passive acoustic monitoring devices (C-PODs). Maps of modelled harbour porpoise distribution were combined with modelled noise maps, showing the area in which effects of pile driving noise can be expected. For seals data of an aerial survey were re-analysed.

The Horns Rev area has been identified to inhabit high numbers of harbour porpoises in previous studies. Maximum densities of up to 20 porpoises/km² have been estimated for the greater Horns Rev area. In this study densities of up to 6.4 porpoises/km² have been registered inside the planned Horns Rev 3 offshore wind farm. Numbers were particularly high in summer when harbour porpoises give birth and mate therefore the area is assumed to be of very high importance.

The number of seals in the area was rather low with 97 harbour seals and 15 unidentified seals in ten survey flights in 2013. There are no haul-out sites close to the Horns Rev 3 area and the area does not seem to have any special importance for harbour and grey seal.

The largest piles that might be installed at the Horns Rev 3 wind farm are expected to be 10 m in diameter. The impact assessment is based on this worst-case scenario while the actual turbine and foundation have not been selected. Noise level of single-strike piling with 3000 kJ is predicted at 181 dB_{SEL} at 750 m distance during pile driving. This effect is only reached at the end of the piling just before the monopile reach maximum depth. The model based on these numbers was calculated for pile driving at two different positions showing the distance in which the sound exposure level falls below defined threshold. The radius in which temporary threshold shifts in harbour porpoises could be expected would extend to 5 to 6 km depending on the location. In seals this area would come to less than 2 km due to the higher TTS threshold. The area in which behavioural reactions would be expected expands to 20 to 25 km around the pile driving activity. The number of harbour porpoises affected by noise of at least 145 dB_{SEL} (behavioural threshold) was estimated to be about 3800-4900 in summer and about 700 to 1000 in winter. Calculations for cumulative noise exposures indicate that porpoise being present in a range of 5-10 km around the construction site would receive noise levels which may induce PTS. For seals this range would be around 2 km.

Habitat loss and habitat change were considered to be negligible for harbour porpoise, harbour seal and grey seal on basis of literature data. Positive effects might occur due to artificial reef structures that might improve the food resources and due to shelter effects. Disturbance might occur due to operational noise of the turbines but the noise levels are low and only detectable above background level at low frequencies below 1000 Hz. Effects on harbour porpoises and seals are considered negligible.

Due to the fact that noise emissions reach levels which may induce PTS in harbour porpoise it is concluded that the project would violate the demands of Art.12 habitats directive unless active noise mitigation is applied. This will only apply in the worst case scenario during ramming of monopiles for the large 10 MW turbines.

Harbour porpoise – mother and calf © Carline Höschle

SAMMENFATNING

Der er planlagt etableret en tredje havmøllepark i Horns Rev området ca. 20 – 30 km ud for Danmarks vestligste punkt Blåvands Huk. Havmølleparken får en samlet kapacitet på maksimalt 4.000 MW, og vil komme til at bestå af 40 til 136 havmøller hver med en kapacitet på mellem 3,0 og 10,0 MW. Havmølleparken skal etableres inden for et projektområde på ca. 160 km^2

Formålet med dette studie er at vurdere de miljømæssige konsekvenser for tre arter af havpattedyr, der alle er almindelige i den danske del af Vadehavet. Det drejer sig om marsvin (*Phocoena phocoena*), spættet sæl, (*Phoca vitulina*) og gråsæl (*Halichoerus grypus*). Udbredelsen og forekomsten af disse arter er kortlagt ved hjælp af flytællinger og udlægningen af passive akustiske bøjer (C-PODS). Den modellerede kortlægning af udbredelsen af marsvin er kombineret med den modellerede støjkortlægning. Herved kan størrelsen af det areal beregnes, inden for hvilken marsvinene kan forventes at blive påvirket af støj fra nedramning af fundamenter.

Tidligere undersøgelser har vist, at Horns Rev området rummer et stort antal marsvin. De største tætheder, der er registreret i det samlede Horns Rev område er på ca. 20 marsvin/km^2. I forbindelse med denne undersøgelse er der inden for projektområdet fundet tætheder på indtil 6,4 marsvin/km^2. Antallet var specielt højt i marsvinenes kælvnings- og parringstid hen over sommeren. Det er derfor antaget, at området er af stor betydning for marsvin.

Antallet af sæler er relativt lavt inden for området, og der blev i alt kun registreret 97 spættede sæler og 15 uidentificerede sæler ved de ti kortlægninger i løbet af 2013. Der findes ingen rastepladser (haul-outs) i nærheden af Horns Rev 3 projektområdet, og området synes generelt ikke at have større betydning for hverken spættet sæl eller gråsæl.

De største fundamenter (monopiles) som forventes installeret i forbindelse med havmølleparken Horns Rev 3 vil have en diameter på 10 m. Der er ikke truffet endelig valg af hverken fundamenttype eller størrelsen af havmøllerne, hvorfor vurderingerne af effekterne er baseret på det værst tænkelige scenarie. Under nedramningen af fundamentet er støjen fra et enkelt slag med en effekt på 3.000 kJ fra den hydrauliske hammer estimeret til 181 dB$_{SEL}$ inden for en afstand af 750 m. Denne effekt opnås først i slutningen af ramningsperioden lige inden monopælen når den maksimale dybde. Under anvendelse af disse værdier er lydudbredelsen blevet modelleret for to forskellige positioner, hvor støjpåvirkningen falder inden for definerede grænseværdier. Det er vurderet, at en midlertidig hørenedsættelse (TTS) for marsvin kan forventes inden for en radius på mellem 5 og 6 km fra ramningsstedet. Lydudbredelsens karakter vil dog afhænge af ramningsstedets position. På grund af sælernes højere høretærskel (TTS) vil disse kun blive påvirket inden for en radius på mindre end 2 km.

Inden for et areal, der ligger i en afstand på 20 til 25 km fra ramningsstedet, kan marsvin forventes at udvise adfærdsændringer. Antallet af marsvin, der forventes påvirket af støj på mindst 145 dB$_{SEL,}$ hvilket er grænsen for adfærdsmæssige forstyrrelser, er i sommerperioden vurderet til at ligge på 3.800-4.900 individer og i vinterperioden på 700-1.000 individer. Beregninger af den akkumulerede støjpåvirkning indikerer, at marsvin, der befinder sig inden for en radius af 5-10 km fra anlægsområdet, kan risikere at blive udsat for

et støjniveau, der kan resultere i en permanent hørenedsættelse (PTS). Den tilsvarende grænse for sæler ligger på omkring 2 km.

På baggrund af litteraturen er habitattab og habitatændringer, som følge af etableringen af havmølleparken vurderet til at være ubetydelige for både marsvin og sæler. Dog vil der kunne være en positiv effekt af de kunstige revstrukturer, som kan bidrage til en forøgelse af fødegrundlaget.

Forstyrrelser fra støj kan forekomme i driftsfasen. Dog er støjen fra møllerne lav og kun hørbar for pattedyrene ved lave frekvenser under 1.000 Hz. Påvirkningen af marsvin og sæler i driftsfasen anses for ubetydelig.

Som en følge af, at støjpåvirkningen kan nå et niveau, som kan medføre permanente høreskader hos marsvin, er det konkluderet, at projektet kan være i konflikt med beskyttelseskriterierne i artikel 12 i habitatdirektivet, med mindre der implementeres de nødvendige afværgeforanstaltninger. Dette vil dog kun gælde i den værst tænkelige situation ved ramning af monopiles til de store 10 MW møller.

Harbour seal inside the Horns Rev 1 Offshore Wind Farm

1. INTRODUCTION

In 1996 the Danish Government passed a new energy plan, ‘Energy 21’, that stipulates the need to reduce the emission of the greenhouse gas CO_2 by 20% in 2005 compared to 1988. Energy 21 also sets the scene for further reductions after the year 2005 (Miljø- og Energiministeriet 1996).

The number of offshore wind farms (OWF) is steadily increasing in Denmark and the rest of Europe due to the high demand, both economically and politically, for renewable energy. Denmark plans to establish OWFs with a total capacity of 4,400 MW (Energistyrelsen 2011). The overall aim is the contribution of offshore wind energy to as much as 50% of the total national consumption of electricity in 2025. The energy generated from OWFs was approximately 665 MW in 2012 (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 OWFs 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 construction of the wind farms. A series of studies on the environmental conditions and possible impacts from the OWFs were undertaken to ensure that offshore wind power does not have damaging effects on the natural ecosystems. These environmental studies are of major importance for the establishment of new wind farms and extensions of existing OWFs like Nysted and Horns Rev 1.

Prior to the construction of the demonstration wind farms at Nysted and Horns Rev, a number of baseline studies were carried out in order to describe the environment before the construction. The studies were followed up by investigations during and after the construction phase, and environmental impacts were assessed. Detailed information on methods and conclusions of these investigations can be found at http://www.ens.dk/en/supply/renewable-energy/wind-power/offshore-wind-power/environmental-impacts.

In March 2011 it was agreed on the construction of two new OWFs:

- Horns Rev 3 (400 MW)
- Kriegers Flak (600 MW)

With orders from the Danish Energy Agency (ESA), Energinet.dk has to perform and contract the preparation of background reports, impact assessment and environmental impact statements for the two wind farms.

The present report comprises the results of the baseline investigations and the impact assessment of the possible impacts from construction, operation and decommissioning of the Horns Rev 3 OWF on marine mammals. The impact assessment covers the impacts from construction works and operation of the wind farm itself as well as the installation and operation of the subsea cables within the wind farm and from the transformer platform to land.

The assessment is based on the dedicated aerial surveys and acoustic studies conducted in the Horns Rev 3 area since January 2013 and available information and data from other studies conducted in the greater Horns Rev area in the past decade. The results of these studies supplement the data collected during this study to describe abundance and distribution of marine mammals in the area. Also the sensitivity of the marine mammal species to different pressures from construction and operation of an OWF was conducted based on literature wherever possible.

1.1. Description of the wind farm area

The planned Horns Rev 3 OWF is located north of Horns Rev in a shallow area in the eastern North Sea, about 20-30 km northwest of the westernmost point of Denmark, Blåvands Huk. The pre investigation area in which the wind farm shall be constructed is approximately 160 km^2. Depending of the final layout the wind farm will cover 70-90 km^2. To the west it is delineated by gradually deeper waters, to the south/southwest by the existing OWF Horns Rev 2, (Figure 1.1).

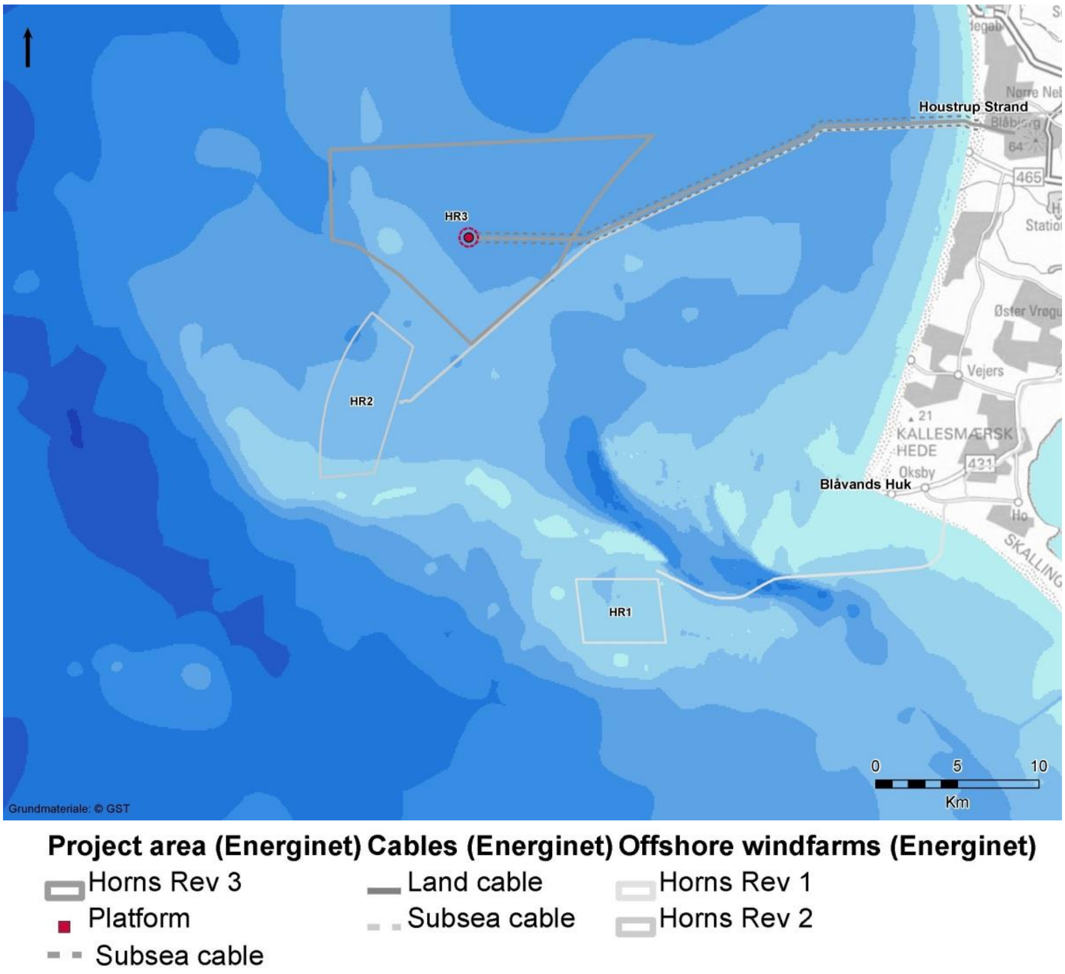

Figure 1.1: Location of the Horns Rev 3 OWF and the projected corridor for export cables towards shore.

In the middle of the Horns Rev 3 area there is a zone occupying 30–35 % of the area that is classified as a former WWII minefield oriented ‘no fishing, no anchoring zone’. Also, just south/southeast of the Horns Rev 2 export cable an existing military training field is delineated. In 2012 the engineering consultant NIRAS completed a desk study on potential UXO (UneXploded Ordnance) contaminations in the Horns Rev 3 area. For the central and eastern parts of the area the report concludes a medium to high UXO threat is present, while for the western part of the Horns Rev 3 area the report concludes a low UXO threat is present.

The water depths in the Horns Rev 3 area vary between app. 10-21 m (Figure 1.2). The Bathymetric map of the Horns Rev 3 area shows depths below DVR90 (**D**anish **V**ertical **R**eference 19**90**) as graded colour. The DVR90 is used as a standard reference for heights above (or below) sea level in Denmark and is based on the defined mean sea level of 1990. The map is based upon the Geophysical survey in 2012.

The minimum water depth is located on a ridge in the southwest of the site and the maximum water depth lies in the north of the area. Sand waves and mega-ripples are observed across the site.

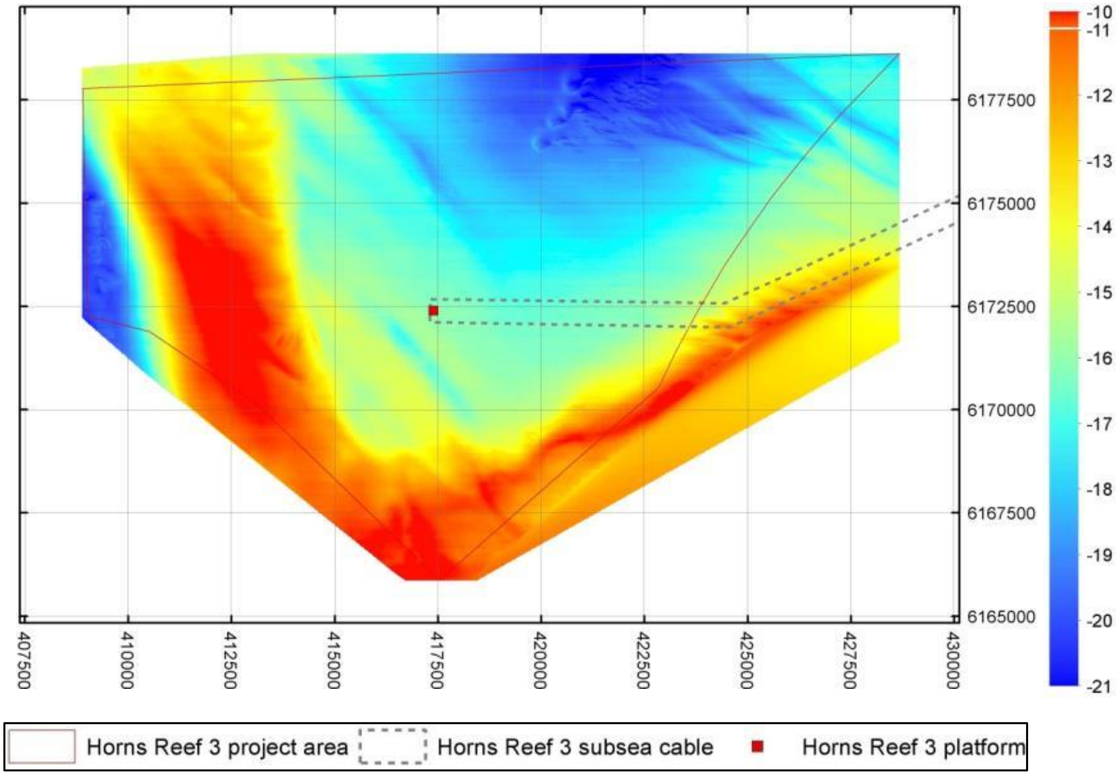

Figure 1.2: Bathymetric map of the Horns Rev 3 area showing depths below DVR90 as graded colour. The map is based upon the Geophysical survey in 2012.

1.2. The turbines

The maximum rated capacity of the wind farm will be limited to 400 MW. The type of turbine and foundation has not yet been decided, however, the wind farm will feature from 40 to 136 turbines depending on the rated energy of the selected turbines corresponding to the range of 3.0 to 10.0 MW.

The 3 MW turbine was launched in 2009 and is planned to be installed at the Belgium Northwind project. The 3.6 MW turbine was released in 2009 and has since been installed at various wind farms, e.g. Anholt Offshore Wind Farm. The 4 MW turbines are gradually taking over from the 3.6 MW on coming offshore wind farm installations. The 6 MW was launched in 2011 and the 8 MW was launched in late 2012, both turbines are being tested and may be relevant for Horns Rev 3 OWF. A 10 MW turbine is under development which may also be relevant for Horns Rev 3 OWF. There is a possibility that more than one turbine model will be installed due to the rapid development of the wind turbine industry and a construction program that can be spread over more than one year.

Suggested layouts for different scenarios are presented in Figure 1.3 to Figure 1.11 below. The layouts are made for 3 MW, 8 MW and 10 MW, respectively – and for three different locations of the turbines; closest to the shore (easterly in pre-investigation area), in the centre of the pre-investigation area, and in the western part of the pre-investigation area.

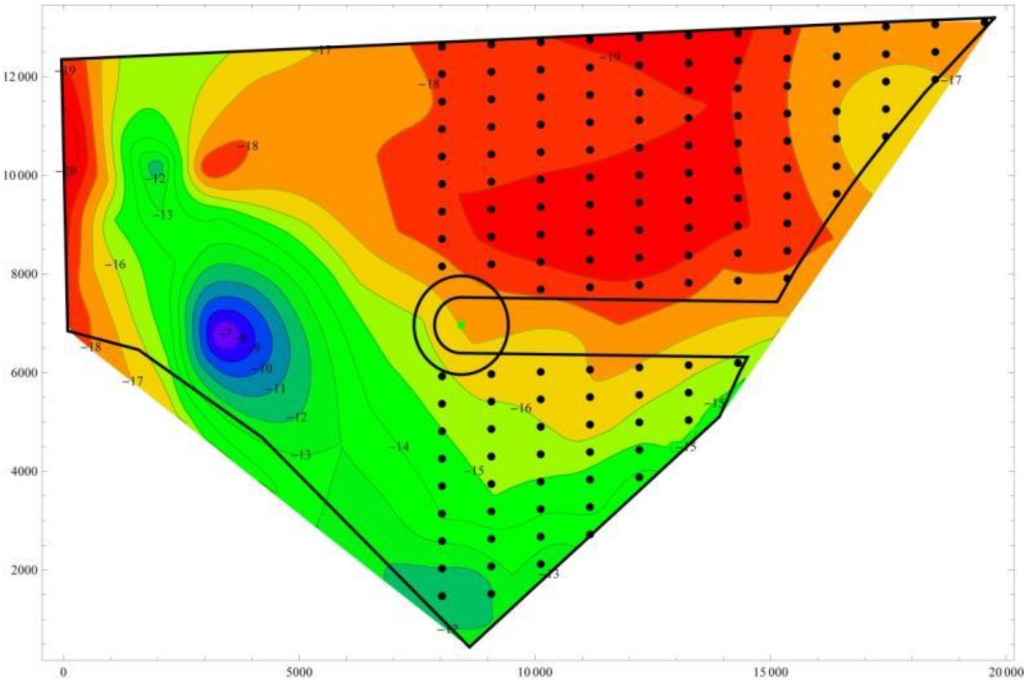

Figure 1.3: Suggested layout for the 3.0 MW wind turbine at Horns Rev3, closest to shore.

It is expected that turbines will be installed at a rate of one every one to two days. The works would be planned for 24 hours per day, with lighting of barges at night, and accommodation for crew on board. The installation is weather dependent so installation time may be prolonged in unstable weather conditions.

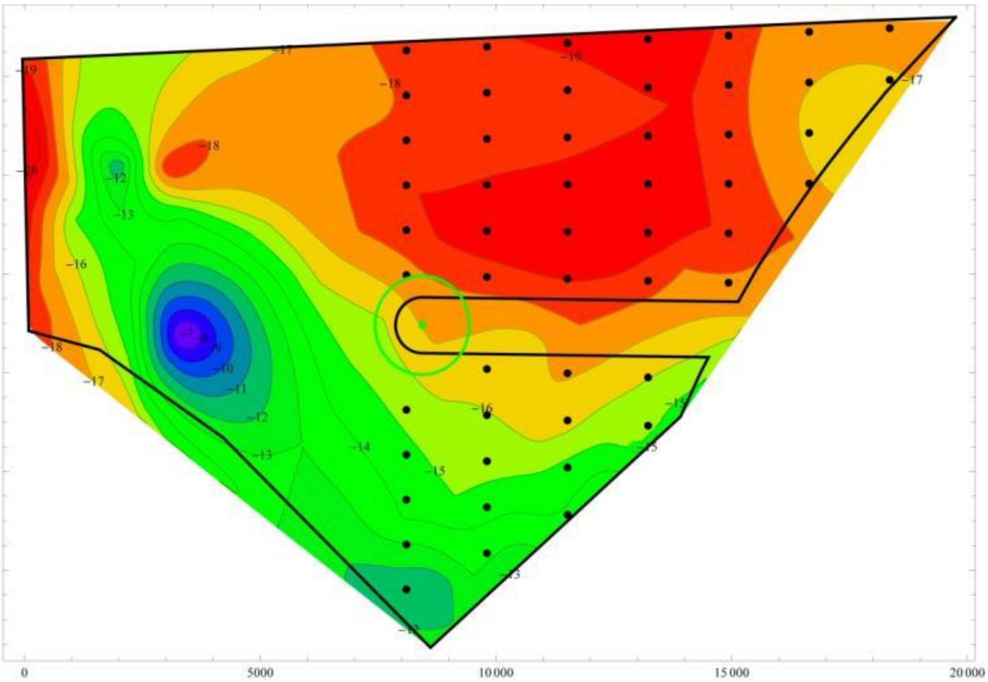

Figure 1.4: Suggested layout for the 8.0 MW wind turbine at Horns Rev 3, closest to shore.

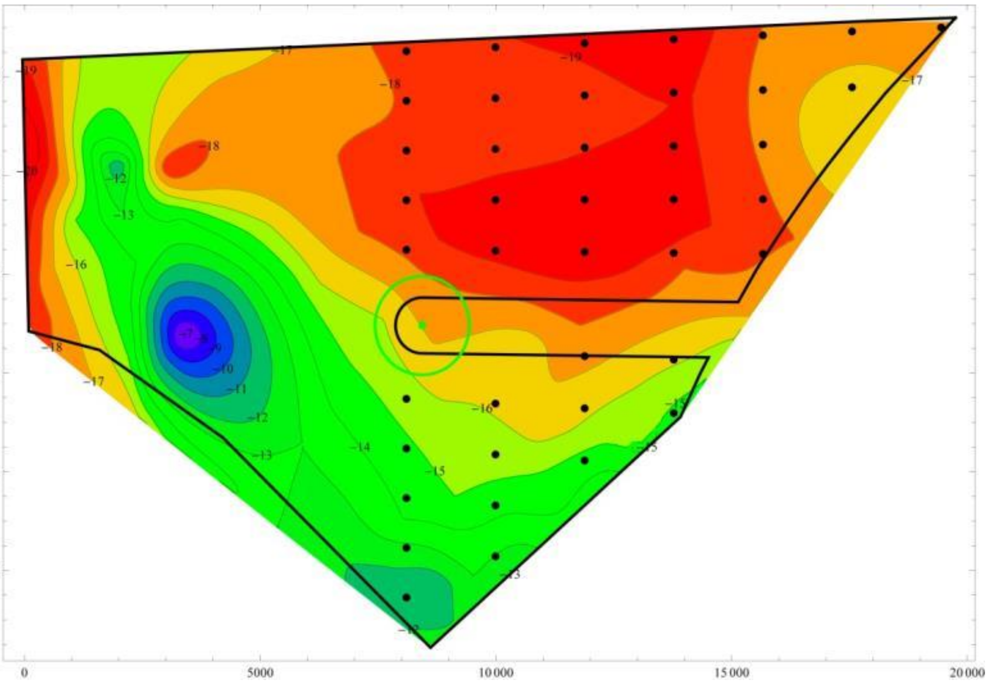

Figure 1.5: Suggested layout for the 10.0 MW wind turbine at Horns Rev 3, closest to shore.

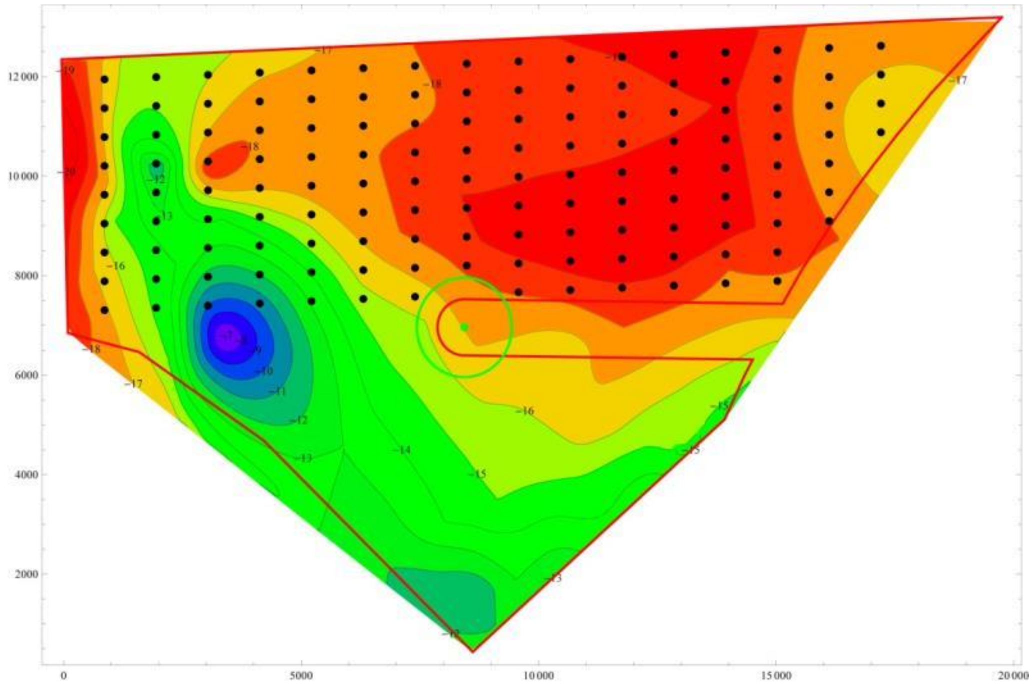

Figure 1.6: Suggested layout for the 3.0 MW wind turbine at Horns Rev 3, located in the centre of the area.

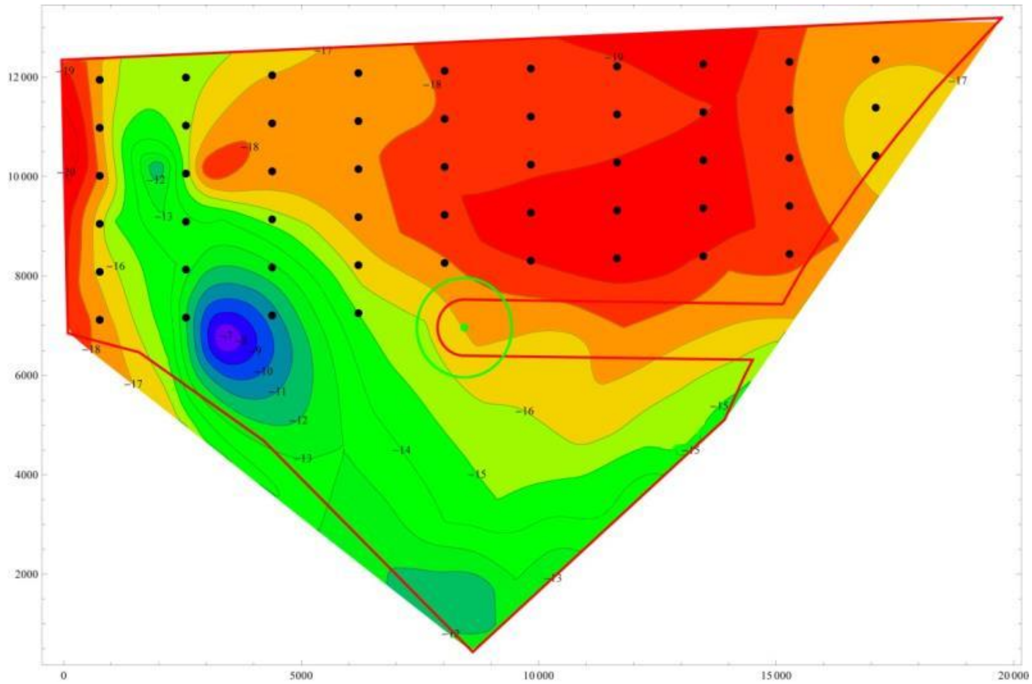

Figure 1.7: Suggested layout for the 8.0 MW wind turbine at Horns Rev 3, located in the centre of the area.

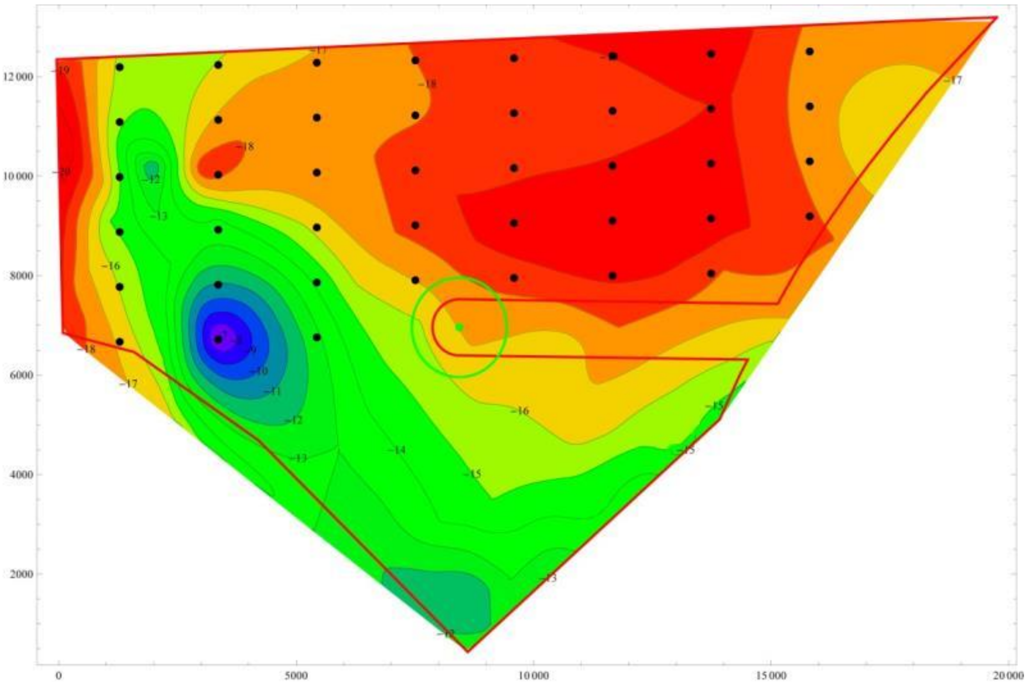

Figure .1.8: Suggested layout for the 10.0 MW wind turbine at Horns Rev 3, located in the centre of the area.

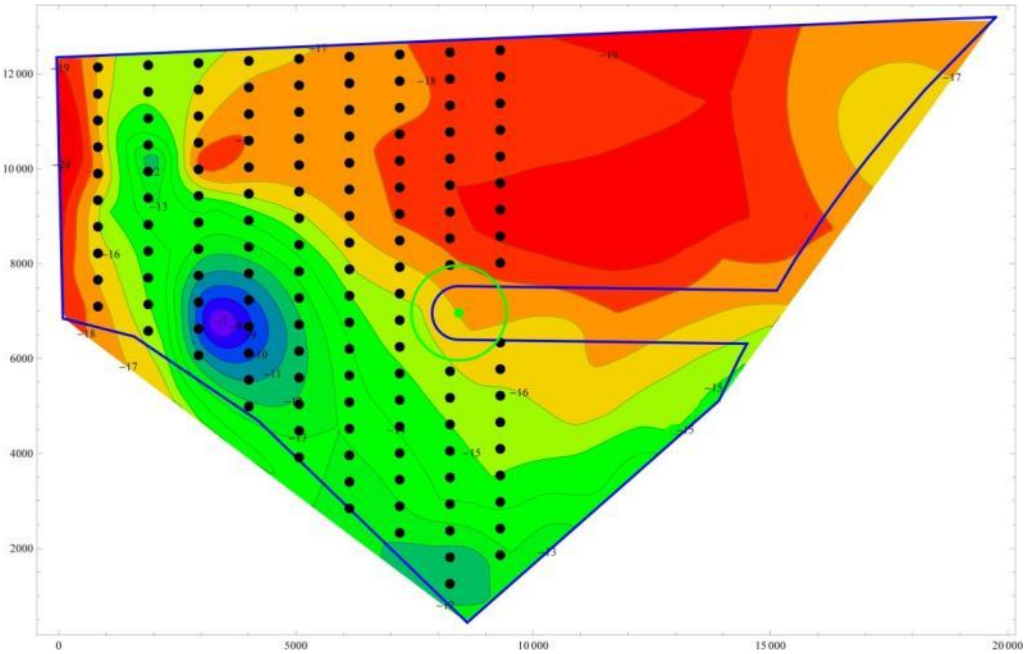

Figure.1.9: Suggested layout for the 3.0 MW wind turbine at Horns Rev 3, located most westerly in the pre-investigation area.

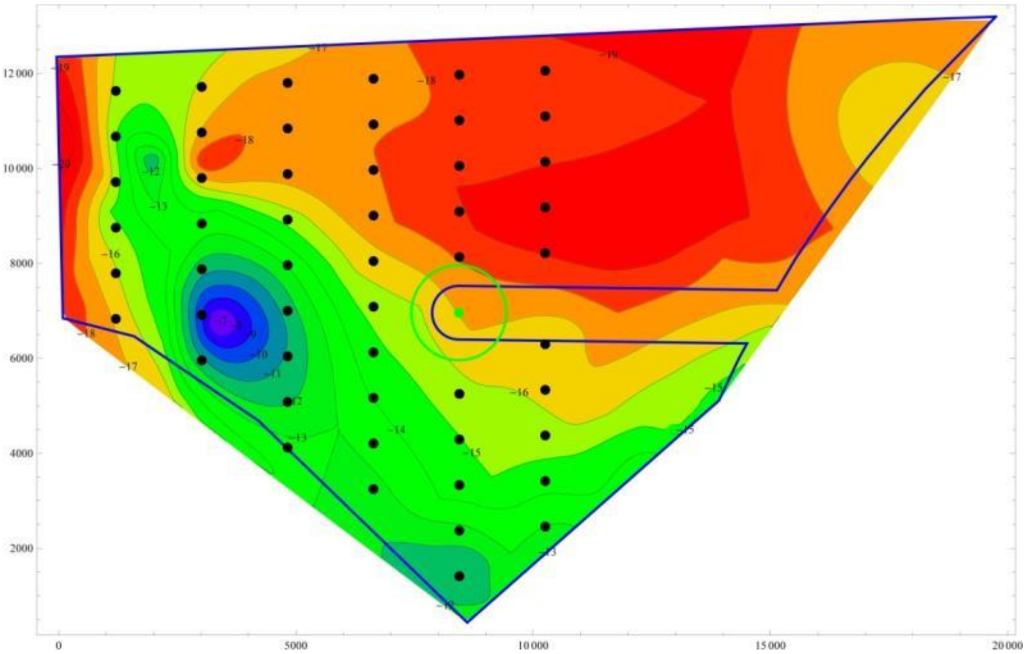

Figure 1.10: Suggested layout for the 8.0 MW wind turbine at Horns Rev 3, located most westerly in the pre-investigation area.

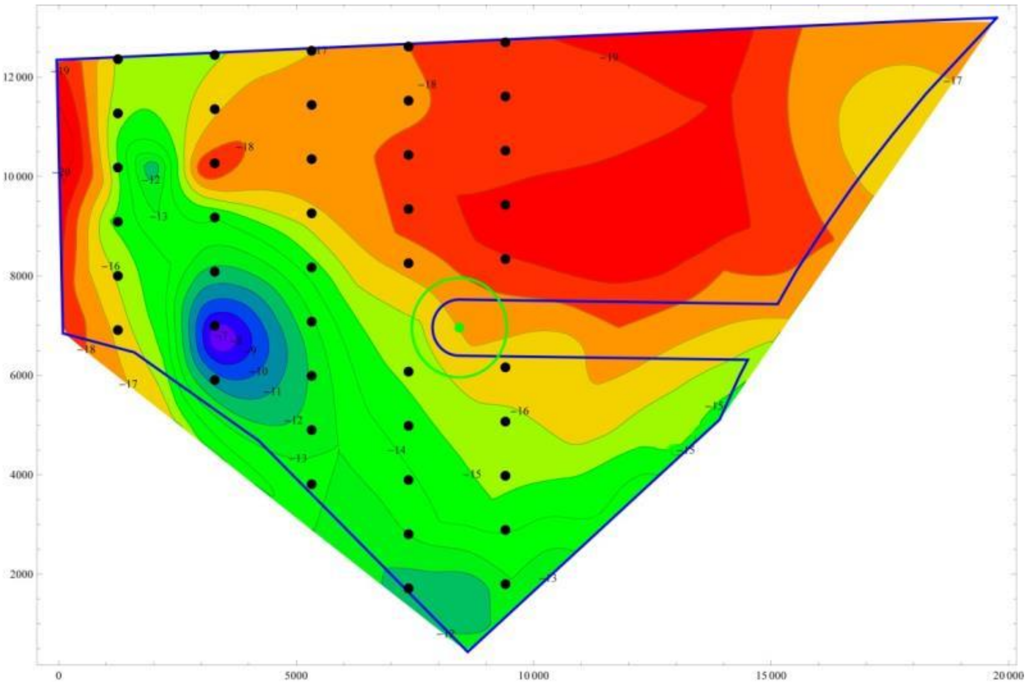

Figure 1.11: Suggested layout for the 10.0 MW wind turbine at Horns Rev 3, located most westerly in the pre-investigation area.

1.3. Foundations

The wind turbines will be supported by foundations fixed to the seabed. It is expected that the foundations will comprise one of the following options:

- Driven steel monopile
- Concrete gravity base
- Jacket foundations
- Suction buckets

1.3.1.Driven steel monopile

Monopiles have been installed at a large number of wind farms in the UK and in Denmark e.g. Horns Rev 1, Horns Rev 2 and Anholt OWF. The solution comprises driving a hollow steel pile into the seabed. The monopile, for the relevant sizes of turbines (3-8 MW), is driven 25 – 35 m into the seabed and has a diameter of 4.5 – 8 m. The pile diameter and the depth of the penetration are determined by the size of the turbine and the sediment characteristics. As a worst case scenario a diameter of 10 m is assumed.

A scour protection filter layer may be installed prior to pile driving and after installation of the pile, a second layer of scour protection may be installed. Scour protection of nearby cables may also be necessary. Scour protection is especially important when the turbine is situated in turbulent areas with high flow velocities.

The underwater noise generated by pile driving during installation has been measured and assessed during construction of wind farms in Denmark, Sweden and England. The noise level and emission will depend among other things on the pile diameter and seabed conditions. An indicative source level of the pile driving operation would be in the range of 220 to 260 dB re 1 µPa at 1 meter. However, the maximum effect of the hydraulic hammer will only apply at the end of the ramming just before the monopile reach the maximum depth.

1.3.2.Concrete gravity base

These structures rely on their mass including ballast to withstand the loads generated by the offshore environment and the wind turbine.

The gravity base concept has been used successfully at operating wind farms such as Middelgrund, Nysted, Rødsand II and Sprogø in Denmark, Lillgrund in Sweden and Thornton Bank in Belgium.

Normally, seabed preparation is needed prior to installation, i.e. the top layer of material upon the seafloor is removed and replaced by a stone bed. When the foundation is placed on the seabed, the foundation base is filled with a suitable ballast material, and a steel “skirt” may be installed around the base to penetrate into the seabed and to constrain the seabed underneath the base.

The ballast material is typically sand, which is likely to be obtained from an offshore source. An alternative to sand can be heavy ballast material, which has a higher density than natural sand. For a given ballast weight, using heavy ballast material will result in a reduction of foundation size, which may be an advantage for the project.

Noise emissions during construction are considered to be small.

1.3.3.Jacket foundations

Jacket foundation structures are three or four-legged steel lattice constructions in the shape of a square tower. The jacket structure is supported by piles in each corner of the foundation construction.

The jacket foundation has been used successfully at operating wind farms such as in the East Irish Sea, the North Sea and the Baltic Sea.

The construction is built of steel tubes with varying diameters depending of their location in the lattice structure. The three or four legs of the jacket are interconnected by cross bonds, which provide the construction with sufficient rigidity.

Fastening the jacket with piles in the seabed can be done in several ways:

- Pilling inside the legs
- Pilling through pile sleeves attached to the legs at the bottom of the foundation structure
- Pre-pilling by use of a pile template

Scour protection of the foundation piles and cables may be applied depending on the seabed conditions. In sandy sediments, scour protection is normally considered necessary in order to protect the construction from bearing failure. Scour protection consists of natural well graded stones

1.3.4.Suction bucket

The suction bucket foundation is a relatively new concept and is a quality proven hybrid design which combines aspects of a gravity base foundation and a monopile in the form of a suction caisson.

The bucket foundation is said to be “universal”, in that it can be applied to and designed for various site conditions. Homogeneous deposits of sand and silts, as well as clays, are ideal for the suction bucket concept.

Layered soils are likewise suitable strata for the bucket foundation. However, installation in hard clays and tills may prove to be challenging and will rely on a meticulous penetration analysis, while rocks are not ideal soil conditions for installing the bucket foundation.

The concept has been used offshore for supporting met masts at Horns Rev 2 and Dogger Bank. Bucket foundations are targeted for 2015/2016 in relation to wind turbines.

As a proven suction bucket design concept for the turbines involved in Horns Rev 3 does not yet exist, suction buckets are here assumed to have same plate diameter as gravity foundations for the respective turbines. However, it is expected that the maximum height of the installed bucket foundation will not rise more than 1m above the surrounding seabed.

1.4. Scour protection

Monopile solution

Depending on the hydrodynamic environment, the horizontal extent of the armour layer can be seen according to experiences from former projects in ranges between 10 and 15 meter having thicknesses between 1 and 1.5m. Filter layers are usually of 0.8m thickness and reach up to 2.5m further out than the armour layer. Expected stone sizes range between d_{50} = 0.30m to d_{50} = 0.5m. The total diameter of the scour protection is assumed to be 5 times the pile diameter.

Gravity base solution

Scour protection may be necessary, depending on the sediment properties at the installation location. The envisaged design for scour protection may include a ring of rocks around the structure.

Jacket solution

Scour protection may be installed as appropriate by a Dynamically Positioned Fall Pipe Vessel and/or a Side Dumping vessel. The scour protection may consist of a two layer system comprising filter stones and armour stones. Nearby cables may also be protected with filter and armour stones. The effect of scour may be incorporated into the foundation design, in which case scour protection can be neglected.

Suction bucket solution

Scour protection of the bucket foundations and cables may be necessary, depending on the seabed conditions at the installation locations. Scour protection may consist of natural well graded stones around the structure, but during detailed foundation design, it might be determined that scour protection is unnecessary.

Alternative scour protection solutions

Alternative scour protection systems such as the use of frond mats may be introduced by the contractor. Frond mats contain continuous rows of polypropylene fronds which project up from the mats and reduce scour.

Another alternative scour protection system is the use of sand filled geotextile bags around the foundations. This system is planned to be installed at the Amrumbank West OWF during 2013, where some 50,000t of sand filled bags will be used around the 80 foundations. Each bag will contain around 1.25t of sand. If this scour protection system is to be used at Horns Rev 3, it will employ around 31,000 to 84,000t of sand for the 50-133 turbine foundations.

1.5. Subsea cables

A medium voltage inter-array cable will be connected to each of the wind turbines and for each row of 80-10 wind turbines a medium voltage cable is connected to the transformer station. The medium voltage is expected to be 33 kV (max. voltage 36 kV), but 66 kV (max. voltage 72 kV) is also possible.

The inter-array cables may be protected with bending restrictors at each J-tube. Scour protection shall also be considered for protecting the cables if exposed.

A 220 kV transmission cable will be installed from the offshore transformer station to the connection point on land – landfall – at Blåbjerg Substation. The length of the transmission cable can be up to 38 km depending on the final position of the transformer station.

Depending on the final position is it most likely that the transmission cable will follow either the northern border of the park or aligned in parallel with the existing transmission cable from Horns Rev 2.

1.6. Electromagnetic fields

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

Harbour porpoise inside the Horns Rev 1 Offshore Wind Farm

2. METHODS

Harbour porpoises and seals were counted using aerial surveys in the area. Additionally passive acoustic monitoring was used to determine the acoustic activity of harbour porpoises.

2.1. Aerial surveys

Baseline aerial surveys were conducted using the German “Standards for the Environmental Impact Assessment” for offshore wind farms (BSH 2007) as guidance. The survey methodology closely followed a line transect survey technique with distance measured as angles as applied elsewhere during several EIA studies and monitoring programmes (e.g. Noer et al. 2000, Diederichs 2002, Piper et al. 2007, Petersen & Fox 2007).

2.1.1.Survey planes

For safety reasons only twin-engine high-wing planes of the type Partenavia P-68 Observer with professional pilots by Bioflight A/S (Holte) were chartered for the aerial surveys. The main observers use bubble-windows. In this type of aircraft the third observer is seated directly behind the two main observers, changing sides depending on best observation conditions (Figure 2.1).

Figure 2.1: Survey plane Partenavia P68 Observer. Photo: Kasper Roland Høberg.

2.1.2.Aerial survey design

The Horns Rev 3 study area for the aerial surveys comprised 2,663 km². In the East it follows the coast line between south of Blåvands Huk in the South and about 5 km south of Hvide Sande in the North. To the West the study area extends to 52-59 km offshore.

Thus, the Horns Rev 3 study area ends north of Horns Rev 1 wind farm, but covers the area of the Horns Rev 2 wind farm. Water depth varies up to a maximum of 35 m (Figure.2.2).

Line transect methodology was used for counting the marine mammals following the Distance sampling approach of Buckland et al. (2001). A total of 12 parallel transect lines in East-West orientation were used with a 4 km spacing between the lines. All survey flights were conducted in an altitude of 250 ft (76 m). Birds and marine mammals were recorded during the same survey flights.

Lengths of individual transects ranged from 52.5-58.8 km. The total transect length was approximately 685 km. Due to different reasons (e.g. active military areas, weather conditions) the achieved survey effort varied amongst surveys completed in different months. The transect design is shown in Figure.2.2, which also shows the military areas where conducting of surveys was restricted if the areas were active at that particular day. Whenever possible surveys were conducted on days without military activities or transect parts within the closed military areas were flown either if the military gave a permit to enter the area for a short period during the active time or it was possible to finish the transect lines after the military opened the area in the evening.

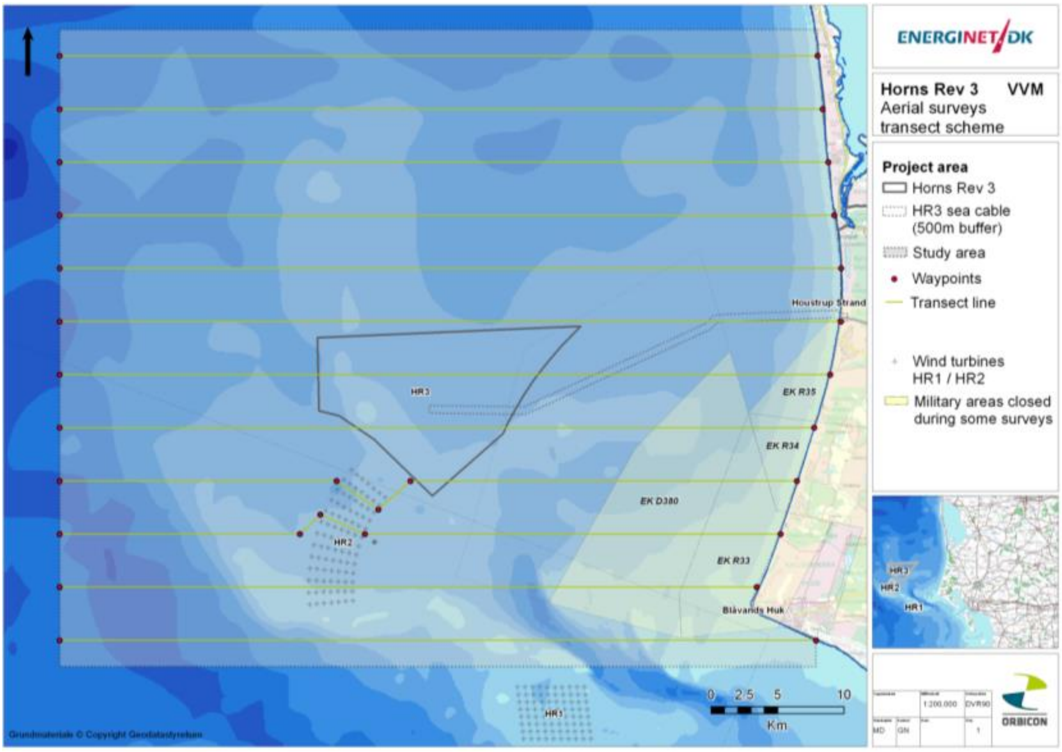

Figure.2.2: Aerial transect survey scheme in the Horns Rev 3 area.

2.1.3.Recording techniques

Three experienced observers recorded marine mammals and birds during the surveys: two main observers sitting next to the bubble windows (which allow also observations directly underneath the plane). The third observer was placed at a normal window behind of the main observers (no observations directly underneath the plane possible). The third observer changed the seat between transect lines, depending which side provided the better observation conditions (usually observing towards North). Observers used headsets and did not communicate with each other while on transect. While on transect the observers continuously observed the area for marine mammals and birds. For every observation the exact time was noted (UTC, synchronised with an on-board GPS) and recorded on a dictaphone. Perpendicular distances from transect were measured in inclination angles. Strips, as indicated in the sketch below (Figure 2.3) were not used for marine mammals, but for recording birds.

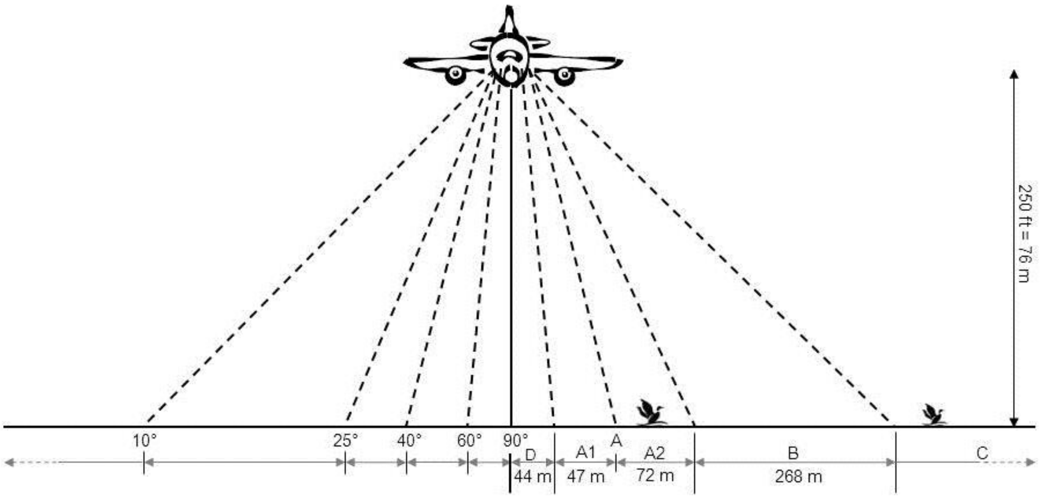

Figure 2.3: Standardised aerial survey method for counting resting birds.

From the angle and the aircrafts altitude the perpendicular distance to the sighting was calculated. For every observation the following information was recorded: Species (group), number, behaviour, distance angle, associations, at or below surface. The flight-track was logged and stored continuously in 3 second intervals by the GPS. Further details of the aerial survey techniques used can be found in Diederichs et al. (2002), Christensen et al. (2006), and Piper et al. (2007).

Weather conditions (sea state, glare, cloud reflections, cloud coverage, precipitation and water turbidity) were recorded at the start of each transect line and whenever conditions changed. Additionally all vessels and fishing equipment observed were recorded (including information on type, distance to the transect line and heading).

Data were only collected in good survey conditions (Douglas sea states below Beaufort 3, visibility more than 5 km). Survey speed was approximately 100 kn (185 km/h, 115 mph).

2.1.4.Aerial survey effort

Aerial survey effort (one-sided valid effort in km) varied among the different surveys (Table 2.1). Depending on weather conditions (especially sun glare) transect lines could either be covered in 1- or 2-sided valid effort. Transect lines or parts of it are regarded as covered with either 1-sided or 2-sided valid effort. Ten aerial surveys were carried out between January and November 2013.

Table 2.1: Aerial survey effort (valid effort for marine mammal observations, sum of both main observers in km) between January 2013 and November 2013.

Date of survey	Valid effort (km)
16.01.2013	878
13.02.2013	1360
04.03.2013	930
01.04.2013	851
07.05.2013	817
05.06.2013	313
06.07.2013	795
22.08.2013	921
13.09.2013	963
17.11.2013	1151

2.2. Passive acoustic monitoring

Visual methods that are effective in giving information about large-scale distribution and abundance have limits when it comes to temporal and spatial resolution of the results. In contrast to aerial and ship-based surveys stationary passive monitoring stations can record continuously and are independent of weather or diel light conditions. This methodology is therefore widely used to investigate rare or deep diving species, even in isolated or rough environments (Tougaard et al. 2003). Since harbour porpoises are highly vocal animals emitting echolocation clicks almost continuously (Akamatsu et al. 2007, Linnenschmidt et al. 2012a) passive acoustic monitoring is an ideal method to study these animals at a very high temporal resolution.

Generally, water is a very good acoustic conductor but the absorption rate is frequency dependent. Thus, the detection radius depends on the frequency range of the animals in question, the physical properties of the water body and the restrictions of the used technology (approx. 300 m C-PODs - Tregenza 2011, Gauger et al. 2012). Even though a close connection between detection rates and absolute densities could be shown by different authors (Siebert & Rye 2009, Kyhn et al. 2012), no direct translation of passive acoustic monitoring data into absolute densities is available yet. Acoustic datasets are therefore often combined with results from visual surveys, which cover larger areas but only represent a snap-shot in time (Tougaard et al. 2003, Diederichs et al. 2004, 2009, Verfuß et al. 2007a). Following this design six stationary passive acoustic monitoring stations (PAM-stations) were deployed over a period of twelve months in addition to ten aerial surveys conducted in the same time. Passive acoustic data can be used as a measure for relative porpoise abundance using acoustic detections as a proxy for harbour porpoise presence. Seasonal and diel variations in harbour porpoise presence are indicators for habitat use and the ecologic importance of the Horns Rev area.

2.2.1.Echolocation of harbour porpoise

Harbour porpoises clicks are relatively short and tonal sounds (Schevill et al. 1969) that are emitted in a narrow beam width (16° in the vertical and horizontal plane; Au et al. 1999, Au et al. 2006) with dominant narrow-band, high-frequency click components within 110 -150 kHz (Møhl & Andersen 1973, Verboom & Kastelein 1995, 1997, Au et al. 1999, Teilmann et al. 2002, Villadsgaard et al. 2007). These clicks are emitted in series – so-called click-trains - which can be identified and classified into different behavioural categories, including orientation (Verfuß et al. 2005, Koschinski et al. 2008), prey capture (Verfuß & Schnitzler 2002, Verfuß et al. 2009, DeRuiter et al. 2009) and communication (Verboom & Kastelein 1997, Koschinski et al. 2008, Clausen et al. 2010). For example while approaching prey clicks succeed in longer intervals getting rapidly shorter down to 2 µs during prey capture (DeRuiter et al. 2009). For communication short inter-click-intervals of < 2 ms are used (Clausen et al. 2010) whereas approaching landmarks results in a slow but steady decrease of click intervals (Koschinski et al. 2008). However, a lot of the recorded click-trains cannot be clearly assigned to these behavioural categories.

2.2.2.C-POD components and recordings

In European Waters one of the most commonly used device to study porpoises is the T-POD and its successor the C POD (Chelonia Ltd., Tregenza 2011, Verfuß et al. 2007b, Kyhn et al. 2008, Brandt et al. 2011a, Dähne et al. 2013). The C-POD (Figure 1) is made up of an underwater microphone (hydrophone), frequency filters, two battery units and a memory unit (4 GB SD card) housed in a pressure resistant housing measuring 54 or 66 cm (V0 and V1 versions). Tonal sounds in a frequency range of 20 to 145 kHz (version 0) and 20 to 160 kHz (version 1) are continuously recorded. C-PODs float vertically in the water column with the hydrophone pointing upwards, which is located beneath a white plastic cap at one end of the housing. The C-POD is anchored with the help of straps attached to the mid-section and to the lower end of the housing. The device is attuned to record only when positioned at a certain chosen angle and recording is stopped automatically by a tilt switch once that angle is surpassed. Data recording also includes angle of the C-POD, temperature and different acoustic properties of the recorded sound (time, duration, intensity, cycles, bandwidth, and upsweep/downsweep).

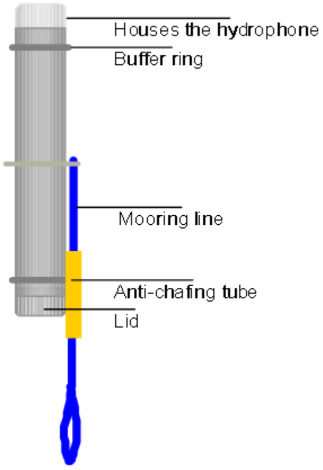

Figure 2.4: C-POD (exterior view, www.chelonia.co.uk)

Data from the memory unit of the C-PODs are stored and analysed with the help of the software C-POD.exe (Chelonia Ltd., UK; Version 2.026). All recorded clicks are stored in real-time with a resolution of up to one microsecond but can be depicted with a resolution up to days or weeks. First the raw data (CP1.files) were exported, after that the completeness and integrity of the data was validated before the C-POD was used again for a new deployment period. Click sounds were analysed by the KERNO classifier the standard algorithm of C-POD.exe Version 2.000 and higher. This algorithm builds trains, series of clicks, by analysing the acoustical similarity of temporal associated click sounds (depicted in CP3.files). The software tests, if the recorded trains stem from random origins (e.g. rain, crustaceans, sediment movements etc.). On the basis of a complex statistical process that incorporates the acoustic background at any given time the analyzed trains are divided into four different quality classes (high, moderate, low and doubtful), of which only the two highest are used for further analyses. Due to their frequency range and other click parameters, trains are then further classified into porpoises, other cetaceans, boat sonar and unknown train sources. After running the algorithm all clicks train details were stored in a SQL-based database (PODIS).

2.2.3. PAM mooring

The mooring system of the PAM-station (Figure 2.5) consists of a yellow spar buoy (N 225/6), two anchors and an inflatable yellow marking ball (Danfender B60) at the sea surface. The C-POD is attached to the rope connecting the marking ball and a small anchor stone (90 kg), 5 m above the seabed. This anchor stone in turn is connected via a Taifun steel wire lying on the seabed to the second anchor stone (600 kg), to which the yellow spar buoy is attached via a further Taifun steel wire (Figure 2.5). The distance between the buoy and the marker ball is approximately 50 m. The spar buoy marks the PAM-station with two radar reflectors (one built-in and on external) as well as visually with a warning cross and a solar lamp (Sealite SL 70) flashing five times every 20 seconds (visibility up to 2 nm).

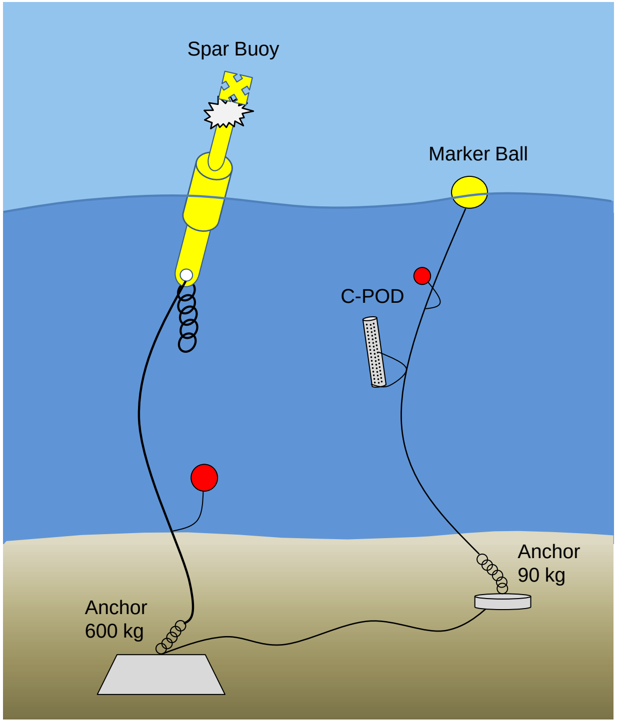

Figure 2.5: Mooring design of a C-POD station

The mooring design ensures a good visibility of the PAM-stations during various weather conditions and allows easy maintenance of the C-PODs. The use of two floating devices, the spar buoy and the marking ball, secures that in case of material damage the C-POD can still be lifted via the rope of the second buoy.

2.2.4. Data collection

Data collection started on 08.12.2012, when the C-PODs were deployed at six different PAM-stations (Table 2.2) in the study area for the planned Horns Rev 3 offshore wind farm. A map with the position of the C-PODs can be found in Figure 2.6 together with the boundaries of the existing wind farms Horns Rev 1 and 2 as well as the study area of Horns Rev 3. The water depth between the stations varied from 14.5 to 20.5 m. C-PODs were spaced with a minimum distance of approximately 5 km from each other and thus relatively evenly distributed over the study area spanning a distance of 18.9 km from west to east and 6.0 km from south to north. Survey cruises (Table 2.3) took place approximately every eight weeks during which C-PODs were changed and redeployed after on-board data extraction and validation. The C-PODs were rotated between different locations during the project.

Table 2.2: Positions, water depths and their distance to the coast of the six POD-stations located in the Horns Rev 3 area (coordinates in degrees, decimal minutes; World Geodetic System 1984).

POD-Station	Latitude (N)	Longitude (E)	Water depth (m)	Distance to coast (km)
Horns Rev 3 - 1	55° 42.888'	07° 36.484'	14.5	33.7
Horns Rev 3 - 2	55° 38.910'	07° 40.352'	14.5	27.2
Horns Rev 3 - 3	55° 42.070'	07° 42.847'	19.5	26.7
Horns Rev 3 - 4	55° 44.086'	07° 47.449'	20.5	23.3
Horns Rev 3 - 5	55° 43.039'	07° 51.116'	18.5	19.1
Horns Rev 3 – 6	55° 44.924'	07° 54.060'	20.5	17.2

Table 2.3: Survey cruises for maintenance of C-POD stations in the Horns Rev 3 area

Cruise	Date	Interval (days)	Comments	Ship
Horns Rev 3_12/01_P	08.12.2012	40	deployment of six moorings; adjustment of settings	Cecilie
Horns Rev 3_13/01_P	17.01.2013	57	maintenance	Cecilie
Horns Rev 3_13/02_P	15.03.2013	54	maintenance; one spar buoy and one C-POD were missing	Reykjanes
Horns Rev 3_13/03_P	08.05.2013	60	maintenance; error within data set	Cecilie
Horns Rev 3_13/04_P	07.07.2013	54	maintenance	Salling
Horns Rev 3_13/05_P	30.08.2013	49	maintenance	Salling
Horns Rev 3_13/06_P	10.11.2013	72	maintenance; only two out of six PAM-stations could be serviced due to unfavourable weather conditions	Sverdrupson

Horns Rev 3_13/07_P	14.12.2013	34	recovery of remaining moorings; two PAM-stations were missing	Arne Tiselius

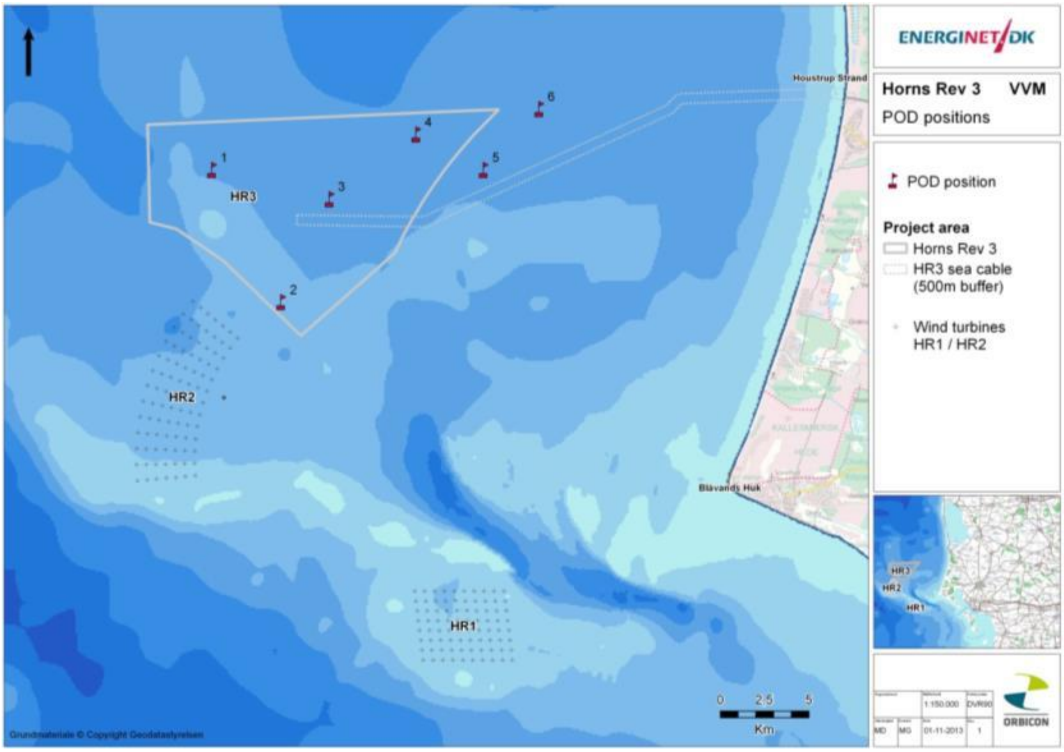

Figure 2.6: Locations of the six C-PODs (red flags) in the Horns Rev 3 area

2.2.5.C-POD recording settings

The default setting of C-PODs is designed to store tonal sounds in a frequency range between 20 and 145/160 kHz as well as a maximum of 4096 clicks per minute. During experiences in other projects located in tidal waters, it was recognised that these settings are not sufficient to guarantee a complete data coverage. In shallow areas or in regions with fast currents sediment transport noise frequently exceed the limit of 4096 clicks per minute, resulting in a loss of temporal coverage. Thus, the standard settings were adapted to avoid truncation of recordings. Instead of 4096 up to 65536 clicks could be stored per minute. The quality control of the first datasets, whilst being on board during the first maintenance cruise in January 2013, showed that rising the click limit to 65536 clicks per minute was not sufficient to prevent the click limit maxed out in each minute. All datasets had an increased number of truncated minutes and the memory of at least one C-POD was filled completely. Despite the adapted settings it was not possible to record the entire time span. To ensure for the following campaigns to have a complete coverage the setup was adapted further. An 80 kHz high pass filter was enabled in order to filter clicks below 80 kHz. Cutting the lower frequency range should not reduce the detection probability of harbour porpoise because their echolocation clicks is centred between 110 150 kHz (Møhl & Andersen 1973, Verboom & Kastelein 1995, 1997, Au et al. 1999, Teilmann et al. 2002, Villadsgaard et al. 2007). Furthermore, there were only 81 click trains that were assigned to dolphins. About one third of these trains had an average frequency below 110 kHz, the rest ranged between 110 to 134 kHz. It is very likely that the majority of the latter group of trains originates from porpoises rather than from dolphins, especially because some of them have a time overlap with trains assigned to porpoises (Figure 14).

Taking into account the adaptation of the setup the processing of all datasets was standardised. Thus, only clicks above 80 kHz were considered during data processing. Despite the adaptation of the setup some of the minutes were truncated. This resulted in a loss of data in 85 out of 1674 days with data. 17 of these days showed losses of recorded time above 1.0 percent and five above 10.0 percent of the day. These five days were excluded from the analysis to reduce biased data.

2.3. Data Analyses

2.3.1. Distance analysis

The term ‘Distance analysis’ used in this report refers to analyses conducted using Distance software (Distance v.6. r2, http://www.ruwpa.st-and.ac.uk, Thomas et al. 2010). These analyses were conducted with the objective to calculate species-specific distance detection functions for data collected during aerial transect surveys, which were used in the estimation of harbour porpoise densities and abundance in the study area. The detection of porpoises along a line transect declines with perpendicular distance from the line. The decline is typically non-linear with a high detection from the line to a deflection point in the transect from where the detection gradually drops to low values in the more distant parts of the transect (Buckland et al. 2001).

Key parametric functions were evaluated with cosines and simple polynomials for adjustment terms: half-normal and hazard rate, and the best fitting function was chosen on the basis of the smallest Akaike Information Criterion (AIC) values (Burnham & Anderson 2002). No constraints were used in the analysis. Parameter estimates were obtained by maximum likelihood methods. In the Distance-analysis and density calculations a left truncation at 36 m was implemented. The observations were post-stratified in 36m-strips up to 360 m perpendicular distance.

A global detection function was calculated for the entire dataset for harbour porpoises, assuming that detectability of porpoises was similar among surveys. The estimated global detection function was used to estimate porpoise densities for each survey. Detection function was estimated using the conventional distance sampling (CDS) engine.

2.3.2. Detection probability – g(0)

A key assumption of line-transect sampling is that animals on the track line are detected with certainty; i.e. the probability of detecting animals at zero perpendicular distance – g(0) – is 1. For most (if not all) cetacean surveys, this assumption is almost certainly violated, and an estimate of g(0) is needed to produce absolute (and unbiased) density and abundance estimates.

There are two sources of bias that need to be accounted for in analysing cetacean aerial survey data, both of which affect detection probability. These are: perception bias, and availability bias.

Perception bias arises when animals were missed by observers, even though they were available to be seen. Availability bias arises because not all animals will be at or near the surface at the time the observers pass over, and therefore are not available to be counted.

We followed the methods of Grünkorn et al. (2005) and used mark-recapture and dive data to estimate perception and availability bias; then combined the two for an estimate of g(0). This value was then added as a multiplier to density calculations for correction of density estimates. Data were pooled across all replicates for g(0) estimation.

Perception bias p(m) was estimated as:

$$p(m) = \frac{N_{1,2}}{N_1}$$

Where N1,2 is the number of duplicate sightings (seen by both main and control observers in the overlap zone); and N1 is the number of sightings seen only by the control observer.

Availability bias was estimated by multiplying the number of sightings on each flight with the average proportion of time spent in the top metre of the water column (Teilmann et al. 2013). This ‘total surface time’ was then multiplied by the total number of sightings to give an estimate of availability bias; g(0) is simply a product of perception bias and availability bias (details, see Thomsen et al. 2006a, 2007).

2.3.3.Distribution modelling

Species distribution models were used to quantify the relationships between the observed harbour porpoise densities and a series of environmental parameters. The model was built with a twofold purpose in mind:

i. to quantify the magnitude of the effects for each density prediction

ii. to predict the density across the whole area of interest. The process of species distribution modelling is a complex one that involves decisions related to the nature of the dataset being analysed and the biology of the species that is being studied. Species distribution data are zero-inflated, spatially auto correlated and their relationship with environmental parameters are highly nonlinear.

2.3.4.Analytical methods

A data exploration exercise showed how the datasets contained a large number of zeros and a number of extremely large density values. Such data are difficult to incorporate into standard parametric models. An efficient way to overcome the zero-inflation is to fit models in a hierarchical fashion (e.g., a ‘hurdle model’), including a component that estimates the occurrence probability, and a subsequent component that estimates the number of individuals given that the species is present (Millar 2009; Potts & Elith 2006; Wenger & Freeman 2008). We adopted that strategy by constructing two separate sets of models, one to predict the presence and one to predict the density of harbour porpoises.

The random Forest algorithm was used to model the occurrence model (presence/absence) and the density (positive part) of the harbour porpoise. Random Forest algorithm was used because of its robustness to outliers. This algorithm is based on the well-known methodology of classification trees (Breiman et al. 1984). In brief, a classification tree is a rule partitioning algorithm, which classifies the data by recursively splitting the dataset into subsets which are as homogenous as possible in terms of the response variable (Breiman et al. 1984). The use of such a procedure is very desirable, as classification trees are non-parametric, able to handle non-linear relationships, and can deal easily with complex interactions.

Random Forests uses a collection (termed ensemble) of classification trees for prediction. This is achieved by constructing the model using a particularly efficient strategy aiming to increase the diversity between the trees of the forest random. Forests is built using randomly selected subsets of the observations and a random subset of the predictor variables. Firstly, many samples of the same size as the original dataset are drawn with replacement from the data. These are called bootstrap samples. In each of these bootstrap samples, about two thirds of the observations in the original dataset occur one or more times. The remaining one third of the observations in the original dataset that do not occur in the bootstrap sample are called out-of-bag (OOB) for that bootstrap sample. Classification trees are then fit to each bootstrap sample. At each node in each classification tree only a small number (the default is the square root of the number of observations) of variables are available to be split on. This random selection of variables at the different nodes ensures that there is a lot of diversity in the fitted trees, which is needed to obtain high classification accuracy.

Each fitted tree is then used to predict for all observations that are OOB for that tree. The final predicted class for an observation is obtained by majority vote of all the predictions from the trees for which the observation is OOB. Several characteristics of Random Forests make it ideal for data sets that are noisy and highly dimensional. These include its remarkable resistance to overfitting and its immunity to multicollinearity among predictors. The output of Random Forests depends primarily on the number of predictors selected randomly for the construction of each tree. After trying several values we decided to use the default number suggested by Breiman for classification problems (Breiman 2001). We made this choice as we did not notice any decrease in the out-of-bag error estimate after trying several values.

In order to measure the importance of each variable, we used measure of importance provided by Random Forests, based on the mean decrease in the prediction accuracy (Breiman 2001). The mean decrease in the prediction accuracy is calculated as follows: Random Forests estimates the importance of a predictive variable by looking at how much the OOB error increases when OOB observations for that variable are permuted (randomly reshuffled) while all other variables are left unchanged. The increase in OOB error is proportional to the predictive variable importance. The importance of all the variables of the model is obtained when the aforementioned process is carried out for each predictor variable (Liaw & Wiener 2002). All the analyses were carried out using the Random Forests package in R (Liaw & Wiener 2002).

2.3.4.1. Modelling evaluation and predictions

In order to evaluate the predictive performance of the models, the original dataset was randomly split into model training (70%) and model evaluation data sets (30%). The training dataset was used for the construction of the model whereas the evaluation dataset was used to test the predictive abilities of the model. The following measures of model performance were computed: the Pearson correlation coefficient for the positive part of the model, and the AUC (Fielding & Bell 1997) for the presence / absence part.

The Pearson correlation coefficient was used to relate the observed and the predicted densities. The AUC relates relative proportions of correctly classified (true positive proportion) and incorrectly classified (false positive proportion) cells over a wide and continuous range of threshold levels. The AUC ranges generally from 0.5 for models with no discrimination ability to 1.0 for models with perfect discrimination. AUC values of less than 0.5 indicate that the model tends to predict presence at sites at which the species is, in fact, absent (Elith & Burgman 2002). It must, however, be borne in mind that the above-mentioned classification is only a guideline and this measure of model performance needs to be interpreted with caution (see Lobo et al. 2008 for criticisms). Most importantly, a true evaluation of the predictive performance of a model can only be carried out using a spatially and temporally independent dataset, which is not possible in most cases for ecological datasets.

2.3.4.2. Passive acoustic monitoring (PAM)

From C-POD data no conclusions on absolute abundances can be made. Nevertheless, using an appropriate analysis, based on the recorded acoustic activity of harbour porpoises, information on relative abundance are obtained. The parameter “detection positive time per time unit” has been proofed to be a powerful tool to describe relative abundance of harbour porpoises (Teilmann et al. 2001, 2002; Diederichs et al. 2004; Tougaard et al. 2004, 2005; Verfuß et al. 2007a). It means the proportion of time units with at least one click train originating from porpoises compared to a larger amount of recorded time units. The different time units give different information about porpoise echolocation activity. The number of detection positive days (DPD) per month is useful to describe seasonal differences in areas with low densities (Verfuß et al. 2004, 2007a, Gallus et al. 2012) More detailed units on a daily scale, like detection positive hours per day (DPH/day), detection positive ten-minutes per day (DP10M/day) and detection positive minutes per day (DPM/day) express the utilization of a specific area with more precision. Detection positive minutes per hour (DPM/hour) are useful for determination of daily activity patterns. The Horns Rev area is a high density area (Teilmann et al. 2008), for which a higher temporal resolution was used (DP10M/day). For statistical analysis the statistical program R (version 2.14.1, Development Core Team, 2011) was used.

2.4. Assessment criteria importance

The importance of the environmental factor is assessed for each environmental sub-factor. Some sub-factors are assessed as a whole, but in most cases, the importance assessment is broken down into components and/or sub-components in order to conduct a fulfilling environmental impact assessment.

Considerations about abundance and spatial distribution are important for some sub-factors, such as marine mammal populations, and are in these cases incorporated into the assessment. The assessment is based on *importance criteria* defined by the functional value of the environmental sub-factor and the legal status given by EU directives, national laws, etc.

The importance criteria are graded into four tiers (see Table 2.4). In a few cases, such as climate, grading does not make sense. As far as possible the spatial distribution of the importance classes are shown on maps.

Table 2.4: *The definition of Importance to an environmental factor*

Importance level	Description
Very High	Components protected by international legislation/conventions (Annex I, II and IV of the EU-Habitats Directive, ASCOBANS), or of international ecological importance. Components of critical importance for wider ecosystem functions.
High	Components protected by national or local legislation, or adapted on national "Red Lists". Components of importance for far-reaching ecosystem functions.
Medium	Components with specific value for the region, and of importance for local ecosystem functions
Low	Other components of no special value, or of negative value

2.4.1. Assessment for harbour porpoise

For harbour porpoise the Horns Rev area serves two specific functions: It serves as a staging area where animals are present during the whole year and during summer harbour porpoises reproduce in the area. For the evaluation of the importance of the area as a staging area numerical criteria were developed.

According to the available data on porpoise abundance from the cited studies and our own investigation, we applied the following criteria for the evaluation of the function of Horns Rev area as a staging area based on animal densities as obtained from visual surveys (see Table 2.5). Our values range from, $<0.5/km^2$ (minor) to $>2/km^2$ (very high). These criteria are specifically developed for the situation in the eastern part of the North Sea, especially German Bight and adjacent waters. The rational for choosing > 2 porpoises/km^2 as highest level is that such densities are the highest values reported for this area at a larger scale, e.g. Natura 2000 areas west of Jutland (e.g. Gilles et al. 2011). On a smaller scale, densities may exceed 10 porpoises/km^2. It needs to be noted, however, that porpoise densities in the North Sea are on average around 0.3 porpoises/km^2 (Hammond et al. 2013) and the criteria are thus applied in order to differentiate on smaller scale within an area where densities are much higher as compared to the overall North Sea.

The assessment of importance as a nursing area very much relies on comparison of observed calve ratios with other areas.

Table 2.5: Criteria for the evaluation of the importance of the area for harbour porpoise

Importance level	Description	Staging	Nursing
Very high	Components protected by international legislation/conventions (Annex I, II and IV of the Habitats Directive, Annex I of the Birds Directive), or of international ecological importance. Components of critical importance for wider ecosystem functions.	>2/km^2	Exceptional high calf ratio, highest abundance during nursing time
High	Components protected by national or local legislation, or adapted on national “Red Lists”. Components of importance for far-reaching ecosystem functions.	1-2/km^2	High calf ratio, high abundance during nursing time
Medium	Components with specific value for the Horns Rev region, and of importance for local ecosystem functions.	0,5-1/km^2	Medium calf ratio, no special function as nursing ground
Minor	Other components of no special value, or of negative value.	<0,5/km^2	Lower calf ratio than average, lower numbers in the nursing period

2.4.2.Assessment for harbour seal and grey seal

For seals there is no indication for a special utilisation of the area as important feeding ground or related to reproduction. Therefore only abundance is considered.

3. ABUNDANCE AND DISTRIBUTION

3.1. Harbour porpoise

The harbour porpoise is a small cetacean of 145 to 160 cm body length (Culik 2011) with a body mass of 50 to 60 kg (Bjorge & Tolley 2009) that inhabits coastal areas of the northern hemisphere including the North and Baltic Sea. It is the only cetacean known to be breeding in Danish waters.

Their lifespan covers an average of 8 to 10 years; very few reach an age of 20 years (Benke et al. 1998) with females reaching sexual maturity at the age of 3 to 4 years (Koschinski 2002). They can give birth to a single offspring once a year, mainly between May and July and nurse their calves for about eight to ten month. Due to the long nursing period many harbour porpoises are nursing their calves while being pregnant with another calve which leads to high nutritional needs.

Harbour porpoises mainly forage in shallow coastal waters where they feed on small demersal and pelagic shoaling fish species (Santos et al. 2004).

Harbour porpoises inhabit the entire North Sea and the English Channel (Hammond 2006). One large high density area of harbour porpoises was identified in the Horns Rev area west of Jutland by the SCANS I surveys (Hammond et al. 1995, Hammond et al. 2002, Hammond 2006) and a number of other smaller scale investigations (Benke et al. 1998 and Sonntag et al. 1999, BioConsult-SH & GfN 2002, Scheidat et al. 2004, Gilles et al. 2006, Teilmann et al. 2008, Tougaard et al. 2006b, Brandt et al. 2008).

Genetic screenings revealed that the population of the Danish harbour porpoise is not homogeneous and at least two populations (or subpopulations) were identified, one in the Northern North Sea and one in the inner Danish Waters (Andersen et al. 2001).

A seasonal pattern was observed in the Jutland area showing high densities of harbour porpoises during summer month and low numbers in winter month (Brandt et al. 2008). For details on density and distribution see Chapter 3.1.2.

3.1.1. Conservation status of the harbour porpoise

The harbour porpoise is an endangered species listed in Annex II and IV of the EU-habitat directive. Article 12 of the EU habitat directive prohibits the “deliberate capture or killing of this species as well as the deliberate disturbance especially during the period of breeding, rearing and migration”. It also prohibits the “deterioration or destruction of breeding and resting habitats”.

Additionally the harbour porpoise is listed in appendix II of the “Convention on the Conservation of Migratory Species of Wild Animals” (Council of Europe 1979) as a migratory species that would significantly benefit from international cooperation. 1991 the “Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas” (ASCOBANS) was concluded and entered into force in 1994. Following its conservation and management plan, work towards “effective regulation to reduce the impact on the animal, of activities which seriously affect their food resources” and towards “prevention of other significant disturbance, especially of an acoustic nature” is required. It also requires research to be conducted to “identify present and potential threats” to this species.

3.1.2.Abundance of harbour porpoise in the Horns Rev 3 area

Harbour porpoise abundance as derived from aerial surveys in 2013 showed a marked seasonal pattern with numbers increasing from winter until late summer (Figure 3.1, Table 3.1). Highest numbers were counted in August with 217 sightings during the survey, resulting in a density of 6.4 porpoises/km^2 and a total number of 17,000 porpoises in the study area. Numbers from the August surveys were exceptionally higher than other surveys in summer 2013, however, a marked seasonal pattern remains evident from the other surveys as well, with low numbers in winter and a tenfold increase until May and summer.

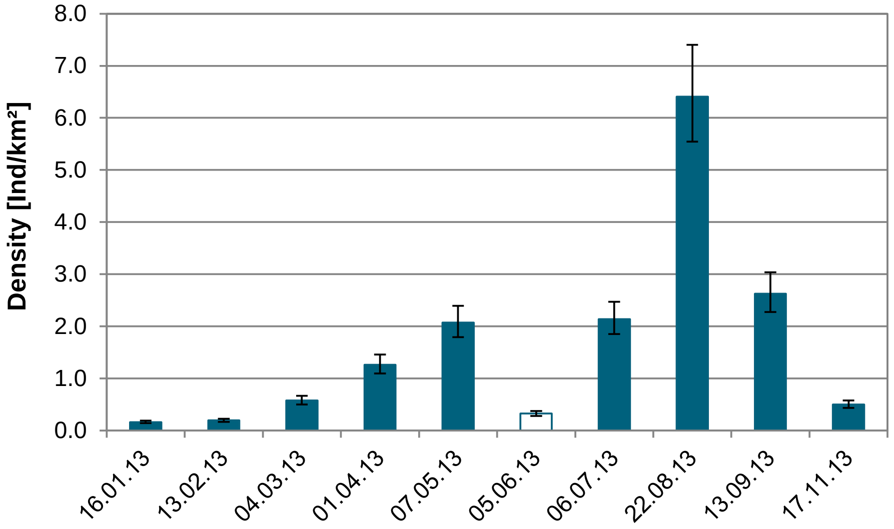

Figure 3.1: Density of harbour porpoises in the Horns Rev 3 area during aerial surveys in 2013

Table 3.1: Numbers of observed harbour porpoises during monthly aerial surveys and results of Distance analysis. 'Effort' represents the coverage of the study area in one- or two-sided valid conditions during the particular survey, 'N porpoises the actual number of porpoises counted within transects. 'D LCI' represents the lower 95% confidence interval, 'D UCI' the upper 95% confidence interval of the density.

Survey	Effort	N porpoises	Density	D LCI	D UCI	Total estimate
16.01.13	76%	5	0.16	0.14	0,19	434
13.02.13	100%	8	0.19	0.17	0,22	518
04.03.13	94%	20	0.58	0.50	0,67	1534
01.04.13	100%	47	1.26	1.09	1,46	3362
07.05.13	90%	69	2.07	1.79	2,39	5515
05.06.13	97%	4	0.32	0.28	0,38	865
06.07.13	100%	69	2.14	1.85	2,47	5697
22.08.13	99%	217	6.41	5.55	7,40	17061
13.09.13	92%	81	2.63	2.27	3,03	6997
17.11.13	100%	19	0.50	0.43	0.58	1334

During the surveys in July, August, September and November the proportion of calves could be determined from the size of the sighted porpoises. Calve ratio was highest in July with about 18% and decreased after this (Table 3.2). No calves were sighted on the survey in June when due to unfavourable weather conditions sighting rate was very low.

Table 3.2: Numbers of observed harbour porpoises and proportion of calves during aerial surveys. Sightings rates are different to Tab. 3.1 which only gives sightings which could be used for density estimates due to left truncation in distance analysis.

Survey	N porpoises	Calves	%
06-07-13	72	13	18.0
22-08-13	232	9	3.9
13-09-13	140	8	5.7
17-11-13	19	1	5.3

3.1.2.1. Distribution based on spatial modelling approach

Two separate Random Forest Models were fitted for the winter and summer seasons. The winter model was fitted using data collected during the months of January, March and April and the summer model was fitted using data collected during the months of May, July, August and September. Although data were collected during the months of February and June, these data sets were not included in the models due to very few sightings and too little effort undertaken under valid conditions because of high sea state.

Current was the most important predictor in the presence-absence part of the summer model, followed by *Mean depth*, *Temperature* and *Distance to land*. Conversely to the presence-absence part, for the positive part of the model the most important variable was *Distance to land*. The other variables, in order of importance, were *Mean depth*, *Temperature* and *Month* (Table 3.3).

Table 3.3: Relative importance of the environmental predictors for the presence/absence and the positive parts of the summer model for the harbour porpoise. The importance of a particular predictor is expressed as the decline in the predictive performance when that particular variable was not included in the model. Evaluation results are presented as area under receiver operator curve (AUC) and Pearson's correlation coefficient respectively. Values for both stages (presence/absence and positive part) of the model are presented on separate panels.

Variable	Presence / absence	Positive part
Month	0.096	0.023
Mean depth	0.120	0.035
Current	0.119	0.016
Temperature	0.158	0.044
Distance to land	0.110	0.055
Model performance		
AUC	**0.661**	
Pearson's correlation coefficient		0.465

The winter model yielded somewhat different results from the summer one. The ranking of the variables for presence/absence part was as follows: Distance to land, Temperature, Month, Mean depth and Current. The positive part of the model highlighted as particularly important Temperature and Month, followed by *Mean depth*, *Current* and *Distance to land* (Table 3.4).

Table 3.4: Relative importance of the environmental predictors for the presence/absence and the positive parts of the winter model for the harbour porpoise. The importance of a particular predictor is expressed as the decline in the predictive performance when that particular variable was not included in the model. Evaluation results are presented as area under receiver operator curve (AUC) and Pearson's correlation coefficient respectively. Values for both stages (presence/absence and positive part) of the model are presented on separate panels.

Variable	Presence / absence	Positive part
Month	0.025	0.018
Mean depth	0.021	0.007
Current	0.020	0.002
Temperature	0.039	0.019
Distance to land	0.042	0.000
Model performance		
AUC Pearson's correlation coefficient	**0.56**	0.01

The direction of the effects of the environmental variables were broadly concordant across seasons (Figure 3.2 and Figure 3.3). The effect of the variables *Current* and *Temperature* were positive, although this varied between the positive and the presence/absence part of the models. The effect of variables seems to show a larger proportion of nonlinearity in the presence/absence part of the model. The variable *Mean Depth* showed a negative effect on the positive part of the models with the species avoiding areas with mean water depth of less than 25 m.

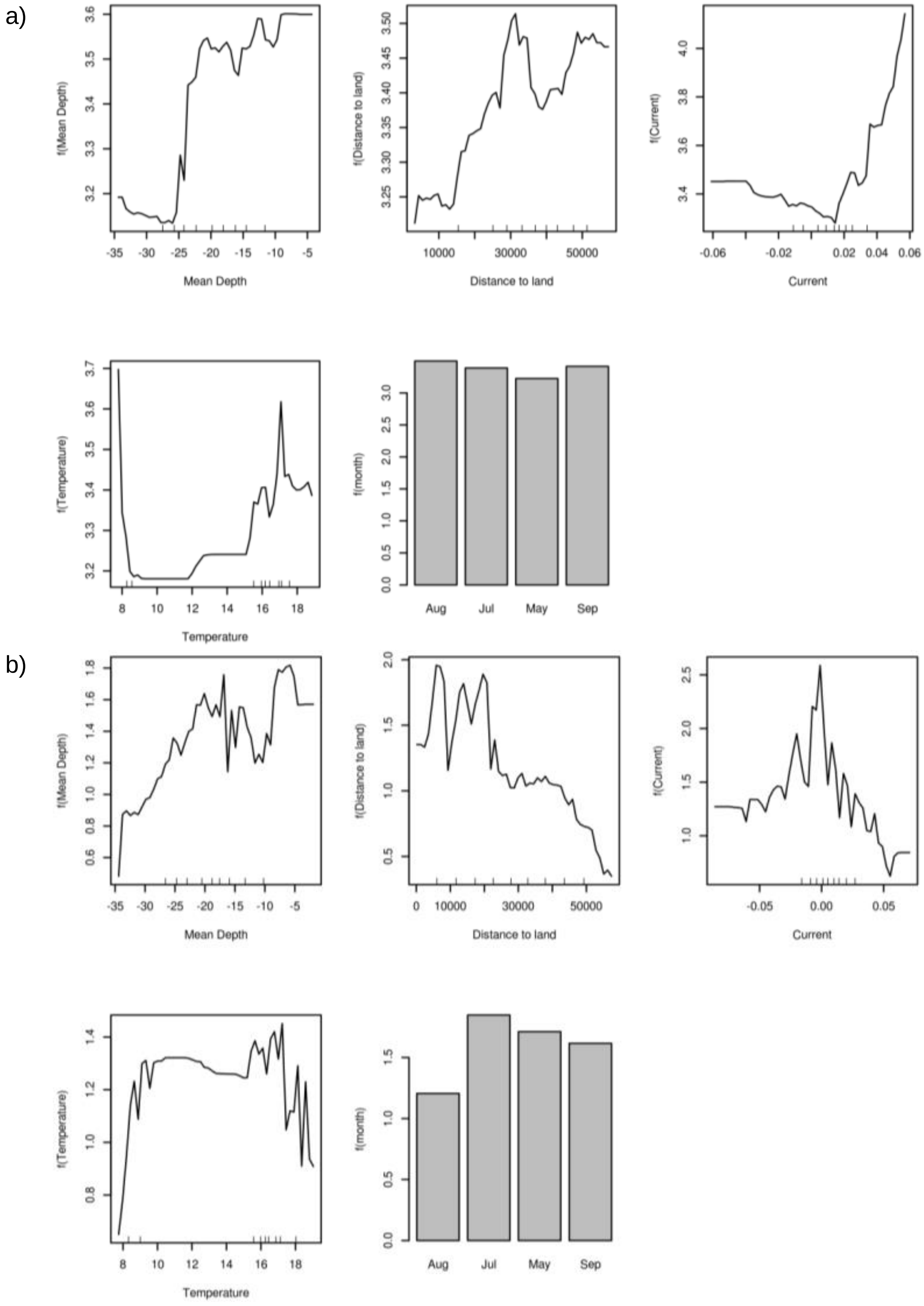

Figure 3.2: Fitted functions for the two-part random forest model representing the relationship between the predictor variables, the positive (a) and presence/absence (b) parts for the harbour porpoise summer model. The values of the environmental predictor are shown on the X-axis and the density (for the positive part) and the probability of occurrence (for the presence/absence part) respectively on the Y-axis.

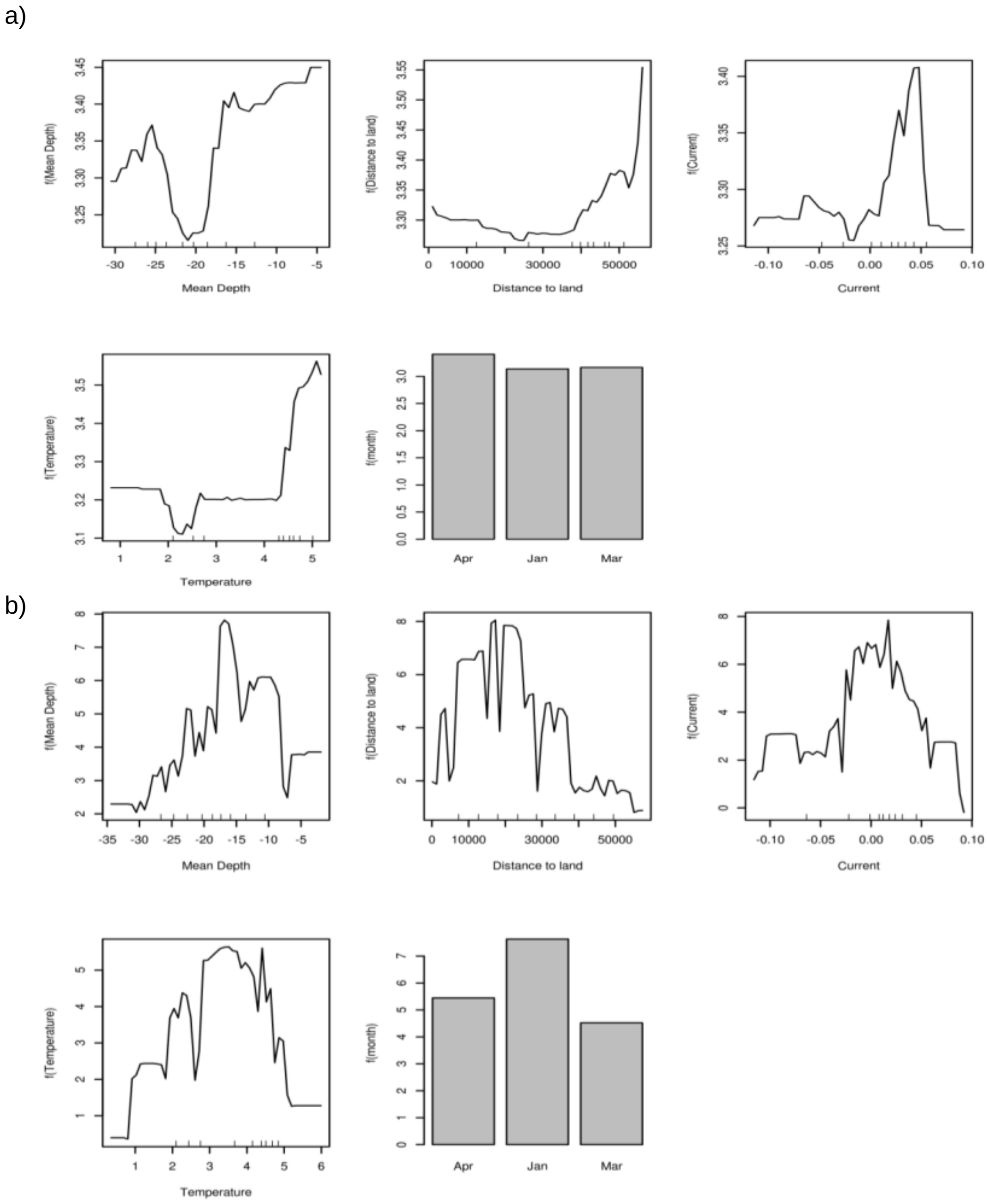

Figure 3.3: Fitted functions for the two-part random forest model representing the relationship between the predictor variables, the positive (a) and presence/absence (b) parts for the harbour porpoise winter model. The values of the environmental predictor are shown on the X-axis and the density (for the positive part) and the probability of occurrence (for the presence/absence part) respectively on the Y-axis.

For the presence/absence part of the model *Mean Depth* showed a negative effect throughout although this was highly nonlinear. *Distance to land* had a variable effect across the positive and presence/absence parts of the models and across seasons. For the positive part of the summer model it showed a peak at around 30 km distance to land, followed by a decrease at higher distances. For the presence/absence part of the model it showed a negative effect throughout.

This pattern was slightly different for the winter model which showed a positive relationship between *Distance to land* and density for the positive part of the model and a negative one for the presence / absence part. The model validation showed a moderate predictive ability for the summer model according to the Pearson correlation coefficient. AUC (Table 3.3). Conversely the winter model showed a poor predictive ability for both the presence/absence and positive parts. The poor predictive ability for the winter model can at least partly be explained by the little number of harbour porpoise observations during the winter months. According to Moran’s I no significant spatial autocorrelation was found in the residuals of the presence/absence part of harbour porpoise models. Results for the positive part were similar, with exception of the residuals for the month of August, which showed a significant amount of spatial autocorrelation (see Appendix).

The results of the model point at a consistent spot of high densities to the southwest of the planning area (Figure 3.4 and Figure 3.5. The area is at the south-western edge of the Horns Rev and thus characterized by a steep gradient in the bathymetry. As can be seen from the underlying bathymetric map similar characteristics are found for the other parts with high porpoise densities where similar changes from deeper to more shallow waters are found. Such structures of decreasing water depth lead to locally higher currents which were found to be an important variable in the model.

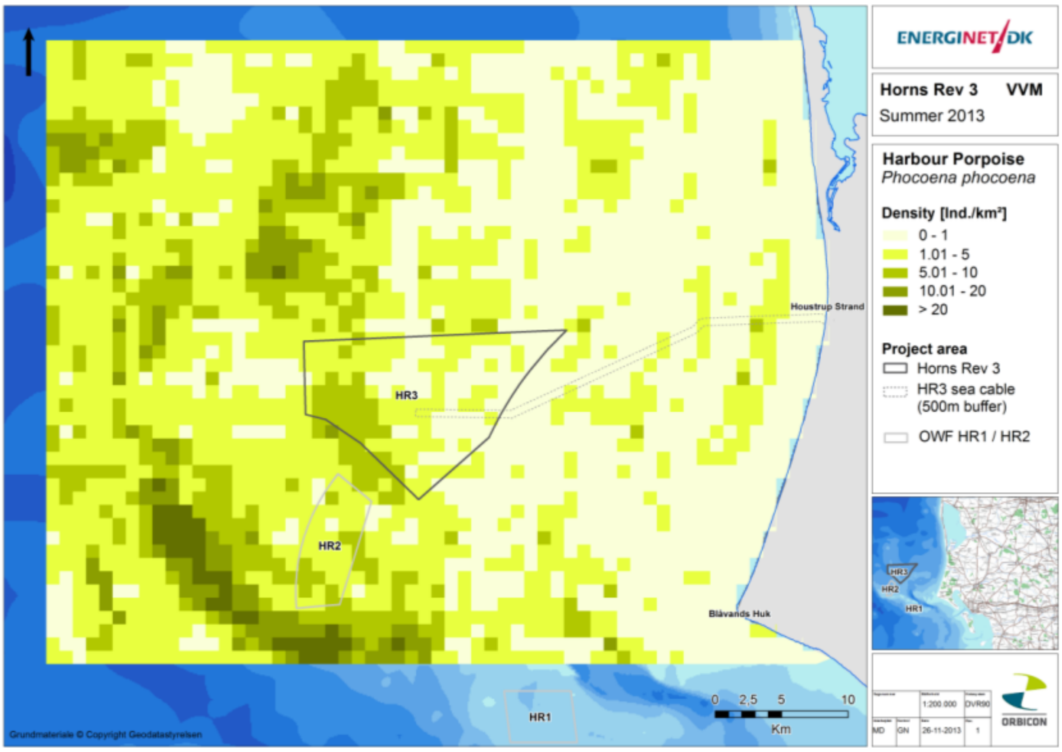

Figure 3.4: Modelled spatial distribution of harbour porpoise in the study area based on aerial surveys undertaken in May, July and August 2013 (summer distribution model).

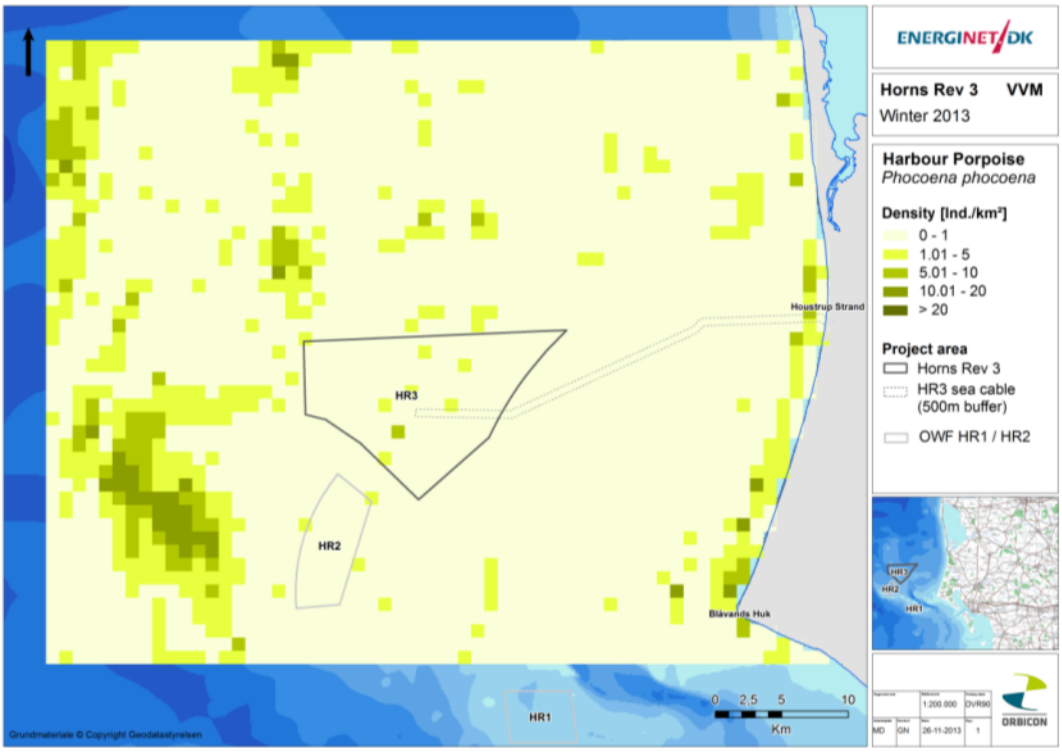

Figure 3.5: Modelled spatial distribution of harbour porpoise in the study area based on aerial surveys undertaken in January, March and April 2013 (winter distribution model).

3.1.2.2. Results of the passive acoustic monitoring (PAM)

Recording time of C-PODs

Generally C-PODs record continuously during deployment, except if the tilt switch is surpassed. At the six PAM-stations a total of 1674 days of recordings out of 2190 days of planned days (six times 365 days) were collected between 08.12.2012 and 14.12.2013. Missing data are a result of a ship strike, which resulted in the loss of a complete PAM mooring including one C-POD at HR1. Two C-PODs were missing at station Horns Rev 3 und HR5 as well (Figure 3.6). Furthermore eight recording errors occurred. Six datasets are partly missing due to premature ending of the data set and two due to an additional technical failure of a C-POD. Although investigated in detail, the reason for these two failures remained unclear. Furthermore, during 85 days data recording was truncated because at least in one out of 1440 minutes recording stopped due to surpassing of the limit of 65536 clicks per minute. In four of these 85 days time losses exceeded 10% of the recorded time and were excluded from the further analyses.

At two PAM-stations (‘Horns Rev 3 – 2’ and ‘Horns Rev 3 – 6’) the phenology of porpoise activity has been recorded over the whole study period. At the other four stations the losses are limited and generally three or four C-PODs recorded simultaneously. Thus, despite the losses a very good seasonal and geographic representation of the activity of harbour porpoises has been sampled in the vicinity of the planed Horns Rev 3 offshore wind farm.

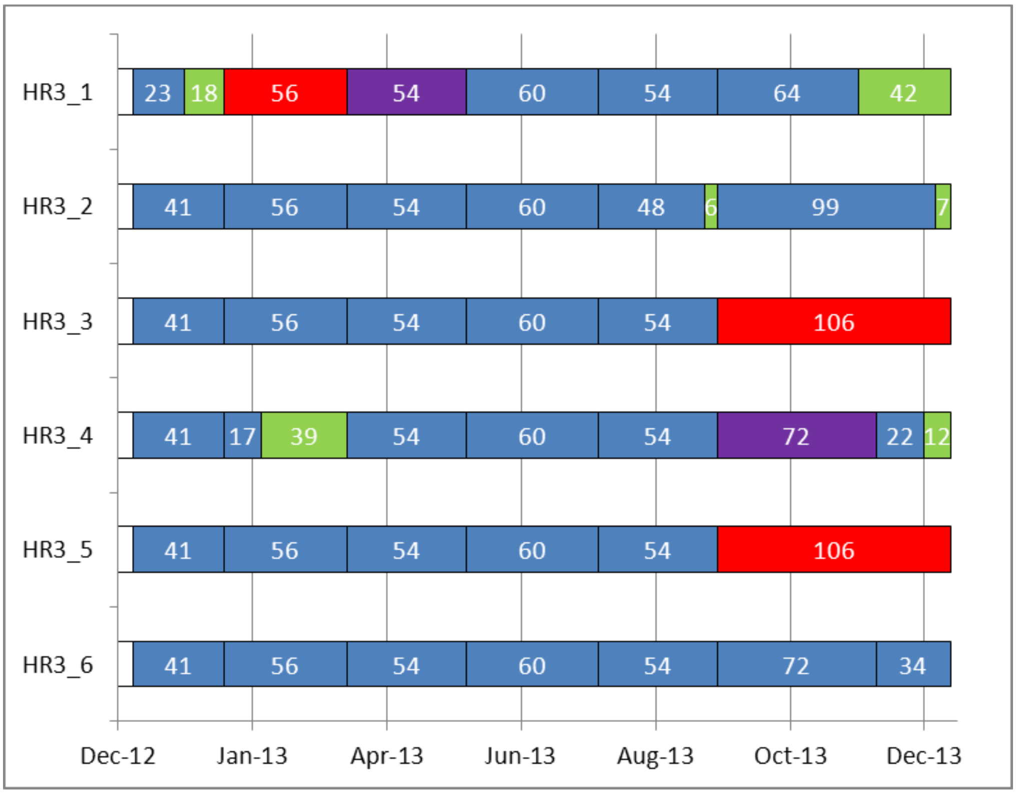

Figure 3.6: Visualisation of data recordings per PAM mooring between December 2012 and August 2013: days of deployment per campaign (white numbers) recorded data (white: C-POD not deployed; blue: data okay; red: C-POD missing; purple: recording error; green: premature ending of recording).

Seasonality of acoustic presence of porpoises measured by C-PODs

Porpoises were present in the study area over the whole study period. 96.2 to 100.0 percent of all days feature at least the detection of one porpoise click-train (Table 3.5). Nevertheless, detection rates differed with position and changed over time, (Table 3.5). Detection rates of porpoises, displayed as 10-minute-intervals per day (% DP10M/day) show that PAM-stations ‘Horns Rev 3 - 1’ and ‘Horns Rev 3 - 2’ located in the western part of the study area, have a high similarity in recording detection rates of porpoises (Figure 3.7 and Figure 3.9). The seasonal pattern at these two stations show a continues increase in detection rates from relative stable detection rates during winter (app. 10% DP10M/day, December to March) until August, when maximum rates between 40% DP10M/day at ‘Horns Rev 3 – 2’ and even more than 60% DP10M/day at ‘Horns Rev 3 – 1’ occurred. After this maximum detection rates decreased again until December (app. 20% DP10M/day).

Detection rates at the four PAM-stations ‘Horns Rev 3 – 3’ to ‘Horns Rev 3 – 6’ show high similarities as well (**Fejl! Henvisningskilde ikke fundet.**). At these four PAM-stations etection rates were generally lower over the whole study period compared with ‘Horns Rev 3 – 1’ or ‘Horns Rev 3 – 2’. At all stations no clear seasonal pattern is recognisable except for low detection rates for all stations in February and August. Maximum detection rates are not distinct and were reached for each station at different months, varying from December (‘Horns Rev 3 – 3’), April (‘Horns Rev 3 – 4’), May (‘Horns Rev 3 – 5’) to July and September (‘Horns Rev 3 – 6’). For the time period from September until December only at ‘Horns Rev 3 – 6’ a complete data set is available, where detection rates increased first during September but then continuously decreased until December. At all PAM-stations a relatively clear minimum in acoustic activity could be detected at the end of January/beginning of February 2013. Generally detection rates strongly changed at a daily scale at all stations. Days with only little detection were alternated with days of very high detection rates on a regular basis.

Table 3.5: Monthly and overall mean porpoise activity in percent per PAM-station; DPD: detection positive day; DPH: detection positive hour; DP10M: Detection positive 10-minute-intervals; DPM: detection positive minutes; p-value: p-value of Kruskal-Wallis-Test

Position	Horns Rev 3 -1	Horns Rev 3 - 2	Horns Rev 3 - 3	Horns Rev 3 - 4	Horns Rev 3 - 5	Horns Rev 3 - 6	
% DPD	100.0	98.9	96.2	99.1	98.8	98.3	Overall mean
	100.0	93.3 – 100	89.7 – 100	96.6 – 100	96.4 - 100	83.3 - 100	monthly mean
	1.000	0.269	0.173	0.801	0.645	<0.001	p-value
% DPH/ day	55.3	46.4	32.6	35.4	41.2	35.5	Overall mean
	22.9 – 86.4	23.4 – 71.0	12.9 - 54.2	20.6 - 56.9	19.0 – 61.0	22.4 - 45.7	monthly mean
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	p-value
% DP10M/ day	28.9	19.1	11.5	12.7	15.5	13.1	Overall mean
	7.6 – 61.7	6.9 – 38.4	3.0 - 25.7	5.7 - 26.1	5.2 – 23.5	6.4 - 20.8	monthly mean
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	p-value
% DPM/ day	8.8	6.3	3.6	3.1	4.9	4.1	Overall mean
	1.0 – 23.8	1.6 – 18.9	0.5 – 11.0	0.9 - 7.4	1.2 - 8.8	1.3 – 9.2	monthly mean
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	p-value

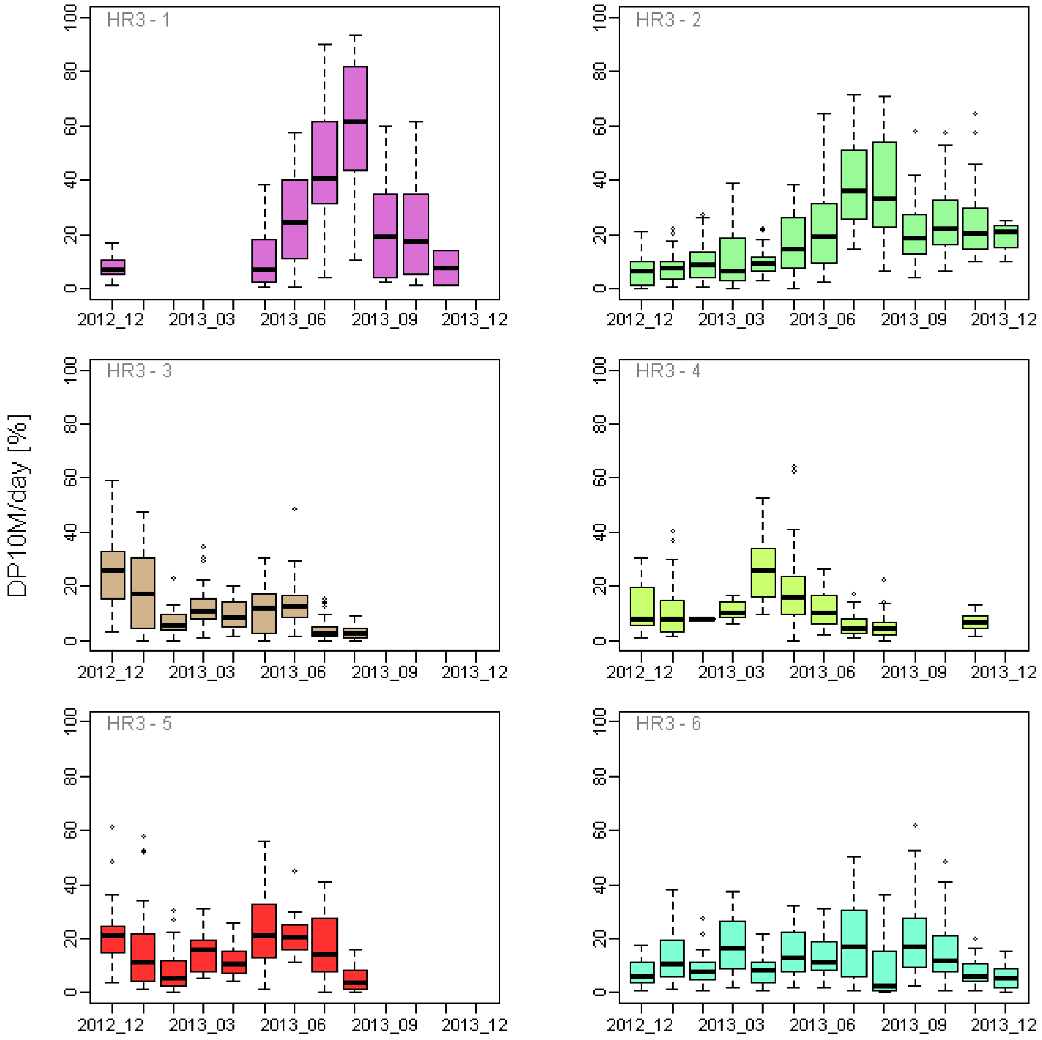

Figure 3.7: Monthly Box- and Whisker plots of acoustic activity of harbour porpoises showing the percentage of detection positive 10-minutes-intervals per day (% DP10m/day)

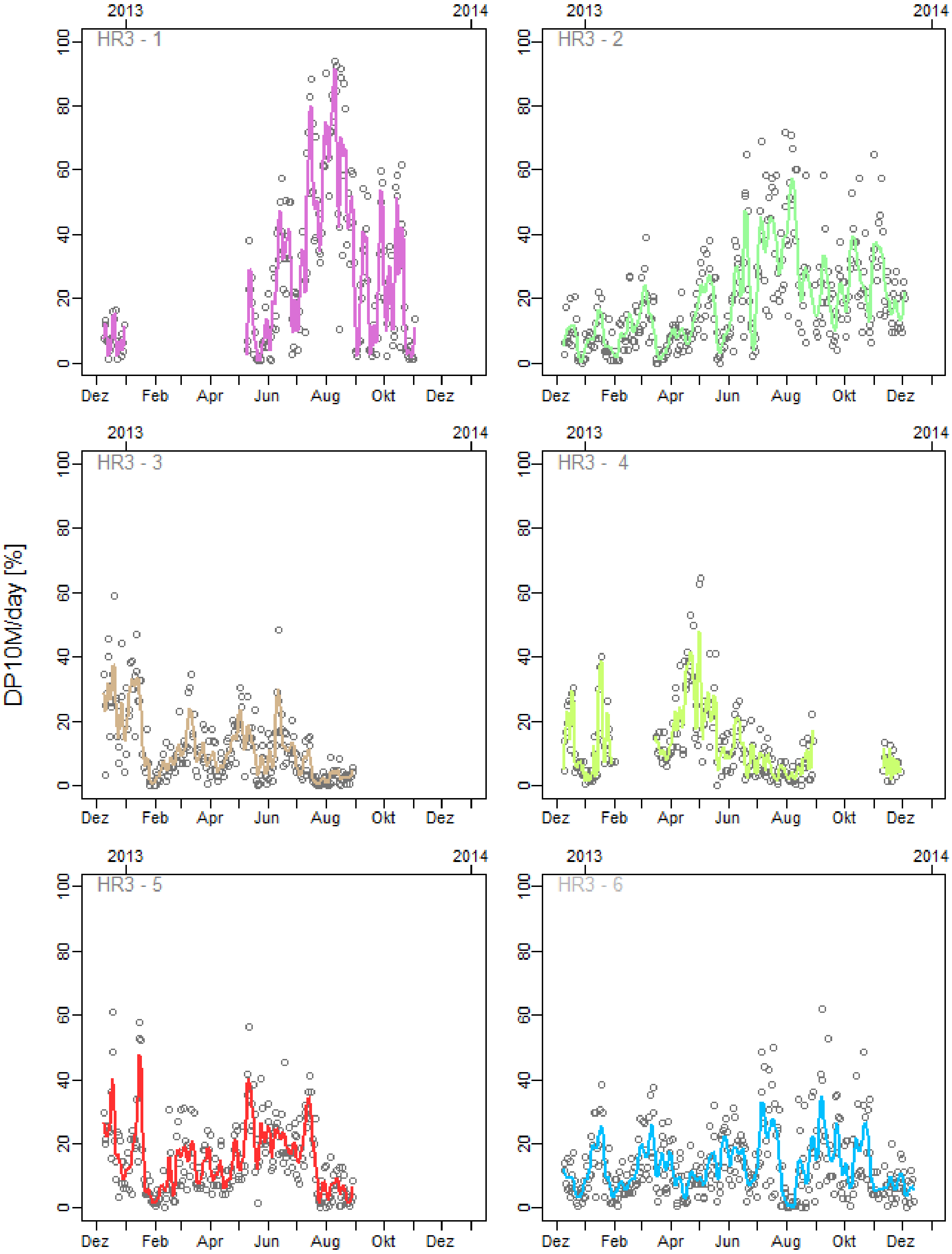

Figure 3.8: Acoustic activity of porpoises shown as the percentage of detection positive 10-minute-intervals per day (% DP10M/day), lines: smooth.spline spar=0.15

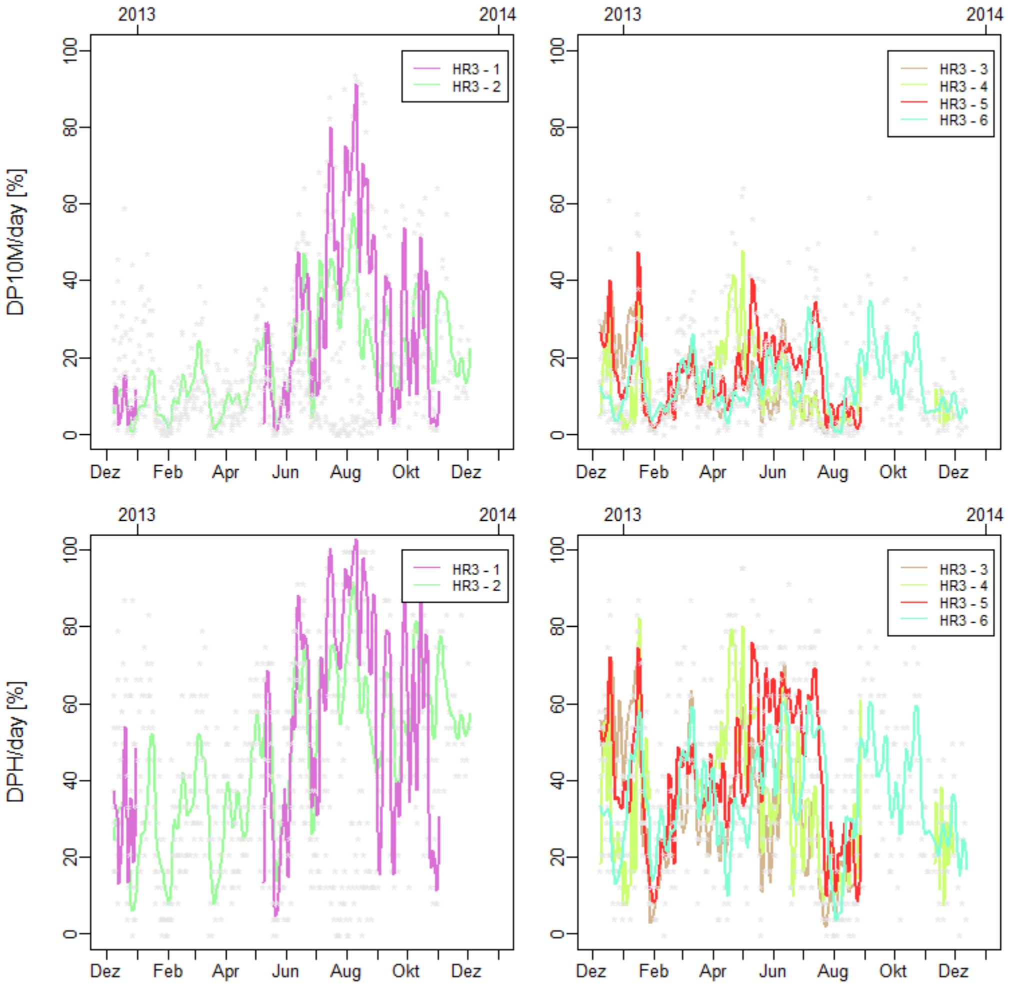

Figure 3.9: Acoustic activity of porpoises pooled geographically – left row: ‘Horns Rev 3 – 1’ and Horns Rev 3 - 2’; right row: Horns Rev 3 – 3’-6’ shown as the percentage of detection positive 10-minute-intervals (% DP10M/day) and hours per day (% DPH/day), lines: smooth.spline spar=0.15

Diel variation of acoustic presence of porpoises

Porpoises used the study area during day and night time, but showed no unbroken preference for either day or night (Figure 3.10). Furthermore, it is evident, that the seasonality of porpoise activity discussed in the previous chapter, was not limited to the daily units of porpoises activity as a whole, but as well the diel pattern of porpoise activity differed seasonally (Figure 3.10). The presence of porpoises may change on a small temporal scale, during which the animals acoustic activity was higher during the day and almost absent during the night and vice versa (for example Figure 3.10: ‘Horns Rev 3 – 1’; mid of May and July 2013). But looking on larger time intervals (months and seasons) the diel changes of porpoise detections are still evident (Table 3.6), indicating that the preference of harbour porpoises for this habitat changed considerably even on these long scales.

In the following passage the most obvious patterns of habitat use are presented (Figure 3.10 and Table 3.6), showing, that at no station an unbroken preference for day or night time habitat use dominated continuously. The most distinctive diel activity pattern at PAM-station ‘Horns Rev 3 – 1’ and ‘Horns Rev 3 – 2’ occurred between May and August 2013. This pattern was most prominent between July and August (Wilkoxon-Test: p<0.001), when porpoise recordings were highest during the whole study period (Figure 3.8). In other months significant differences occurred as well. Especially at ‘Horns Rev 3 – 2’ this difference was very clear between October and November 2013 when the acoustic activity was higher during the night (Table 3.6) In contrast at PAM-station ‘Horns Rev 3 - 3’ porpoise activity was higher at night during December 2012 and January 2013, but not as distinctive in spring and summer (Table 3.6). At PAM-station ‘Horns Rev 3 - 4’ the diel habitat use also shows a higher activity at night during December 2012 and during January 2013. Furthermore, a higher acoustic activity during day was detected at this position in April and May 2013 when activity was again highest (Table 3.6). At PAM-stations ‘Horns Rev 3 – 5’ porpoise activity was higher during night in December, whilst in May 2013 habitat use was higher during day than during night At ‘Horns Rev 3 – 6’ in March, July, September and October 2013 diel habitat use was significantly higher during day than during night time (Table 3.6), these were the months with the highest acoustic presence of porpoises at this PAM-station (Figure 3.8).

Summarizing, habitat use at the two western PAM-stations shows a preference for day time presence between May and August 2013 which peaked in July and August and a preference for night time between October and December 2013. In the other months a diel preference was less eminent. A preference for night time habitat use in December 2012 and January 2013 was shared by the three PAM-stations in the middle of the study area, whilst all four eastern PAM-stations showed a tendency for higher daytime activity between March and May 2013. It seems that there is a tendency to distinct diel habitat use when acoustic activity of porpoises was high.

Monopile foundation – Horns Rev 2

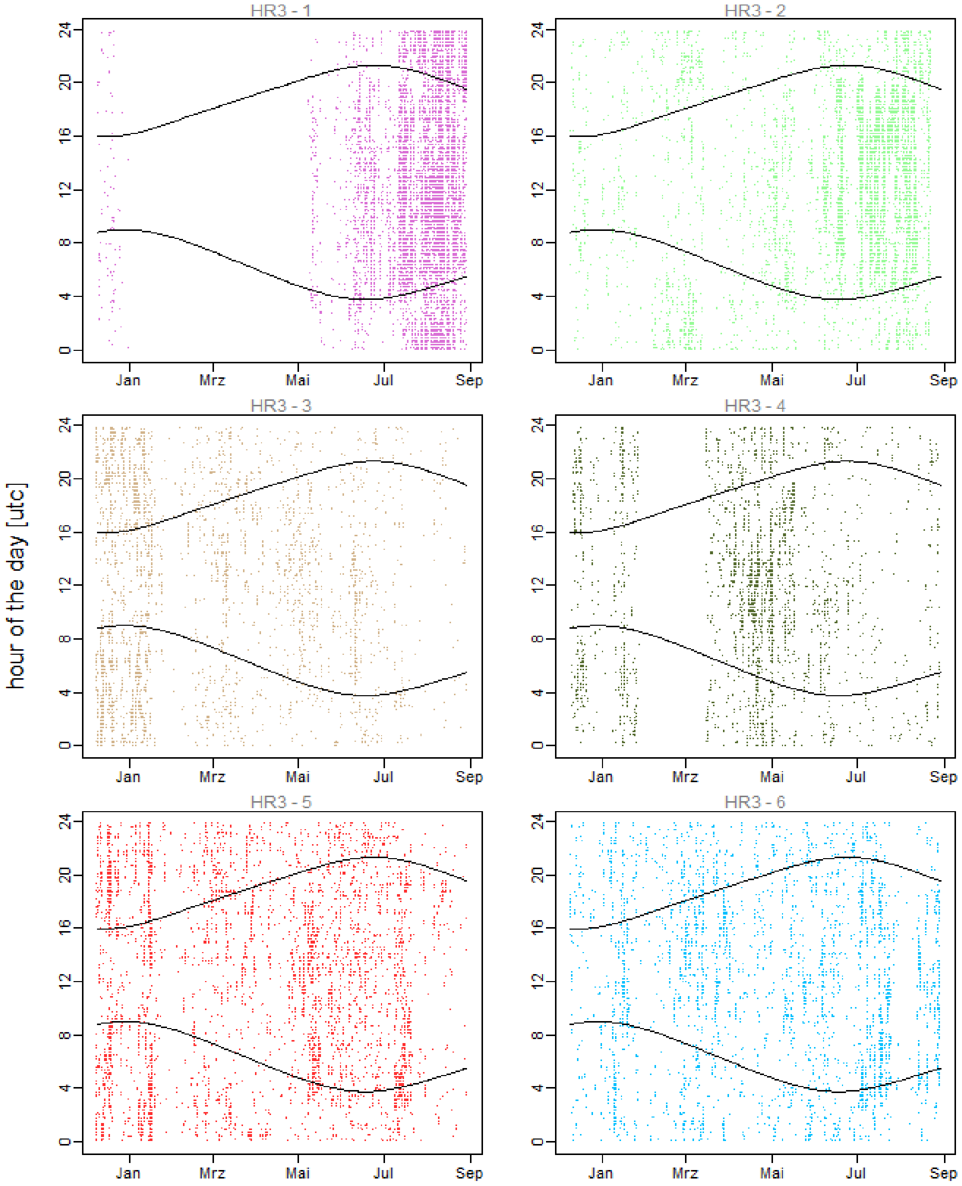

Figure 3.10: Diel variation of acoustic presence of harbour porpoises shown as detection positive minutes per ten minute interval at each station; upper black line: sunset; lower black line: sunrise

Table 3.6: Comparison of acoustic presence of porpoises during daytime and nighttime per month at each PAM-station (Kruskal-Wallis-Test, p-values; * significant; ** highly significant)

	Horns Rev 3 -1	Horns Rev 3 -2	Horns Rev 3 -3	Horns Rev 3 -4	Horns Rev 3 -5	Horns Rev 3 -6
all days	0.0001 **	0.0001 **	0.0001 **	0.3827	0.0671	0.0001 **
2012_12	0.8269	0.7549	0.0001 **	0.0001 **	0.0148 *	0.4458
2013_01	-	0.4799	0.1276	0.0012 **	0.1192	0.3685
2013_02	-	0.0001 **	0.0203 *	0.0069 *	0.1627	0.9095
2013_03	-	0.0001 **	0.0413 *	0.9625	0.3267	0.0023 **
2013_04	-	0.9551	0.5215	0.0078 *	0.6722	0.1036
2013_05	0.0005 **	0.0001 **	0.0003 **	0.0001 **	0.0001 **	0.0841
2013_06	0.0001 **	0.0029 **	0.4123	0.5548	0.2824	0.8265
2013_07	0.0010 *	0.0001 **	0.0038 **	0.0291 *	0.7883	0.0924
2013_08	0.0280 *	0.0184 *	0.8601	0.0299 *	0.4541	0.3461
2013_09	0.4835	0.1856	-	-	-	0.0001 **
2013_10	0.0041 **	0.0105 *	-	-	-	0.0001 **
2013_11	0.1604	0.0001 **	-	0.0268	-	0.3500
2013_12	-	0.877	-	0.4617	-	0.8669

3.1.2.3. Abundance and distribution based on literature

The SCANS surveys in 1994 and 2005 estimated 250,000 respectively 230,000 harbour porpoises in the North Sea and the English Channel (Hammond et al. 1995, Hammond et al. 2002 , Hammond 2006). SCANS I identified an area of high density west and east of the Jutland peninsula, whereas SCANS II (Hammond et al. 2013) did not catch up with high porpoise densities as reported by various other surveys on regional scales (Figure 3.11). According to Gilles et al. (2011) the Horns Rev area lies to the north of a high-density area for harbour porpoises west of Jutland (Figure 3.12).

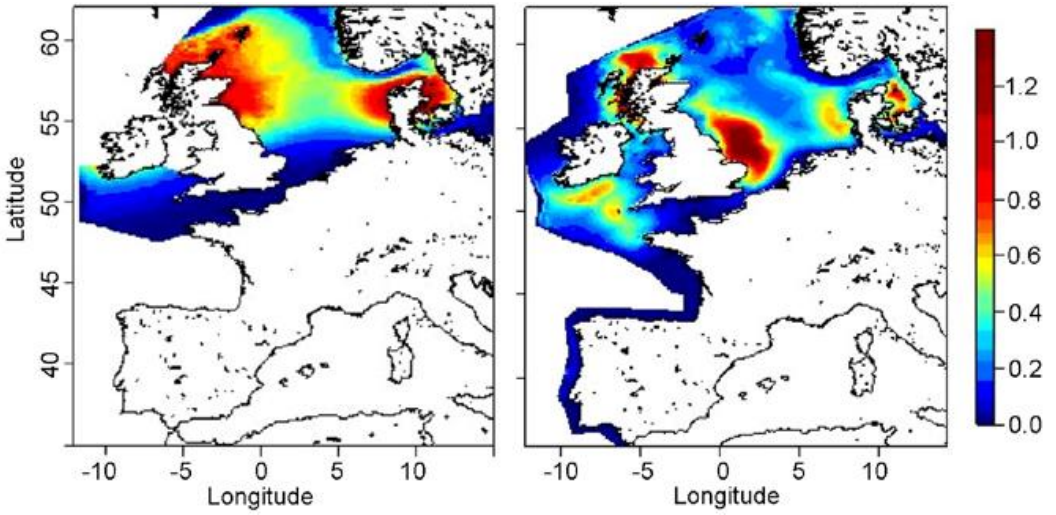

Figure 3.11: Abundance of harbour porpoises in the North Sea estimated in the SCANS I (left) and SCANS II (right) surveys 1994 and 2005 (Hammond et al. 1995, Hammond et al. 2002 , Hammond 2006)

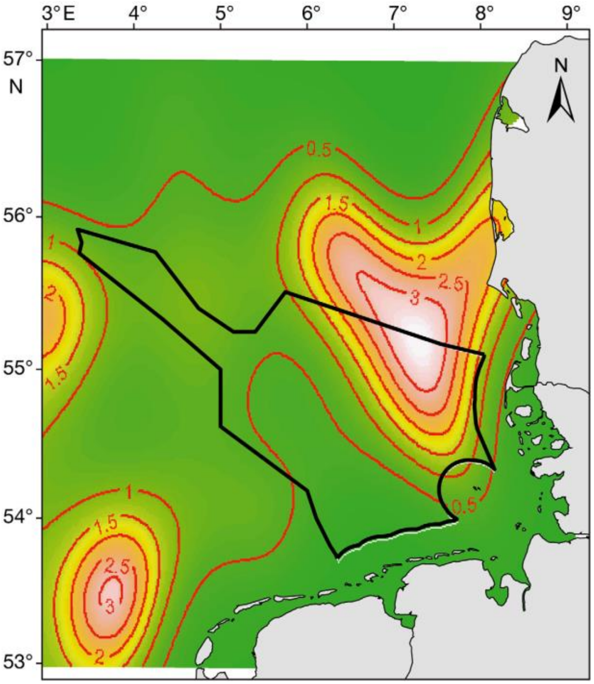

Figure 3.12: High density areas of harbour porpoises in the North Sea The numbers present modelled densities (porpoises/km²) in summer (Gilles et al. 2011).

The distribution of harbour porpoises in the North Sea is inhomogeneous with areas of higher or lower abundance. Teilmann et al. (2008) focused on the harbour porpoises in Danish waters and identified sixteen high density areas of harbour porpoises based on the results of satellite tracking, aerial, ship and acoustic surveys between 1991 and 2007. The Horns Rev area was one of the identified high density areas that was ranked as “area of high importance” for harbour porpoises besides 8 other high importance areas.

The distribution of harbour porpoises west of Jutland shows a marked seasonal pattern with maximum densities between May and July and lower numbers during winter month (Diederichs et al. 2004, Gilles et al. 2006, Brandt et al. 2008). The same pattern was observed during studies in the offshore wind farm areas Horns Rev I and Horns Rev II (Tougaard et al. 2006b, Skov & Thomsen 2006). Tougaard et al. (2003) estimated a population of 700 to 1000 harbour porpoises in the Horns Rev area during summer peak times which was in accordance to earlier results from Skov et al. (2002).

The accumulation of harbour porpoises in certain areas is presumably linked to the distribution of prey, which in turn depends on parameters such as hydrography and bathymetry (Raum-Suryan & Harvey 1998; Skov & Thomsen 2008). The study of Skov and Thomsen (2008) which focused on the Horns Rev area indicated that the distribution of harbour porpoises might be related to upwellings caused by tidal currents. The authors assumed that distributional changes might be related to movements of prey as observed in other studies (Johnston et al. 2005, Sveegaard 2011). So far there is no knowledge about the prey preferences of harbour porpoises in the Horns Rev area. Most common species in the area are Sandeel (*Ammodytes sp.*), Plaice (*Pleuronectes platessa*), Sand goby (*Pomatoschistus minutus*), and Dab (*Limanda limanda*) (Jensen et al. 2006, Carl & Nielsen 2013) which are likely to serve as important prey species for the local harbour porpoise population.

Sonntag et al. (1999) found high proportions of harbour porpoise calves in North Sea waters off the coast of Schleswig Holstein near the islands of Sylt, Amrum and southern Rømø, in about 70 to 80 km distance to the planned offshore wind farm Horns Rev 3. Fourteen percent of harbour porpoises sighted during aerial survey were calves. The authors also reanalyzed data from the SCANS I survey in 1994 and found an average percentage of 5.4% calves for the North Sea in general. The authors therefore concluded that the area is a calving ground for harbour porpoises (Sonntag et al. 1999).

Also the Horns Rev area shows highest abundance of harbour porpoises between May and July (Diederichs et al. 2004, Gilles et al. 2006, Brandt et al. 2008). This is the time when harbour porpoises give birth and mate and therefore the Horns Rev area is used during most important reproduction periods and disturbance in the area might impair reproduction.

A total of 54 aerial surveys for harbour porpoises have been conducted in the Horns Rev area by the National Environmental Research Institute of Denmark (NERI) between 1999 and 2007 as well as from 2011 to 2012. The raw data of these surveys were kindly provided by NERI for further evaluation. Overall, more than 38,800 km (26 transects) have been surveyed and 1204 harbour porpoises were sighted in total. 63% (34 surveys) of the survey flights took place between February and May while 37% (20 surveys) took place between August and January; there is no data from June and July. Survey flights were undertaken at an altitude of 250 feet using a high-winged, twin-engine Partenavia (P68), equipped with bubble windows by the middle seats, similar to the planes used for this study. Maps of the positions and group sizes of harbour porpoises based on the NERI flights with at least 18 sighted animals can be found in Appendix Figure 7.6 to Figure 7.26. As no information on weather condition is given, no effort can be calculated and thus no conclusions on realistic densities can be drawn. As a result no distance analysis is possible. However, numbers of counted harbour porpoises per survey (with at least 18 sighted animals) are represented in Table 3.7. Sighted numbers of all surveys can be found in Appendix Table 7.4. No information can be given on calf-numbers from the NERI-flights.

Table 3.7: Number of sighted harbour porpoises and transect lengths during NERI flights (with≥18 animals) within the area of Horns Rev

Survey date	Harbour porpoises	Transect length (km)
03.09.1999	29	803.54
17.02.2000	18	819.44
27.04.2000	80	731.86
20.03.2001	20	818.71
22.08.2001	37	823.06
08.08.2002	95	680.49
16.03.2003	54	868.46
23.04.2003	58	861.57
26.03.2004	34	859.59
10.05.2004	18	857.71
14.05.2005	56	862.93
17.08.2005	83	861.36
25.02.2006	24	840.65
11.05.2006	37	844.92
25.01.2007	18	710.50
15.02.2007	18	667.38
01.04.2007	31	794.11
11.04.2011	64	640.78
13.10.2011	76	633.31
02.03.2012	20	596.60
22.03.2012	41	618.69

Harbour porpoises occurred at 54 out of 54 flights showing that they use the area of Horns Rev throughout the whole year. During 21 survey flights more than 18 harbour porpoises each were counted. The highest number of animals was sighted in August 2002 with 95 harbour porpoises, followed by 83 (August 2005), 80 (April 2000) and 76 animals (October 2011). During 33 surveys less than 18 individuals were counted being lowest with just two sightings in February 2003 and April 2012. In general average numbers were lowest in winter, steadily increasing during spring from March to May with highest numbers in summer (August) indicating patterns for seasonal use of the area by harbour porpoises. This pattern is depicted in Figure 3.13.

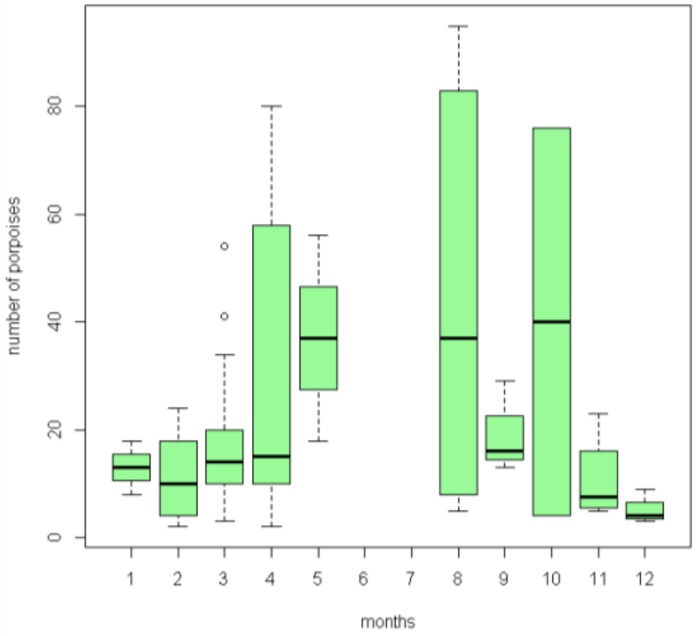

Figure 3.13: Box plot of seasonal use of Horns Rev area by harbour porpoises based on NERI aerial surveys 1999 – 2007 and 2011 – 2012 per month

Group size varied from one to six animals where 68% of all sighted animals occurred as single individuals. Highest group size of six animals occurred just once. Sightings showed a large area distribution across the whole research area with no specific subarea preferred but they seem to avoid areas close to the coast. Based on NERI data no effects of the construction of Horns Rev I could be observed, also due to insufficient data. Between 2008 and 2010 no flights were conducted, thus no conclusions on effects due to construction of Horns Rev II can be drawn from aerial survey data.

3.1.2.4. Importance of the Horns Rev 3 area to the harbour porpoise

The area around Horns Rev has been studied by visual surveys since the mid-1990s and by means of passive acoustic monitoring since early 2000 (Skov et al. 2002, Hammond et al. 1995, 2013, Tougaard et al. 2006b, Diederichs et al. 2008a, Brandt et al. 2009, 2011a, Teilmann et al. 2008). These studies showed that the coastal area adjacent to Horns Rev is an area with temporally high densities with up to 20 ind./km² (Skov et al. 2002). This is an indication for the importance of Horns Rev as foraging habitat for harbour porpoises, whilst continuous presence of calves in the months between May and August are an indication for their relevance as nursery ground. These waters are part of a high density area stretching from the eastern German Bight northwards along the Danish coast (Gilles et al. 2011).

The results of the POD study are comparable to results from other studies on harbour porpoises in the northern German Bight and in the vicinity of Horns Rev (Tougaard et al. 2006b, Diederichs et al. 2008a, Brandt et al. 2009, 2011a). They show a distinctive seasonality with low acoustic activity in winter and springtime, increasing detection rates in summer that peak in August and September before the detection rates decrease in autumn. During the baseline study of Horns Rev 1 and thereafter the lowest acoustic activity of porpoises has been found between January and March, medium values between April and July as well as in November and December and highest values between August and

October (Tougaard et al. 2006b: July 2001 and December 2005). Similar results were found during the baseline investigations of Horns Rev 2 (June 2005 until October 2006), though, the results are not directly comparable with the prior study PAM data of the EIAs for the projects Horns Rev 1 and Horns Rev 2 were based on the first generation of T-PODs, thus, absolute numbers in detection rates cannot be compared directly with the C-POD data presented in this study. Nevertheless, since both devices detect porpoise echolocation clicks at a relative scale, seasonality and day-night rhythms in detection rates are comparable but with limitations. Furthermore some of the data from Horns Rev 2 were recorded during the construction phase in summer of 2008 and might be biased by pile driving activities (Brandt et al. 2011a).

The observed seasonality at the six PAM-stations also appears in the results from aerial surveys during this study and earlier investigations more to the south (Skov et al. 2002, Hammond et al. 1995, 2013, Tougaard et al. 2006b, Diederichs et al. 2008b, Teilmann et al. 2008). The shallow areas around Horns Rev were intensively used in April and May as well as in August 2013, and low densities of harbour porpoises in January, February and March well as during September and November 2013 coincide with low detection rates during these months. As well the results from previous years in other studies show that low counts of porpoises coincide with low activity in spring, autumn and winter and high counts in April and August coincide with high detection rates in these months (Tougaard et al. 2006b, Diederichs et al. 2008b).

The results of both the aerial surveys and the passive acoustic monitoring show a density gradient during summertime with increasing numbers of porpoises from the east to the west, which hasn’t been shown before for the Horns Rev area. In this respect it is interesting to note that the distribution of suitable sandeel habitats coincides nicely with the geographic position of the western PODs ‘Horns Rev 3 - 1’ and ‘Horns Rev 3 - 2’ (Figure 3.14, see Carl & Nielsen 2013), while the position of the other four eastern C-PODs coincide with the area used for brown shrimp fishery (Figure 3.14 see report on Fisheries EIS). Landings of sandeel peak normally between May and July. Sandeels rest during the night buried in the sand banks and despite the echolocation abilities of harbour porpoises foraging is limited to daylight conditions (Jensen et al. 2003, 2011, Linnenschmidt et al. 2012b). Considering the feeding ecology of harbour porpoises (Santos & Pierce 2003, MacLeod et al. 2007, Jansen et al. 2012, Nabe-Nielsen et al. 2011, Sveegaard et al. 2012) and the ecology of sandeels this study could show a close link between habitat utilisation of harbour porpoises in the western part of the study area during May, June, July and August 2013 and their food source. The diel pattern observed in other months and other parts of the study area might be linked to fishing activities more to the east. Our results are in line with two other studies that analysed diel pattern in echolocation activity of harbour porpoise next to a North Sea offshore gas installation and a re-established reef structures in the Kattegat (Todd 2009, Mikkelsen et al. 2013). Both studies showed a higher activity at night than during daytime and concluded that increased numbers of click trains with interclick intervals below 10 ms confirmed the importance as foraging habitat.

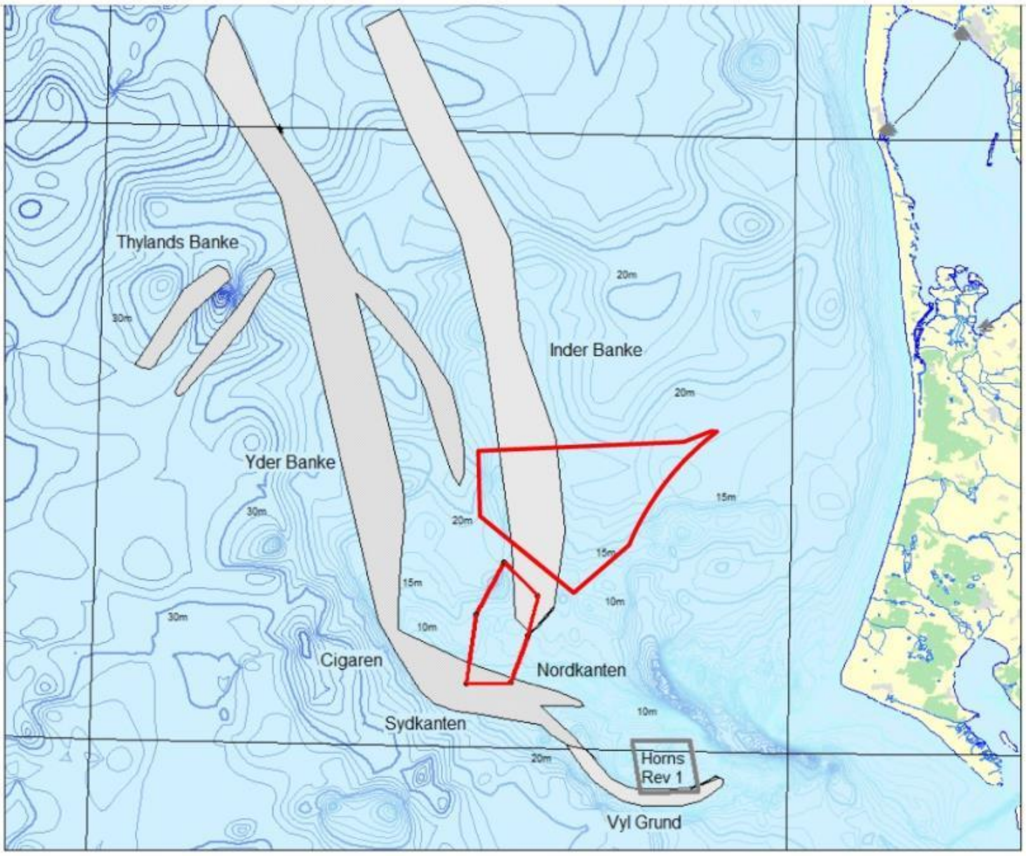

Figure 3.14. Outlines of sandeel fishing grounds in the region of Horns Rev derived from electronic map plotter data from four experienced fishermen. The Horns Rev 3 pre-investigation area is the largest area outlined in red to the north of the smaller Horns Rev 2 area – also outlined in red (modified from Krog 2009).

Following the criteria as defined in Table 2.4 the Horns Rev area is of very high importance for harbour porpoise.

3.2. Harbour seal

Harbour seals are found around the coasts of the North Atlantic and North Pacific from the subtropics to the Arctic and are one of the two pinniped species native to the North Sea. Males grow up to 180 cm in length while females are a bit shorter with up to 150 cm (King 1983). Fecundity in females is reached at age 4 – 5 (Riedmann 1990). Normally a female gives birth to a single pup during the breeding season in June/July. The newborn is weaned for approximately four weeks and is able to swim almost immediately after birth (King 1983, Riedmann 1990). The life history of harbour seals is characterised by an alternation of the importance of inshore areas for hauling out and offshore areas frequently used for foraging. Harbour seals spend roughly 80% of their time in the water except during breeding, weaning and moulting from June to September when they haul-out extensively (Hammond et al. 2003). Between hauling out, harbour seals undertake foraging trips normally within 40 – 50 km of their haul sites, showing certain site fidelity. The seasonal importance of haul-out sites varies between animals of different age or sex. The consequence is a strong seasonal variability in the occurrence and behaviour of harbour seals at sea. They feed on a wide variety of fish and cephalopods. European populations suffered extensively from two epidemics of the phocine distemper virus (PDV) in recent times (1988 and 2002). Whereas responses of seals to human activities at haul-out sites is well documented (e. g., review in Dietz et al. 2000, Teilmann et al. 2006a, Teilmann et al. 2006b, Osinga et al. 2010, Skeate et al. 2012) there is limited information on response to pile driving at sea (McConnell et al. 2012) but recent studies with harbour seals (Kastelein et al. 2011, Kastelein et al. 2013) suggest that pile driving sounds are audible to them in distances in order of hundreds of kilometres from pile driving sites.

3.2.1.Conservation status of the harbour seal

Harbour seals in the Wadden Sea area are protected under the Trilateral Seal Agreement between Denmark, Germany and the Netherlands under the Bonn Convention from 1991 which aims at achieving and maintaining a good conservation status and a close cooperation between countries with access to the Wadden Sea. In addition it is covered by Annex II of the Bonn Convention and protected under Annex III of the Bern Convention which also involves the cooperation of the nations with bordering the Wadden Sea. The harbour seal is further listed in Annex II and Annex V of the European Commission’s Habitat Directive resulting in the definition of distinct conservational areas and in the management of exploitation and taking in the wild as a means for protection (Council of Europe 2002, Bundesamt für Naturschutz 2011, CMS 2012). The red list regional for Germany (Bundesamt für Naturschutz 2009) as well as the IUCN red list (IUCN 2012) classifies harbour seals with least concern.

3.2.2.Abundance and distribution based on aerial surveys

Between January and August 2013 a monthly combined aerial survey for marine mammals and seabirds was conducted within the area of Horns Rev 3. Maps depicting the positions and numbers of the sighted harbour seals and unknown seals during surveys on the track line can be found in Appendix from Figure 7.27 to Figure 7.34. Figure 3.15 shows the number of sighted animals during the monthly survey flights. See

Table 3.8 for more detailed descriptions.

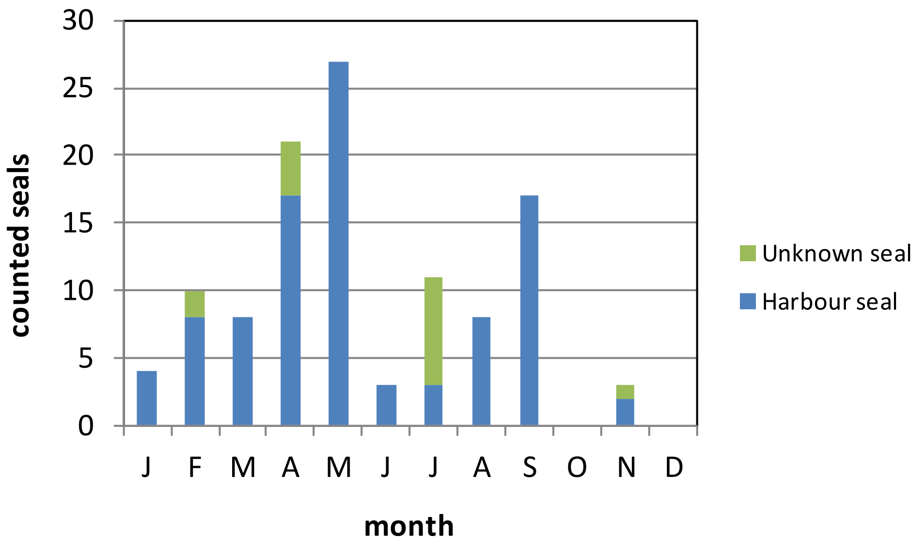

Figure 3.15: Number of seals per monthly aerial survey from January to November 2013 at Horns Rev 3 (blue= harbour seals, green= unknown seals); for details see Appendix

Table 3.8: Number of harbour seals, grey seals and unknown seals per aerial survey at Horns Rev 3

Survey date	Harbour seal	Grey seal	Unknown seal	Total
16.01.2013	4	0	0	4
13.02.2013	8	0	2	10
04.03.2013	8	0	0	8
01.04.2013	17	0	4	21
07.05.2013	27	0	0	27
05.06.2013	3	0	0	3
06.07.2013	3	0	8	11
22.08.2013	8	0	0	8
17.09.2013	17	0	0	17
17.11.2013	2	0	1	3

Harbour seals were observed in ten out of the ten months when surveys were carried out. During this time period a total of 112 seals, of which 97 could be clearly identified as harbour seals (15 were seals where species identification was not possible), were counted. Numbers of seals (harbour and unknown seals) increased from low numbers in January (n=4) to a maximum in late spring (April: n=21, May: n=27), before the start of the breeding season. Numbers decreased again in summer. In June the second lowest number was (n=3) recorded whereas numbers slightly increased again in July (n=11) and August (n=8). In September numbers continued to rise (n=17) before they declined in November (n=2). This gives a first insight into seasonal use of the Horns Rey 3 area by harbour seals. Group size varied between one and three individuals; at seven surveys only single animals could be observed whereas in May, July and September also groups of two or three seals were encountered. No calves could be clearly identified. Sightings showed a large area distribution across the whole research area with no specific subarea preferred. The used counting method is practical and optimized for harbour porpoises and cannot be applied in the same way for pinnipeds.

3.2.3. Abundance and distribution based on literature

Several studies have been conducted in the waters around Horns Rev in order to monitor seal populations and investigate possible effects of the construction and operation of wind farms on pinnipeds inhabiting this area (e.g., Fisheries and Maritime Museum 2000, Boesen & Kjaer 2005, Teilmann et al. 2006b, Tougaard et al. 2006c, Müller & Adelung 2007). However, to be able to assess possible effects of wind farms on seals a number of studies in the North Sea, partly also within the area of Horns Rev, were conducted within the last decade utilizing an array of methods including satellite transmitters (Tougaard et al. 2006c), the employment of dead-reckoning systems (Müller & Adelung 2007), and the use of ship-based and aerial line-transect surveys (Tougaard et al. 2006c, Herr et al. 2009) or surveys of the known haul-out sites (Trilateral Seal Expert Group 2012).

The population size of harbour seals in the Wadden Sea area has been determined since 1975 by the TSEG (Trilateral Seal Expert Group) using aerial survey methods where seals were counted when hauling out on sandbanks. Periods of population growth were followed by catastrophic events caused by two epizootics in 1988 and 2002. In 2002 only 47% of the expected number of seals was counted (Reijnders et al. 2009; Figure 3.16). The annual average increase in population size since the epizootic in 2002 was 10.4% until 2012 being close to the theoretical maximum population growth of 13% (Reijnders et al. 2009, Trilateral Seal Expert Group 2012).

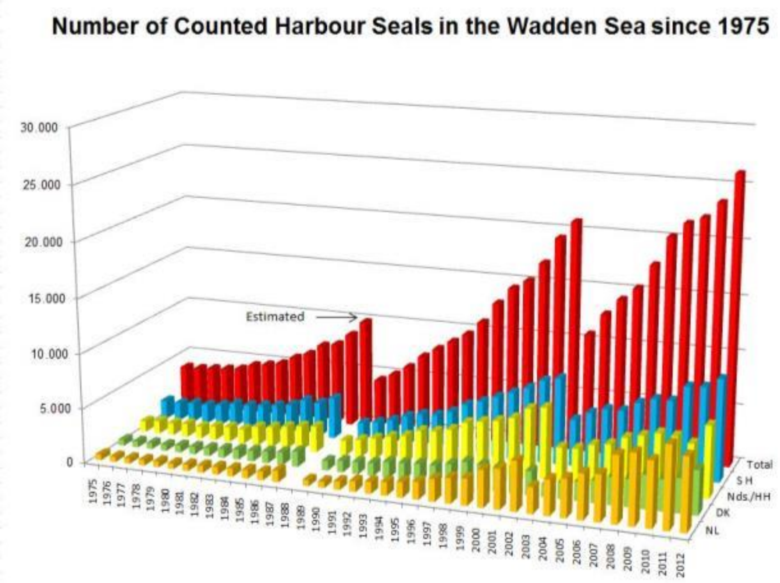

Figure 3.16: Population size of the harbour seal (*Phoca vitulina*) in the Wadden Sea 1975-2012 (red columns: total numbers, blue: Schleswig-Holstein, yellow: Lower Saxony and Hamburg, green: Denmark, orange: Netherlands) (Trilateral Seal Expert Group 2012)

The MINOS projects showed that the highest abundance of pinnipeds occurred near the coast (Figure 3.17) which correlates with findings from telemetry studies (Gilles et al. 2008). The results of the ship-based survey conducted in the winters of 1992/93 in the coastal, eastern North Sea revealed a high concentration area of harbour seals around the tidal inlets off the Ems estuary. Another cluster of observations was found around the 10 m isobath off Schleswig-Holstein. Low densities were found in the inner German Bight and in Danish waters with no sightings north of Rømø (Leopold et al. 1997). It could be shown that some 20% of the entire population observed in the Wadden Sea during summer could be detected offshore in the North Sea in mid-winter (Leopold et al. 1997). The seasonal pattern of seal numbers on their haul-outs in the Wadden Sea further indicates that a substantial part of the population utilizes offshore areas during winter.

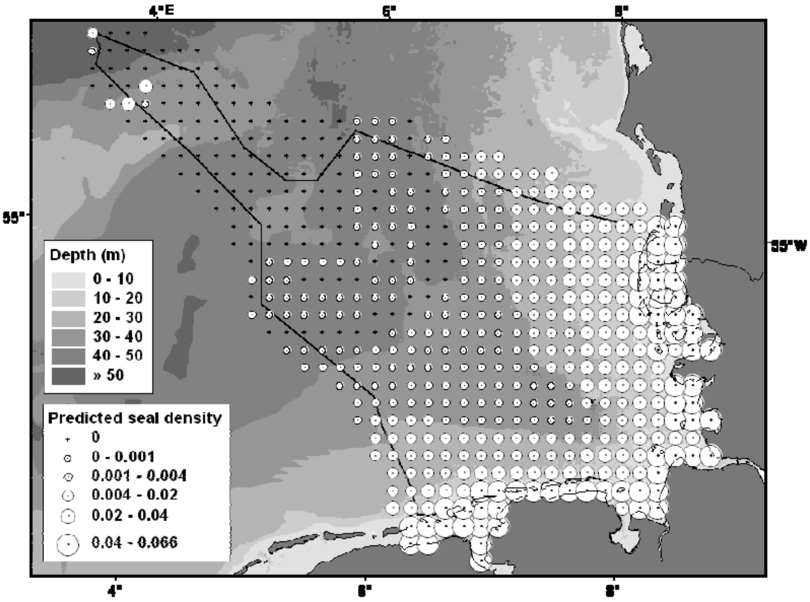

Figure 3.17: Abundance of the harbour seal (*Phoca vitulina*) in the German North Sea. (Gilles et al. 2008).

Aerial surveys and the ship-based counts 1999-2000 in the Horns Rev area provided few sightings at sea. First telemetry studies in the Danish Wadden Sea area in the early 1990's (Nørgaard 1995), indicated the use of the Horns Rev area by harbour seals from haul-out sites in the Wadden Sea. Later studies provided evidence that harbour seals regularly utilize the offshore areas adjacent to the Wadden Sea for extended foraging trips (Tougaard et al. 2008, Figure 3.18). The Horns Rev area is part of this area utilized as foraging ground or passed by seal between foraging grounds and the Wadden Sea.

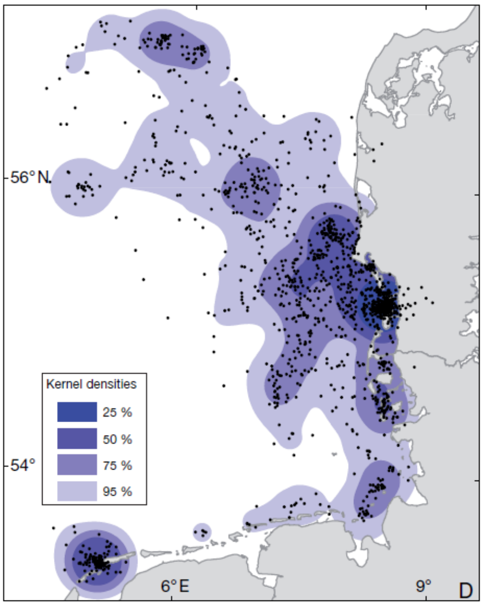

Figure 3.18: Kernel densities from harbour seal recordings by means of satellite telemetry tagged at the island of Rømø (Tougaard et al. 2008).

3.2.4. Importance of the Horns Rev 3 area to harbour seal

Data from different surveys and telemetry studies (see chapters 3.2.2 and 3.2.3 above) suggest that Horns Rev and the surrounding waters are utilized by seals. It can be concluded that harbour seals observed in or adjacent to the Horns Rev area are part of a larger Wadden Sea population. Thus, the Horns Rev area is only a minor fraction of the area used by this population and it is concluded that the area is of medium importance to harbour seals without any special functions as haul-out or nursing area.

3.3. Grey seal

Grey seals are found in the North Atlantic, Barents and Baltic Sea with their main concentrations on the northeast coast of North America and north-west Europe. The grey seal is also the second of the two pinniped species native to the North Sea. Males grow to a length of 220 cm whereas females are slightly shorter with a length of 180 cm (King 1983). First pupping occurs at the age of 4 – 5 years (King 1983). Pupping takes place at different times of the year ranging from September to December depending on the population (King 1983, Hammond et al. 2003). In the Wadden Sea this period extends to January (Reijnders et al. 1997). Unlike harbour seals grey seals are born with a white lanugo coat which they shed after approximately three weeks with the end of the lactation period (King 1983). Since this first fur does not protect against cold water, pups stay on dry sandbanks and beaches until then. Moulting takes places in late winter to early spring (Hammond et al. 2003). Grey seals are generalist predators with a diet mainly consisting of small demersal and pelagic fish. They migrate from the Wadden Sea to the UK East coast and vice-versa (TSEG, 2006). Even if the actual population growth is supported by the pups recruiting into the breeding population, there is still a large number of animals immigrating into the area from the British East Coast, especially the Farne Islands (Reijnders et al. 1997, Trilateral Seal Expert Group 2012).The actual number of grey seals using the Wadden Sea is unknown as well as the number of pups born, population structure and genetic relationship with other populations in the North Sea. The largest stock of grey seals in the North Sea comprising an estimated 180,000 animals is found at breeding colonies around Scotland (Niedersächsischer Landesbetrieb für Wasserwirtschaft 2011).

3.3.1.Conservation status of the grey seal

Grey seals in the Wadden Sea area are protected under the Trilateral Seal Agreement between Denmark, Germany and the Netherlands under the Bonn Convention from 1991 which aims at achieving and maintaining a good conservation status and a close cooperation between countries with access to the Wadden Sea. It is protected under Annex III of the Bern Convention which also involves the cooperation of the nations with access to the Wadden Sea. It is further listed in Annex II and Annex V of the European Commission's Habitat Directive resulting in the definition of distinct conservational areas and in the management of exploitation and taking in the wild as a means for protection (Council of Europe 2002, Bundesamt für Naturschutz 2011, Council of Europe 2002). The BfN red list regional for Germany (Bundesamt für Naturschutz 2009) as well as the red list for Schleswig-Holstein (Landesamt für Natur und Umwelt des Landes Schleswig-Holstein 2001) classifies grey seals as endangered; the IUCN red list as with least concern.

3.3.2.Abundance and distribution based on aerial surveys

Between January and November 2013 ten combined aerial surveys for marine mammals and seabirds were conducted within the area of Horns Rev 3. For further description of surveys and counted seals refer to chapter 3.2.2.1.

During the ten flights no grey seals could be clearly identified. A total of 15 unidentified seals could be encountered, which occurred only in February, April, July and November in group sizes of one or two individuals (Table 3.8). These animals could partly be grey seals as well as sightings of grey seals in the Danish Wadden Sea has increased during the last decade to 76 sighted individuals in summer 2012 (Trilateral Seal Expert Group 2012). But as no species identification of all seals was possible, this assumption is just speculative and no further conclusions can be made. Nevertheless, even if all unknown seals were grey seals, the total number of 15 animals during ten surveys is comparatively low.

3.3.3.Abundance and distribution based on literature

Around the 15th century grey seals became extinct in the Wadden Sea and along the Dutch North Sea coast (Reijnders et al. 2009). In the late 1970s a colony established near Amrum (Trilateral Seal Expert Group 2006; Reijnders et al. 2009) and in the late 1980s on the dune island of Helgoland whereas in the Dutch Wadden Sea grey seals first colonized a sandbank near Terschelling in 1980. By the late 1990s further colonies had established in western Wadden Sea (Trilateral Seal Expert Group 2001). Surveys at Amrum revealed an average increase in numbers of 5.7% between 1976 and 2000 and an increase of births between 1988 and 2000 of 7.7% per year. Large numbers obtained in spring might reflect influx from other colonies in the North Sea splitting the population into a resident breeding colony and seasonally appearing animals stemming mainly from the UK (Abt et al. 2002). From 1980 to 2006 an overall average annual increase of the grey seal population size by 20% at the main haul-out sites in the Wadden Sea was estimated (Trilateral Seal Expert Group 2006). At the same time a shift in preferred breeding colonies and an increase of newly established colonies by a factor of 2 - 3 could be observed

(Abt & Engler 2009) indicating an ongoing re-colonisation of the Wadden Sea. In recent seal counts, grey seal numbers counted in the Wadden Sea have increased by 22% from 2011 to 2012 (Trilateral Seal Expert Group 2012) while a sustained population growth without immigration would not allow more than 11% growth (Trilateral Seal Expert Group 2012). The distribution of grey seals has expanded from a few local sites to an almost continuous distribution throughout the Wadden Sea (Trilateral Seal Expert Group 2009). Taken into account the differing counting methods, variation of population development in the different countries and immigration of animals a general population growth could be observed (Trilateral Seal Expert Group 2011). This variability noted in grey seal counts and pup production and their survival also depended upon ecological factors such as winter conditions (Trilateral Seal Expert Group 2009).

Data from marked and satellite-tagged grey seals indicate an exchange between haul-out sites within the Wadden Sea and haul-out sites in the UK (Härkönen et al. 2007, Brasseur et al. 2010). As a consequence, the Wadden Sea population can be considered as an open population (Trilateral Seal Expert Group 2009). Even though grey seals are so far sighted less frequently in the Danish Wadden Sea compared to the German or Dutch Wadden Sea, the overall increase in population size in the Wadden Sea might lead to the establishment of a breeding colony in the Danish Wadden Sea at some point (Tougaard et al. 2006c). Data from 27 grey seals tagged in the Netherlands between 2005 and 2008 show that most movements occurred close to the haul-out sites (Brasseur et al. 2010). However, often grey seals also forage far offshore such as at the Frisian front of the Doggerbank. Long distance movements of various seals parallel to the Dutch coast or even to the British east coast were also commonly observed.

3.3.4.Importance of the Horns Rev 3 area to the grey seal

Data from different surveys and telemetry studies (see chapters 3.3.2 and 3.3.3 above) suggest that Horns Rev and the surrounding waters are utilized by seals.

So far there is no indication that the area of Horns Rev 3 is of more than minor importance to grey seals.

4. IMPACT ASSESSMENT

To ensure a uniform and transparent basis for the EIA, a general impact assessment methodology for the assessment of predictable impacts has been prepared together with a list of terminology.

4.1. The impact assessment scheme

The overall goal of the assessment is to describe the **Severity of Impact** caused by the project. The assessment comprises two steps; where the first step is an analysis of the magnitude of the pressure and an analysis of the sensitivity of the environmental factor. Combining the two analyses leads to the **Degree of Impact**. In the second step; the results from the Degree of Impact is combined with the importance leading to the Severity of Impact.

As far as possible the impacts are assessed quantitatively, accompanied by a qualitative argumentation. The assessment steps are shown in Figure 4.1

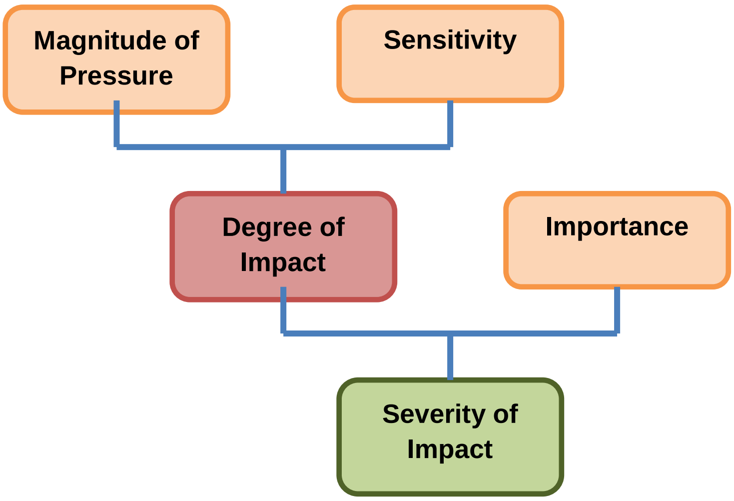

Figure 4.1: Drawing of the overall assessment approach

4.1.1. Magnitude of pressure

There are several crucial steps in the outlined assessment procedure shown in Figure 4.1. The foremost is the determination of the Magnitude of Pressure and the Sensitivity.

The Magnitude of Pressure is described by pressure indicators. These indicators are based on the modes of action on environmental factors in order to achieve most optimal descriptions of pressure for the individual factors; e.g. mm deposited sediment within a certain period and area. The content of the Magnitude of Pressure is thus made up of:

- intensity
- duration
- range

The *intensity* evaluates the force of the pressure and should as far as possible be estimated quantitatively.

The *duration* determines the time span of the pressure. Some pressures (like footprints) are permanent and do not have a finite duration. Some pressures occur as events of differing durations.

The *range* of the pressure defines the spatial extent. Outside of the range, the pressure is regarded as non-existing or negligible.

Distinctions are made between direct and indirect pressures where direct pressures are those imposed directly by the Project activities on the environmental factors while the indirect pressures are the consequences of those impacts on other environmental factors and thus express the interactions between environmental factors.

As far as possible the Magnitude of Pressure is worked out quantitatively. The method of quantification depends on the specific pressure (spill from dredging, noise, vibration, etc.) and on the environmental factor to be assessed (calling for different aggregations of intensity, duration and range).

4.1.2.Sensitivity

The optimal way to describe the sensitivity to a certain pressure varies between the environmental factors involved. To assess the sensitivity, more issues may be taken into consideration; such as intolerance to the pressure and the capability of recovering after impairment or a temporary loss. In most cases, the sensitivity of a certain environmental factor will be collected from the literature and is very often given as a threshold value.

4.1.3.Degree of impact

In order to determine the Degree of Impact; the Magnitude of Pressure and Sensitivity are combined in a matrix, see Table 4.1. The Degree of Impact is the pure description of an impact to a given environmental factor without putting it into a broader perspective (the latter is done by including the Importance in the evaluation).

Table 4.1 The matrix used for the assessment of the Degree of Impact.

Magnitude of pressure	**Sensitivity**			
	Very high	High	Medium	Low
Very high	Very High	Very High	High	High
High	Very High	High	High	Medium
Medium	High	High	Medium	Low
Low	Medium	Medium	Low	Low

4.1.4.Severity of impact

Severity of impact is assessed from the grading of Degree of Impact and Importance of the environmental factor using the matrix in Table 4.2. If it is not possible to grade Degree of Impact and/or Importance, an assessment is given based on expert judgment.

Table 4.2 The matrix used for the assessment of the Severity of Impact.

Degree of impairment	Importance of the environmental component				
	Very high	Very high	Very high	Very high	Very high
Very High	Very high	Very high	Very high	Very high	Very high
High	High	High	High	High	High
Medium	Medium	Medium	Medium	Medium	Medium
Low	Low	Low	Low	Low	Low

4.1.5. Assessment of cumulative impacts

The aim of the assessment of cumulative impacts is to evaluate the extent of the environmental impact of the project in terms of intensity and geographic extent compared with other projects in the area and the vulnerability of the area. The assessment of the cumulative conditions includes activities associated with existing utilised and unutilised permits or approved plans for projects.

When more projects within the same region affect the same environmental conditions at the same time, they are defined to have cumulative impacts. A project is relevant to include, if the project meets one or more of the following requirements:

- The project and its impacts are within the same geographical area as other projects
- The project affects some of the same or related environmental conditions as other projects
- The project has permanent impacts in its operation phase interfering with impacts from other projects

For each environmental component possible cumulative impacts with other projects will be considered.

4.2. Relevant project pressures

The possible effects of the offshore wind farm Horns Rev 3 can be separated in short-term effects during construction and long-term effects during operation of the wind farm.

Main pressures are considered to be

1. underwater noise
2. habitat change and habitat loss

4.2.1. Construction

The main pressures during construction of the offshore wind farm Horns Rev 3 will be underwater noise (especially in case of pile driving), increased ship traffic and disturbance of the bottom sediment during foundation and cable trenching. These pressures are likely to cause displacement of Harbour porpoises and seals from the construction site. Noise immissions from pile driving have been modelled in a separate study (Mason & Barham 2013) using the **I**mpulse **N**oise **S**ound **P**ropagation and **I**mpact **R**ange **E**stimator (INSPIRE) to model the impact of pile driving during construction of the wind farm Horns Rev 3 (Mason & Barham 2013). INSPIRE is based on a database containing data from 10 individual sites with measurements of sound propagation along 29 different transects. Pile diameters range from 0.5 to 6.1 m. Blow energies between 400 kJ and 1100 kJ have been recorded.

For the construction of Horns Rev 3 pile diameter of 10 m and a maximum hammer blow energy of 3000 kJ was taken as a basis. The 10 m pile diameter is the maximum size considered for the proposed 10 MW turbines. A proprietary underwater sound propagation model was used that enables the behaviour of noise with distance from the piling to be estimated for varying tidal conditions, water depths and piling locations based on an existing database of measurements of piling noise (Mason & Barham 2013).

4.2.2. Operation and structures

During operation noise emissions and habitat changes due to artificial reef structures could affect harbour porpoises and seals. The habitat change due to artificial reef structures and hydrographical changes will alter the species community in the predominantly sandy bottom area which will alter the food availability of marine mammals.

4.3. Sensitivity analysis

The following chapter describes sensitivity; the general response of marine mammals to the pressures associated with construction and operation of the offshore wind farm Horns Rev 3. The analysis is based on peer-reviewed literature, environmental impact assessments of other wind farm projects and data collected for the Horns Rev 3 area. In establishing the relationships between the pressures and the responses of marine mammals, the aim of the chapter is to conclude on the degree of impairment in relation to the magnitude of the pressures.

4.3.1. Noise

4.3.1.1. Importance of sound for marine animals

Sound in water travels much further and faster than in air and due to poor visibility in many marine environments sound is the most important source for information about the surroundings for a large number of marine organisms. It is used for orientation and communication and contains biologically important information about short and long range surroundings such as waves indicating the location of the coastline or other topographic landmarks, or the presence of prey, predators or conspecifics (Richardson et al. 1995). The speed of sound in water is about 4.5 times faster than in air (MacLennan & Simmonds 1992) and low frequency sound can travel over very long distances (Wille 1986).

Marine mammals use sound in communication, orientation and navigation, foraging and predator avoidance (Tyack 2008). Depending on species and context a wide frequency range from very low frequencies in baleen whales to high frequency ultrasound clicks is used (Southall et al. 2007).

Seals use sound in different social contexts such as mating, mother-calf relation and territorial behaviour (Richardson et al. 1995). In seals however, the tactile sense is very acute and they can sense even the slightest water movements such as those produced by the movement of prey with their whiskers. Therefore, the range in which they can sense hydrodynamic movements can exceed their audible or visible range (Hanke et al. 2010).

4.3.1.2. Hearing ability of harbour porpoise

The hearing ability of harbour porpoises has been investigated in a number of studies using either behavioural or physiological (auditory brainstem) tests. The audiograms available from these studies showing the hearing thresholds at different frequencies are displayed in Figure 4.2. The audiograms show large differences in frequency range and hearing thresholds of harbour porpoises which are most likely not only caused by differences in methodology but by individual differences in hearing ability, motivation and tolerance towards sound. The widest frequency range from 250 Hz to 180 kHz and lowest hearing thresholds were determined in a behavioural study by Kastelein et al. (2002). The best hearing ability (defined as the range up to 10 dB above the highest sensitivity) was measured between 16 and 140 kHz with lowest hearing thresholds of 33 dB re 1µPa at frequencies between 100 - 140 kHz (Kastelein et al. 2002) which contains the frequency range in which harbour porpoises produce ultrasound signals for echolocation (Kastelein et al. 1999).

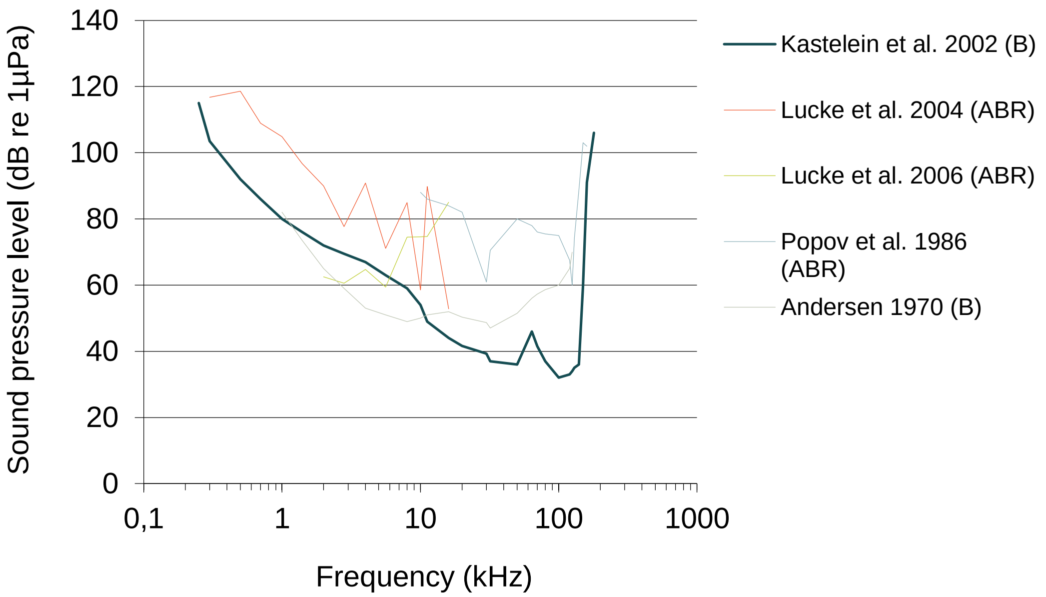

Figure 4.2 Audiograms of harbour porpoises determined by behavioural studies (B) (Andersen 1970 in Thomsen et al. 2006b, Kastelein et al. 2002) and auditory brainstem response (ABR) (Lucke et al. 2004, 2006, Popov et al. 2006 all summarised in Thomsen et al. 2006b)

The hearing ability in the low frequency range from 1-10 kHz might be underestimated due to experimental conditions (Cummings et al. 1975 in Richardson et al. 1995).

For details on sound production in harbour porpoises see chapter 2.2.1.

4.3.1.3. Hearing ability and communication in harbour and grey seal

The hearing ability of phocid seals in air and underwater differs, mainly due to the different ways in which the sound waves reach the cochlea (Hemilä et al. 2006). The best hearing ability of most seals under water is in the frequency range between 1 to 20 kHz (National Research Council 2003). Harbour seals show best hearing ability in a frequency range between 1 to 50 kHz with hearing thresholds of about 58 to 60 dB re 1 µPa (Møhl 1968, Kastak & Schusterman 1998, Kastelein et al. 2008, Kastelein et al. 2009). Low frequencies of 100 Hz can still be detected if they exceed the threshold of 96 dB re 1µPa (Kastak et al. 1995, Richardson et al. 1995). Harbour seals can also detect very high frequencies of about 180 kHz under water if the signal is loud enough (Richardson et al. 1995) while the high frequency limit on land is much lower (Hemilä et al. 2006). Figure 4.3 shows the varying audiograms for the harbour seal reported by various studies, while Figure 4.4 shows the only grey seal study available.

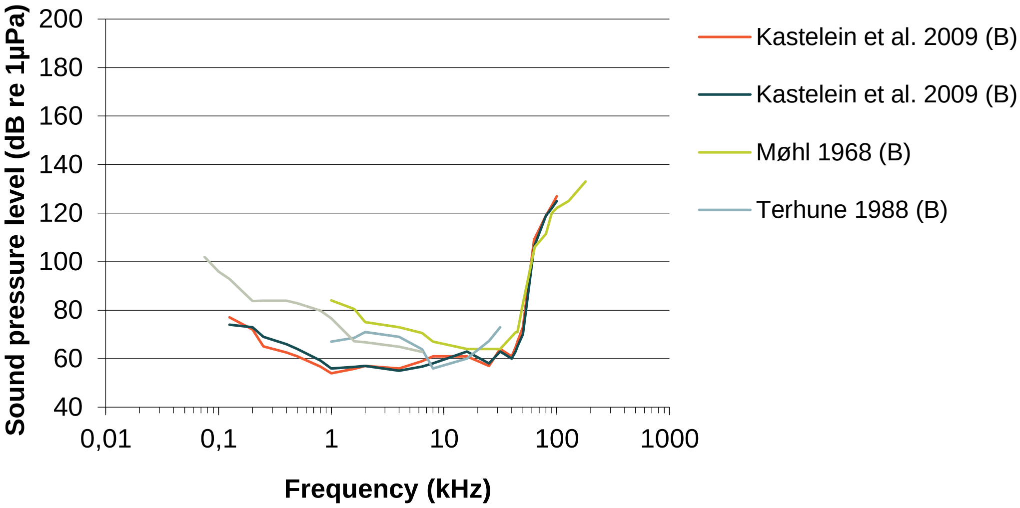

Figure 4.3: Audiograms of harbour seals determined in behavioural studies by different authors

The only study relating to grey seals indicates that their best hearing ability is in a rather narrow frequency range between 10 to 40 kHz with lowest thresholds of more than 60 dB re 1µPa at 20-30 kHz (Ridgway & Joyce 1975 in Nedwell et al. 2004).

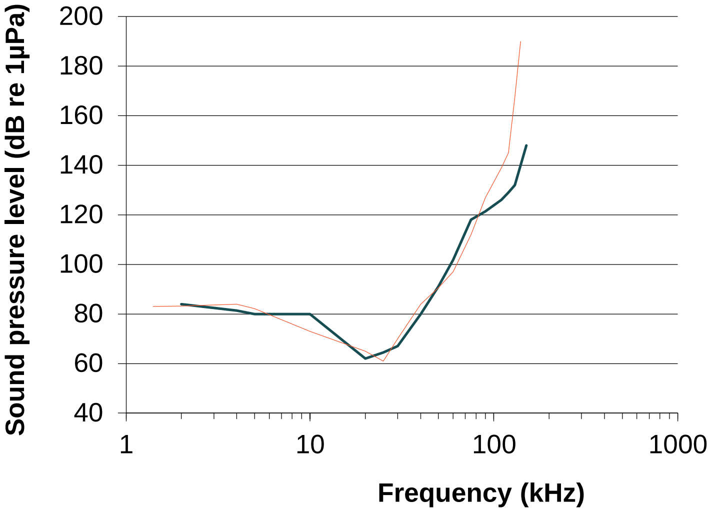

Figure 4.4: Audiograms of two female grey seals obtained by using the cortical evoked response method (Ridgway & Joyce 1975 in Nedwell et al. 2004).

The wide vocal repertoire of seals is mainly related to mating behaviour and social communication (Schusterman et al. 1970, Asselin et al. 1993, Richardson et al. 1995; Schusterman et al. 2000; Schusterman & Van Parijs 2003). Male harbour seals produce broadband roaring sounds in a frequency range between 0.5 and 4 kHz (Van Parijs & Kovacs 2002 in Kastelein et al. (2009) in areas which are frequently visited by females during mating season (Bjørgesæter et al. 2004). These calls could both attract females and repulse competitors (Hanggi & Schusterman 1994). Individual contact calls between mother and calf are in a frequency range between 0.2 and 0.6 kHz (Khan et al. 2006). Therefore anthropogenic low frequency noise is likely to mask communication signals of harbour seals.

4.3.1.4. Anthropogenic sound sources

The natural soundscape in the sea is influenced by biotic and abiotic factors. Currents, waves, rain and earthquakes contribute to the sound level such is a large number of animals such as snapping shrimps, fishes and marine mammals.

While it is presumed that marine mammals have evolved and adapted to natural sounds in the marine environment man-made noise in the sea is a relatively recent and fast-paced development. Over the last about 50 years the background noise level in the sea increased by about 10 to 12 dB which is mostly related to increasing ship traffic (Andrew et al. 2002, Hildebrand 2009, McDonald et al. 2006). Especially high anthropogenic sound sources are seismic surveys, SONAR manoeuvres, explosives and pile driving activities connected to offshore construction sites such as offshore wind farms.

Shipping is by far the most important source of marine noise and accounts for about 75% of the anthropogenic noise in the sea (ICES 2005). Its noise is mainly in the low frequency band of up to 500 Hz (Hildebrand 2009).

During different construction work types such as harbour construction or erection of offshore wind farms piling and dredging are important noise sources. Dredging is often necessary to prepare and level the sea bed for especially for alternative foundations like gravity based foundations or suction buckets. An overview about some anthropogenic sound sources, their source levels and frequency range is given in Table 4.3.

Noise immissions from underwater pile driving greatly exceeds those from the more constant noise source.

Table 4.3: Sound sources from various maritime activities (from Evans 1996; *[1] Robinson et al. 2011, *[2] Hildebrand 2009) (numbers are based on a transmission loss of 20*log(distance)).

Activity	**Frequency Range (kHz)**	**Av. Source Level (dB/1µPa at 1m)**	**Estimated Received Sound Level at different ranges (km) by spherical spreading**			
			0.1	**1**	**10**	**100**
Dredging						
- Gravel island		130	90	70	49	28
- Suction dredge	0.38	160	120	100	79	58
- TSH dredger*[1]	0.032 – 1 1 – 40	157 – 181 155 – 176	117 – 141 115 – 136	97 – 121 95 – 116	77 – 101 75 – 96	57 – 81 55 – 76
Vessels						
- 90 hp outboard inflatable	0.8 – 20	105 – 130	65 – 90	45 – 70	24 – 49	<25
- 240 hp inboard fishing boat	0.1 – 20	110 – 130	70 – 95	50 – 75	29 – 54	<25
- Large merchant vessel	0.05 – 0.9	160 – 190	120 – 150	100 – 130	79 – 109	58 – 88
- Super tanker	0.02 – 0.1	187 – 232	147 – 192	127 – 172	106 – 151	85 – 130
- Military vessel		190 – 203	150 – 163	130 – 143	109 – 122	88 – 101
Other anthropogenic sound sources						
- Seal scarer *[2]	8–30	205	165	145	125	105

4.3.1.5. Potential effects of anthropogenic sounds on marine mammals

Due to the importance of natural sound to marine animals, anthropogenic noise can seriously affect orientation, communication and other biologically important processes in marine animals. The detection of and response to the sound depends not only on the acoustic properties of the sound source but on the habitat in which the sound propagates (Madsen et al. 2006), the received sound level at and internal factors of the receptor. Individual sensitivity can depend on factors such as individual experience to earlier sound exposures, age, sex, stress level, time of the year or the presence of dependent off-springs.

With increasing distance from a sound source the sound pressure level and therefore the likely effect of sound on animals decreases. Richardson et al. (1995) distinguished different areas around a sound source in which different effects could be expected. These effects span from severe physiological damage or death due to very high sound pressure levels, to the zone of audibility in which the sound can be heard but does not cause any effects. Based on this model the potential effects are categorised as follows.

Physical damage

Very high sound pressure levels can cause physical damage in different tissues especially in organs with air filled cavities. Sound sources like explosions with high peak levels and very short rise time can cause severe damage however, tissue damage can also appear at lower sound levels and when sound is presented for a longer period of time.

Damage to the hair cell tissue of the inner ear of animals can occur at various sound levels and affects the acoustical perception of marine animals' surroundings. Sound can cause a shift in hearing sensibility causing higher hearing thresholds that can be temporary (temporary threshold shift, TTS) or permanent (permanent threshold shift, PTS) (Clark 1991). The temporary threshold shift - a fatiguing response of the ear to high noise levels - affects the animal for a limited period of time depending on the pressure level and the duration of sound while a permanent threshold shift continuously decreases the hearing ability of the animal as hair cells or nerves in the inner ear are damaged (Southall et al. 2007).

Not much direct knowledge exists about permanent threshold shift in marine mammals. There is only a small number of marine mammals available for hearing studies and for ethical reasons a permanent damage of the animals should be prevented (Kastak et al. 2008). Therefore PTS-estimations for marine mammals are mainly inferred from measured TTS-thresholds of marine mammals and the relationship between TTS and PTS known from terrestrial animals (Southall et al. 2007). The authors concluded that sound with a peak level of 230 dB re 1µPa or a SEL (sound exposure level) of 198 dB_{SEL} during a 24 hour period could lead to a permanent threshold shift in harbour porpoises (Table 4.4). However, this conclusion was drawn on the basis of mid-frequency cetaceans, while harbour porpoises are classified as high-frequency cetaceans. For harbour porpoise investigations by Lucke et al. (2009) and Kastelein et al. (2012) indicate a lower threshold for hearing damage and a TTS-threshold of 165 dB_{SEL} (s.a. Tougaard 2013) and a PTS-threshold of 180 dB_{SEL} (following Southall et al. (2007) that onset of PTS is 15 dB above TTS) is used for this assessment (Table 4.4).

For seals lower values of 218 dB re $1µPa_{peak}$ and 186 dB_{SEL} SEL were calculated (Southall et al. 2007).

Table 4.4: Thresholds of received Sound Exposure Levels to induce temporary (TTS) and permanent threshold shifts (PTS) in marine mammals (see text).

Marine mammal group	Threshold shift	SEL (Pulsed sound)	SEL (Non-pulsed sound)
Pinnipeds	Permanent	186 dB	203 dB
	Temporary	171 dB	183 dB
Cetaceans (mid frequency)	Permanent	198 dB	215 dB
	Temporary	183 dB	195 dB
Harbour porpoise	Permanent	180 dB	197 dB
	Temporary	165 dB	180 dB

Behavioural effects

Sound can cause obvious behavioural reactions such as startle response or flight behaviour but there is a number of other behavioural reactions that are less obvious but not less important. Behavioural effects range from a change of physiological features like heartbeat rate via brief disturbance of normal activities (e.g. feeding or resting) to long-term displacement from an area (Richardson et al. 1995). In many cases behavioural reactions are connected with higher energy consumption for the individual (Southall 2005). The behavioural response is highly variable and depends not only on the sound the animal is exposed to but on a number of internal factors and the strength and type of behavioural reactions cannot simply be derived from the hearing ability of an animal. (National Research Council 2003).

One important factor for the behaviour of an animal is the habitat situation. The lack of suitable substitute habitats (comparable in terms of food availability, competition, predators) or high amounts of energy that would be necessary to explore a new habitat (territorial defence, position in the hierarchy, gathering of information on the habitat) are likely to reduce the motivation to move away from areas with high sound levels (Tyack 2008). But habitat deterioration can have negative effects on individuals and the population level even if obvious impacts cannot be observed in the short term (Bain & Williams 2006). Lusseau et al. (2009) observed orcas (*Orcinus orca*) being more active but spending less time foraging in the presence of ships. The authors assumed that reduced food intake might be a reason for the significant decrease of individuals in the observed group.

A significant decrease in acoustic activity of harbour porpoises was observed during construction of the offshore wind farm Horns Rev 2 at a distance of up to about 18 km from the construction site. The effects were less pronounced with increasing distance (Brandt et al. 2011a). The duration of the effect after the end of sound exposure decreased with distance lasting for 24-72 hours in the vicinity (2.5 km) of the sound source and 10-23 hours at approximately 18 km distance. From the results it cannot be determined whether the harbour porpoises left the area of high sound levels or remained in the area but reduced acoustic activity (Brandt et al. 2011a). The results during construction of the wind farms Alpha Ventus (Diederichs et al. 2010) and Horns Rev 2 (Brandt et al. 2011a) revealed subtle and short-term disturbance effects down to noise levels of 145 dB_{SEL} and stronger responses at 150 -160 dB_{SEL}. The duration of the response was clearly related to the strength of the noise immission.

In a recent study, during the construction of 40 Tripod foundations for the Trianel Borkum offshore wind farm in the German Bight, Pehlke et al. (2013) documented a gradient in the temporal and spatial response of harbor porpoises to underwater noise from offshore piling (Figure 4.5). Measurements over whole piling operations showed a strong reduction of harbor porpoise presence until noise levels of about 150 dB_{SEL}. A response still could be measured until about 145 dB_{SEL}. At noise levels above 160 dB_{SEL} displacement was almost complete though some porpoise detections during pile driving were regularly made at higher noise levels. In total, about 60% of the harbour porpoises would leave the area exposed to noise levels > 145 dB_{SEL} and the disturbance effect would last 1-3 days in the nearzone, where noise levels exceed (> 160 DB_{SEL}) but only a few hours at lower noise levels.

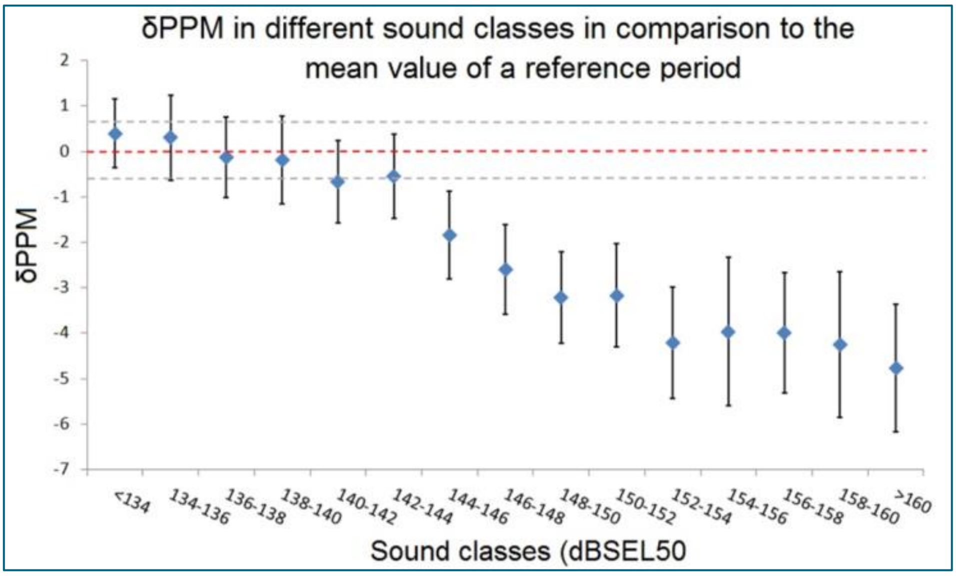

Figure 4.5: Response of harbour porpoise to pile driving. The values give the change in porpoise detections in relation to noise levels (Pehlke et al. 2013), (PPM = Porpoise Positive Minutes = Minutes including at least one recording of a harbour porpoise click train. SEL_{50}= Median Sound Exposure Level in dB of a given number of pulsed sounds, e.g., hammer blows).

Harbour seals showed a variety of responses to pile driving activities ranging from no obvious response to departure from haul-out sites (Madsen et al. 2006). A reduction of 10-60% of seals was observed at a haul-out site 10 km away from pile driving at Nysted offshore wind farm (Edrén et al. 2004, Edrén et al. 2010). Teilmann et al. (2004) observed that the number of seals returned to pre-construction level even during other construction work. The reaction seemed to be short-term, as surveys did not show any decrease in the general abundance of seals during the construction period as a whole (Teilmann et al. 2004). However, it must be considered that only one foundation was driven into the seabed while all other 79 wind turbines are based on gravity foundations, which did not cause a comparable sound emission.

In seals not only underwater noise but airborne sound sources are of importance. Seals show behavioural reactions to shipping noise (that might be coupled with visual cues) mostly by leaving their haul out site and entering the water. This interruption of the resting period may be critical especially during the breeding season (Dietz et al. 2000) and may lead to abandonment and reduced pup survival (Mees & Reijnders 1994). Vessels that pass at a distance of more than 200 m do not seem to cause reactions (Richardson et al. 1995).

Seals may also avoid sound sources such as seismic surveys and acoustic pingers (Yurk & Trites 2000, Bain & Williams 2006, Kastelein et al. 2006, Kastelein et al. 2008).

Seals might show tolerance toward repeated disturbances such as ferries or operational wind farms that do not pose any threat (Grøn & Buchwald 1997).

Masking of biologically important signals

The detection threshold of a biological signal can be raised by the presence of another signal. This effect is called masking. The closer the frequencies of the two signals are together (Southall et al. 2000) and when both signals originate from the same direction (Holt & Schusterman 2007) the stronger is the masking effect. Masking occurs in a so-called critical bandwidth; in other words, a signal is only masked by another signal of a certain frequency band around the frequency of the signal to be detected (National Research Council 2005). Additionally very loud signals can cause masking outside the frequency of the critical bandwidth (Richardson et al. 1995).

The width of the critical band depends on frequency and seems to cover less than 11.6% of the central frequency of the band in mammals (Richardson et al. 1995). Animals with narrow critical bands are therefore less prone to masking by other signals (Sveegaard et al. 2008). In contrast to many other mammals harbour porpoises seem to have a relatively constant critical band of 3-4 kHz above 22.5 kHz (Popov et al. 2006) and therefore, the effects of masking do not increase with higher frequencies.

Masking can affect animals at sound levels below reaction thresholds; therefore the range around a sound source in which masking can occur can be larger than the range in which behavioural reactions can be observed (MMC 2007).

As construction noise for offshore wind farms is characterized by short pulses from pile driving masking is not considered as a relevant issue and will not be treated in detail.

Habituation

The strength of a reaction to a sound signal often decreases with the length of exposure. This habituation effect can be observed when the signal does not cause a threat or can even be connected to positive effects (Bejder et al. 2009). Seals for example that did not show any reaction to the sounds from a known fish-eating orca population showed strong avoidance reactions to the sounds of an unknown fish-eating orca group (Deecke et al. 2002). It has also been observed that the deterrent effect of acoustic harassment devices used to keep seals away from fish farms decreased with time not causing an immediate danger to the animal. On the contrary seals may connect the signal with easily accessible food in the fish cage and may therefore rather be attracted to the deterrent device (Jefferson & Curry 1996; Fertl 2009).

The term habituation is often misused for every change in tolerance and is interpreted as neutral or positive reaction towards the disturbance which can cause misinterpretations on the effects of disturbance on animals (Bejder et al. 2009). It might be that a disturbance is only tolerated due to the lack of alternatives for individuals or populations to avoid the noisy area. The effort and energy need to move away might be higher than the effort to adapt to the new and noisy situation. Therefore, it is possible that the animals showing the smallest reaction are the ones that have no choice (Jasny et al. 2005). An increased tolerance against a sound source can therefore be connected to higher energetic costs, stress and reduced fitness (Lusseau & Bejder 2007).

4.3.1.6. Definition of assessment criteria

The degree of impact is based on the magnitude of pressure and sensitivity (PTS, TTS and disturbance) of the affected species based on literature (Table 4.5). The criteria for ‘very high’ and ‘high’ magnitudes of pressure are based on a TTS-study on harbour porpoise (Lucke et al. 2009) and the assumption that the onset of PTS occurs 15 dB above the TTS threshold by Southall et al. (2007).

The threshold for medium magnitude was derived from results of Brandt et al. (2011b) by extrapolating their measured sound exposure level at 2.3 km to the distance where responses in porpoises would begin to occur (calculated with transmission loss, TL = 15 log (r)).

For harbour seals, the zone of responsiveness of impact pile driving is even more difficult to assess than for porpoises. Seals seem to be less sensitive to impulsive sounds (Richardson et al. 1995, Gordon et al. 2004). Tougaard et al. (2006c) even observed harbour seals transiting an offshore wind farm construction site during pile driving while a short-term decrease of 10 – 60% of hauled out harbour seals was observed in 10 km distance from a construction site (Edrén et al. 2004).

As a conservative measure, the behavioural reaction radius of seals should be viewed as a similar dimension as in porpoises. The defined impact assessment criteria for harbour porpoises and seals are summarized in Table 4.5. TTS and PTS-criteria for seals are based on Southall et al. (2007) and criteria for harbour porpoises are derived from Lucke et al. (2009).

Table 4.5: Criteria for assessing impacts from underwater noise on marine mammals.

Pressure	Impacts and Criteria	Degree of impact
Noise and vibration (construction, impulsive sounds)	**Porpoises**: Received sound levels are high enough to cause injury or PTS, SEL exceeds 180 dB re1µPa^{2}s **Seals**: Received sound levels are high enough to cause injury or PTS, SEL 186 dB re 1 re1µPa^{2}s (Southall et al. 2007)	Very High
	Porpoises: Received sound levels are high enough to cause TTS, SEL exceeds 165 dB re1 µPa^{2}s (Lucke et al. 2009) **Seals**: Received sound levels are high enough to cause TTS, SEL exceeds 171 dB re 1µPa^{2}s (Southall et al. 2007)	High
	Sound levels are high enough to cause behavioural disturbance (received SEL exceeds 150 dB re 1µPa^{2}s (porpoises and seals) (Brandt et al. 2011b)	Medium
	Sound levels are high enough that some minor behavioural reactions might be expected (received SEL exceeds 145 dB re 1µPa^{2}s (porpoises and seals) (Brandt et al. 2011b)	Low

4.3.1.7. Assessment of cumulative noise exposures

Marine mammals are exposed to a variable number of noise impulses during a full cycle of pile driving which may total several thousand strikes to drive a pile to final depth. While the physical approach to cumulative noise levels is rather straightforward by summing the energy of each strike, there is no consensus in the scientific community how to apply this to the different effects on marine mammals. Here, it is suggested to apply cumulative calculations only to high noise levels causing PTS (Permanent Threshold Shift) to the marine mammal species in consideration.

Interim criteria for protection of fish from piling noise take the number of impacts into account using a simple summation model described in Stadler and Woodbury (2007) for a cumulative SEL. A result of this model is that the area in which injury may occur would gradually increase with the number of strikes in the course of any operation that emits strong noise. Basic assumptions of the method are:

- No tissue recovery between strikes
- Fish is exposed to the same SEL for each strike
- A simple summation model that follows the Equal Energy hypothesis:

SELcum = SELss + 10*log(number of strikes)

where SELss = estimated single strike SEL

- As the SELss increases, the number of strikes to exceed the cumulative threshold decreases.

Southall et al. (2007) use a similar approach for marine mammals. An important assumption of the model is that SELss ≤ 150 dB re 1µPa do not cause injury and do not accumulate ("effective quiet") and there is no need to take cumulative impacts at low sound levels into account. It is considered to be realistic that noise of low intensity does not accumulate to harmful levels even over infinite time and repetition as otherwise also all natural sounds from waves and other sources and especially permanent anthropogenic ambient noise from ships would inevitably accumulate to physical impacts. However, a fixed threshold at 150 dB might be an oversimplification and it is unclear, whether the summation model applies equally well to all sound exposures above 150 dB. It might thus be more appropriate to assume a decrease of cumulation from high to low sound levels. As recovery functions between strikes and exposure to different noise levels of fleeing animals are not known, there is no sufficient scientific basis to assess cumulative exposures in this case. It is thus decided to apply the summation method of Equal Energy Hypothesis to calculate cumulative noise for high levels only and calculate the range of the noise contour causing PTS at a given species over a piling operation (s. Brandt et al. 2011b). PTS is inferred from Southall et al. (2007) or – for harbour porpoise – assuming the onset of PTS to be 15 dB above the TTS threshold which has been estimated at 165 dB_{SEL}.

The following input variable were agreed to be used for the assessment of cumulative noise exposures between the consortia conducting the EIA studies for Krieger Flak and Horns Rev 3 offshore wind farms and Energinet (Table 4.6).

Table 4.6: Conclusion of discussion on underwater noise (Horns Rev 3 and Kriegers Flak EIA consortia, Energinet)

Underwater noise input conditions, as agreed during online meeting November 6th 2013.	
Marine Mammal Fleeing	YES, with the assumption of 1,5 m/s swim speed away from the source. Implementation is allowed to vary
Fish Fleeing	NO, fish are calculated as being stationary
Soft start	YES, 20 minutes at low power - maximum 500 kJ
Ramp up	YES, linear (stepwise) increase in hammer force, with the last hour at 100% (3000 kJ)
Piling duration	Can differ, chosen to be 6 hours
Strike rate	Can differ, chosen to be 1 strike per 2-3 sec.
Number of strikes	7000 strikes, as this to the best of our knowledge is a valid worst case scenario
Hammer Force	3000 kJ at maximum power
Pile size	10 m diameter
Cumulative calculations	YES, to the extent of activities within a 24 hour period. Only 1 installed foundation within a 24 hour period.
Source levels	At maximum hammer force (3000 kJ), 250.7 dB SPLpp, 221.6 dB SEL

4.3.2.Habitat loss or change

Habitat is the ecological or environmental area that is inhabited by a particular marine mammal species. It is the natural and physical environment in which a population lives and that surrounds and thus influences its living. The population inhabiting the habitat is limited by the critical resources provided inside the area. Other factors influencing the population can be besides others predation pressure and diseases.

The specific habitat for a particular marine mammal population is defined by its structures such as substrate type, sediment dynamics, hydrographical features, bathymetry and chemistry. Changes to these structures can lead to temporary or permanent habitat loss, habitat deterioration or the creation of new habitats. Ultimately, changes in habitat will affect the hydrography of the local environment and the fauna and flora within the affected ecosystem.

In marine mammals prey availability and distribution is one of the environmental key drivers that defines a suitable habitat. The prey availability on the other hand is strongly connected to the structure of the habitat, currents, sediment type and so on. Therefore the sensitivity of marine mammals towards habitat loss or change is determined by a change in environmental key drivers which govern directly or indirectly the presence of these animals in a specific area. Any change in important key drivers may lead to a negative impact on marine mammals.

In the following sections the complex relations between habitat capacity its alteration due to habitat change and population size are reviewed.

4.3.2.1. Habitat loss

It is likely that animal populations are limited by availability of suitable habitats so that any loss of habitat or deterioration of habitat quality will lead to an equivalent reduction in the number of animals living in this habitat.

The habitat loss during construction might be a temporary loss while the footprint of the wind turbines and supporting structures such as scour protection will cause habitat loss especially for soft bottom benthos fauna which may lead to a negative impact on marine mammals due to changes in food availability.

The sensitivity of harbour porpoises and seals is assessed on the basis of their behaviour against artificial structures in the sea.

Whether the habitat loss of the project footprint is relevant for a particular species will be assessed later in the respective chapters to determine the severity of loss.

4.3.2.2. Habitat change

The pressure habitat change comprises different pressures related to the construction and operation of the wind farm Horns Rev 3 and can be divided into three categories: change of seabed habitat; change of intertidal and terrestrial habitats and changes in hydrography and/or turbidity.

4.3.2.3. Change of seabed habitat

Preparation of the seabed for foundation or the wind turbine, the deployment of extra hard bottom layers for scour protection and the erection of the wind turbines itself will cause changes in the local benthic communities and the food chain for higher trophic levels including marine mammals. Therefore changes of the seabed habitat will directly or indirectly influence the food resources of harbour porpoises and seals.

Habitat changes have the potential to cause temporary or permanent changes in distribution in response to modified foraging areas or haul-outs (seals). They could also affect fecundity and survival.

The construction of the offshore wind farm Horns Rev 3 will cause changes to the sandy bottom habitat and will introduce artificial hard bottom substrates.

During construction the bottom habitat will be disturbed by introduction of the wind turbine structure and depending on the foundation type there might be some preparation of the site (e.g. dredging to level the foundation site) and some scour protection necessary.

There is no information available on the direct impact of bottom habitat changes on marine mammals but this subject has been studied in fish related to certain fishing practices, particularly benthic trawling and dredging for fish and shellfish (De Groot 1984, Jones 1992, Thrush et al. 1995). Other studies dealt with the biological impacts of marine aggregate extraction (Desprez 2000, Wilber & Clarke 2001). Desprez (2000) showed a drastic reduction of biomass, abundance and species richness in dredged tracks and that the community structure of the post-dredging period differs from the original one. This will also affect the macrofauna which may be using the existing flora and fauna to forage, as shelter or as a breeding/nursery area.

The water column living zone is not directly affected by changes on the seabed, as the animals still are able to stay in or to cross the area, but changes on the seabed could lead to possible effects on food availability for marine mammals.

The introduction of extra hard bottom layers for scour protection or the erection of the wind turbines itself leads to the creation of new habitats within the ecosystem. Studies on the effects of different types of artificial structures on fish and invertebrates showed fast settlement of epifauna on the structures (Jørgensen et al. 2002, Petersen & Malm 2006, Inger et al. 2009). The structures might therefore act as fish aggregation devices (Inger et al. 2009) due to higher food availability which could in turn provide better food sources for marine mammals.

4.3.2.4. Change of intertidal and terrestrial habitats

Seals utilise the intertidal area and terrestrial habitats to haul out. As haul-out sites are important areas during the annual life cycle of seals for resting, breeding, pupping and nursing any change in terrestrial habitats are of concern for these animals. The next haul-out sites for seals in the Horns Rev area are at least 50 km away from the offshore wind farm Horns Rev 3 and are therefore not considered to be influenced by construction or operation of the wind farm. Hence, no further sensitivity due to habitat change will be considered.

4.3.2.5. Changes in hydrography and/or turbidity

Habitat changes can alter the hydrography of the local environment and hence the fauna and flora within the affected ecosystem. The sensitivity of marine mammals towards changes in hydrography will be primarily driven by the sensitivity of prey species to these changes and therefore the availabilty of food resources.

Therefore, it is assumed that the most significant habitat variables are those which are important in relation to marine ecological processes which enhance the concentration and prediction of fish prey (Fauchald & Jumars 1979, Iverson et al. 1979, Schneider & Duffy 1985, Schneider 1990, Fauchald 2010). The distribution of prey species is believed to be linked to hydrographical parameters such as salinity, temperature, hydrographic fronts etc. (see Reid et al. 2003, Johnston et al. 2005, Camphuysen et al. 2006, Fontaine et al. 2007, Skov & Thomsen 2008, Edrén et al. 2010). A number of studies showed effects of hydrographical and meteorological variables such as temperature, salinity, storminess and cloudiness on fish life history (e.g. success of reproduction, spatial distributions, migration patterns, growth and mortality rates) (Bakun 1996; Stenseth et al. 2004). The distribution of harbour porpoises in the Horns Rev area showed a close relationship to upwellings caused by tidal currents which most likely affected the distribution of prey species for harbour porpoises (Skov & Thomsen 2008).

Since the presence of the planned offshore wind farm Horns Rev 3 will affect some local factors such as currents an influence on important prey species and therefore an effect on marine mammals could be expected.

4.3.2.6. Reactions of harbour porpoise to change of seabed habitat

Habitat changes and habitat loss are most significant to species with a restricted and/or coastal range. Harbour porpoises show a preference for shallow continental shelf waters up to 50 m depth (Hammond et al. 2002, Hammond 2007, MacLeod et al. 2003). The preference for coastal waters makes them highly susceptible to maritime and terrestrial anthropogenic activities.

Results from the Baltic Sea showed lowest densities of harbour porpoises in water depth of less than 10 m (FEMM 2013). The water depths in the area of Horns Rev 3 are between 10 to 21 m and therefore in a range most suitable for harbour porpoises. Changes in the seabed habitat that decreases water depth like extensive scour protection could therefore affect the distribution of porpoises.

Sediment spill could be a short term effect during construction of the wind farm. There is only very limited information on the effects of sediment spill on harbour porpoises. A comparison between an area in which sand dredging took place (Island of Sylt, Germany) and three reference areas did not show any significant difference in long-term harbour porpoise use based on aerial surveys and passive acoustic monitoring (Brandt et al. 2008). Therefore, no direct sensitivity of porpoises towards sediment spill is expected.

The availability and distribution of prey is thought to be a main factor for the distribution of harbour porpoises (e.g. Sveegaard 2011) which is on the other hand linked to parameters such as hydrography and bathymetry (Raum-Suryan & Harvey 1998, Skov & Thomsen 2008; Embling et al. 2010). Habitat changes can therefore affect harbour porpoises directly or indirectly through effects on prey species.

The composition of the diet of harbour porpoises in the Horns Rev area is not known but they are opportunistic feeders that prey on small demersal and pelagic shoaling fish species (Santos et al. 2004). The most common species in the area are Sandeel (*Ammodytes sp.*), Plaice (*Pleuronectes platessa*), Sand goby (*Pomatoschistus minutus*), and Dab (*Limanda limanda*) (Jensen et al. 2006) which are likely to serve as important prey species for the local harbour porpoise population. But the preferences and dietary need of harbour porpoises in the area are not known and therefore changes in prey composition could affect the population.

The introduction of artificial structures such as wind turbines and scour protection will influence the surroundings. It is known that reef structures are suitable habitats for different fish species and may aggregate fish from the surrounding area (e.g. Grossman et al. 1997, Inger et al. 2009, Lindeboom et al. 2011). Scheidat et al. (2011) observed significantly higher porpoise activity inside the Dutch offshore wind farm Egmond aan Zee compared to two reference sites. The higher abundance of fish inside the ”artificial reef” would be one explanation for the higher harbour porpoise activity, another would be a shelter effect that provides an area protected from the heavy ship traffic and fishery activities of the surrounding waters.

Todd et al (2009) measured higher harbour porpoise detection rates close to an oil rig at night time and related the result to higher prey availability close to the artificial structure. Similar results could be seen at the wind farm Nysted, where more harbour porpoise activity occurred during the night close to the turbines (Diederichs et al. 2008a). Leonhard et al. 2006 suggest that this could be related to higher fish abundance close to the turbines during the night.

However, based on studies focusing on the effect of artificial hard substrate on porpoises, the sensitivity of porpoises to these artificial reef structures was assessed to be of minor importance or moreover even positive through increase of food resources.

4.3.2.7. Reactions of harbour porpoise to changes in hydrography and/or turbidity

The distribution of harbour porpoises is also influenced by hydrodynamics and water structure. Areas of consistently higher harbour porpoise densities have been linked to areas of low current (Embling et al. 2010) and other studies highlighted the importance of eddies on the distribution of harbour porpoises, particularly at the tips of islands and within Straits (Johnston et al. 2005; Skov & Thomsen 2008). But as discussed before the affects might strongly be related to the hydrographical preferences of prey species. A study conducted in the Fehmarn Belt area identified bathymetry, geographical position (lat/long), water temperature, strength of the east-west current and current gradient as significant hydrographic variables influencing the distribution of harbour porpoises (FEMM 2011). Therefore changes in these variables might cause distributional changes. But the effects are likely to be rather small and no strong sensitivity of porpoises regarding these features is expected.

4.3.2.8. Reactions of harbour and grey seals to change of seabed habitat, hydrography and/or turbidity

Hydrographic and seabed substrate changes, brought about by the construction of the Horns Rev 3 wind farm, have the potential to influence the distribution of harbour and grey seals presumably by causing changes in fish distribution and abundance. The particular environmental characteristic of the foraging areas is therefore rather the characteristic that provides good conditions for the prey species rather than being of major importance for the seals.

Harbour seals are opportunistic feeders and their prey largely depends on the local species composition. For the Danish Wadden Sea area plaice (*Pleuronectes platessa*) and other bottom dwelling fish species are expected to provide the largest part of prey (Tougaard et al. 2006c).

Movements of adult harbour seals are mainly restricted within an area of 50 km from their haul-out sites (Thompson et al. 1998; Dietz et al. 2003; Cunningham et al. 2009; Sharples et al. 2009) therefore habitat changes around haul-out sites are likely to influence harbour seals.

Grey seals also forage on epibenthic prey. Thompson et al. (1996) analised the diet of grey seals at the Scottish east coast and found more than 95% of the diet consisting of sandeels, gadoids, flatfish and cephalopods. Sandeel, plaice and dab are three of the four most common species in the Horns Rev area (Jensen et al. 2006) and are therefore likely to provide a large part of the prey for grey seals. The fourth very common fish species in the area is the sand goby. In the Baltic Sea sand gobies are part of the food spectrum of grey seals (Lundström et al. 2007) which is likely to be the case too in the Horns Rev area.

Depending on the food distribution grey seals forage at distance of more than 80 km from their haul-out sites (McConnell et al. 1999). This greater mobility suggests that they may be less susceptible to changes in habitat, which can affect prey.

4.3.2.9. Sensitivity of marine mammals to suspended sediment in the water column

Suspended sediment will impair visibility in the water column. It scatters light and degrades the image contrast, it limits the visual range and also determines the spectral bandwidth and intensity of light available for vision at certain water depths (Weiffen et al. 2006). But many marine mammals, including harbour porpoises, grey and harbour seals, are known to visit turbid inshore waters with high prey abundance for hunting activities and some species such as the Ganges river dolphin live in so turbid waters that they are functionally blind.

Marine mammals will rely on the integration of information from any sensory channel providing relevant input (Schusterman 1965; Weiffen et al. 2006) and are able to compensate for the loss of a sense in particular environmental conditions, including loss of vision in turbid waters. Therefore the effect of suspended sediment on vision of marine mammals is expected to be minor.

But increased sediment suspension may affect the prey or marine mammals. Settlement of suspended sediment may smother areas of seabed affecting benthic fauna and flora, and subsequently the food chain. It may also cause changes in the seabed topography and community structure and alter the suitability of habitats formerly used for vital functions; foraging, cover from predation, nursery ground etc.

4.3.2.10. Sensitivity of harbour porpoise to suspended sediment

Visibility in the sea is often very restricted and therefore other senses such as hearing, tactile sense or electromagnetic sense are of great importance to many marine animals. The hearing and echolocation of harbour porpoises are adapted for navigation and foraging in conditions where vision is limited or absent (Kastelein et al. 2002).

For foraging and orientation they produce click trains which were emitted every about 12 seconds in studies in Danish waters (Akamatsu et al. 2007, in Todd et al. 2009).

In captive harbour porpoises the ability to catch live prey was investigated comparing the acoustic behaviour of seeing and blindfolded animals (Verfuß et al. 2009). While the swimmimg speed was halved in blindfolded porpoises, the acoustic activity remained on the same level with the effect that they emitted more clicks per metre swum. The results of this study suggest that the animals used multi-modal sensory information from vision and echolocation when possible for searching and approach of prey, but compensated for lack of vision by adjusting their acoustic search behaviour (Verfuß et al. 2009).

The assumption that echolocation is the primary sense for navigation and foraging when vision is poor is supported by the results from studies on diel acoustic behaviour of porpoises. Diel patterns in echolocation activity have been recorded, with increased acoustical activity at night (e.g. Carlström 2005; Todd et al. 2009). The results suggest that the acoustic sense becomes more important when vision is limited and/or increased foraging activity associated with diel patterns in prey availability.

4.3.2.11. Sensitivity of harbour and grey seals to suspended sediment

Seals often inhabit turbid waters such as the Wadden Sea and therefore other senses than vision must be well developed to find prey. The vibrissae (whiskers) are likely to play an important role especially in poor visibility and when foraging at night (Renouf 1980). The ability to find prey using vibrissae has to be practiced and perfected in young animals and to do so vision and/or additional sensory cues are used. The foraging behaviour of seals in poor visibility was unchanged compared to good visibility but when the vibrissae were removed the ability to capture prey was temporarily impaired (Renouf 1980).

Studies in the Baltic Sea showed foraging behaviour mainly in daytime, while harbour and grey seals spent more time hauled-out during the night. (e.g. Sjöberg et al. 1995, Sjöberg et al. 1999). This might be related to better foraging condition in good visibility but it could also be related to diel movements of prey species that makes nighttime foraging less successful (Sjöberg et al. 1999).

4.4. Impact of construction

So far it is not decided which size of wind turbines will be used at the offshore wind farm Horns Rev 3. Three different scenarios are displayed in Table 4.7.

Table 4.7: Possible size and number of turbines in Horns Rev 3

Size of turbines	Number of turbines
3 MW	136
8 MW	52
10 MW	40

Hereafter the impact of construction of the largest piles will be assessed as a worst case scenario.

The planned offshore wind farm Horns Rev 3 covers an area of about 160 km² but the area in which wind turbines will be installed will cover only about 2/3 of the whole area. Different layouts exists planning the turbine positions in either the east, west or north part of the area in water depths between 10 to 21 m.

The construction program is scheduled for more than one year with one to two days needed for each turbine installation. Construction work will take place 24 hours per day, with lighting of barges at night. Since the installation is weather dependent installation time may be prolonged in unstable weather conditions.

Piles will be driven 25 to 35 m into the seabed depending on the size of the turbine and sediment characteristics. Presumably this will take about four hours per pile. The pile diameter is expected to be 10 m for a 10 MW turbine.

Additionally scour protection might be installed which could come up to an extent of 5 times the pile diameter.

The pressures associated with construction of wind farms are summarized in Table 4.8.

Table 4.8: Construction activities and associated pressures for marine mammals

Construction Activity	**Pressure on marine mammals**
Installation of wind turbines	Habitat loss and change – physical loss suspended sediment / sedimentation Noise (pile driving, ship traffic)

4.4.1.Habitat change

The area affected by foundation, scour protection and cable installation will cover only a small part of the wind farm area. The Environmental impact assessment for the wind farm Horns Rev II calculated 0.2-0.3% of the wind farm area to be affected depending on the type of foundation (Skov & Thomsen 2006), while Engell-Sørensen & Skyt (2001) expected 1.1% of the area of Rødsand wind farm to be affected by direct disturbance, destruction or removal. Engell-Sørensen & Skyt (2001) compared gravitation foundation with pile driving in terms of sediment movement and spill which showed that the effects of pile driving on the sediment are comparably small (Table 4.9).

Table 4.9: Comparison of sediment movement in different foundation types (Engell-Sørensen & Skyt (2001))

	Gravitation low	Gravitation high	Monopile pile driving
Material removed (m^3) total	106.000	40.000	16.000
Tipped material (m^3) total	102.000	38.000	15.000
Sedimentary spill (m^3) total	4.000	2.000	1.000
Time per foundation			
- Preparation	7 days	5 days	2 days
- Installation	6 hours	6 hours	4 hours
- Scour-protection.	4 days	4 days	2 days

4.4.1.1. Harbour porpoise

Sediment spill during construction reduces visibility which is not considered to affect harbour porpoises due to their ability to inhabit turbid waters and to hunt in darkness.

Indirect effects of sediment spill and changes in the seabed habitat are expected due to effects on the prey species of harbour porpoise. Based on the estimation of sediment spill of 1000 m³ per pile for pile driving given by Engell-Sørensen & Skyt (2001) 40,000 m³ sediment spill would be expected for the overall number of piles during construction of the wind farm. The effect of sediment spill on the fish community was estimated for the construction of a bridge in Fehmarnbelt. It was concluded that sediment spills of 110,000 m³ over a period of 2 years would have insignificant effects on the fish populations in the area (FeBEC 2013). Therefore the expected spills in Horns Rev 3 are considered to be local and insignificant for the fish population in the greater wind farm area. As a consequence effects on harbour porpoises are considered to be neglectable.

4.4.1.2. Harbour seal

Sediment spill during construction reduces visibility which is not considered to affect harbour seals due to their ability to inhabit turbid waters and to hunt in darkness.

As described in chapter 4.4.1.1 the effects of sediment spill on the fish community in the Horns Rev 3 offshore wind farm is considered to be negligible and therefore the prey availability for harbour seals is not likely to be affected.

4.4.1.3. Grey seal

Sediment spill during construction reduces visibility which is not considered to affect grey seals due to their ability to inhabit turbid waters and to hunt in darkness.

As described in chapter 4.4.1.1 the effects of sediment spill on the fish community in the Horns Rev 3 wind farm is considered to be negligible and therefore the prey availability for grey seals is not likely be affected.

4.4.2.Noise from construction activities

The main sound source during construction will be noise emitted by pile driving. But increased ship traffic during the construction phase and dredging activity for sea bed preparation will add to the noise level in periods in-between pile driving. Increased sound levels from shipping traffic and dredging noise with source levels of 155 to 181 dB re 1µPa at 1 m distance (Table 4.3) are likely to affect the behaviour and distribution of marine mammals at the construction site.

The underwater noise generated by pile driving during installation has been measured and assessed during construction of wind farms in a number of locations. Important factors influencing the emitted noise levels are - among others -pile diameter and seabed conditions.

It was agreed for the Horns Rev 3 EIA to standardize ‘source’ level to a distance of 750 m as this is better comparable to other data as it avoids nearfield problems in calculating noise levels which have been measured in greater distance to 1 m from the source. Therefore the noise model at Horns Rev 3 is based on a sound source of 181 dB_{SEL} at 750 m distance (Table 4.10).

Table 4.10: Peak and SEL values at 750 m distance during pile driving at different pile driving positions (Mason & Barham 2013).

Level at 750 m	dB_{peak}	dB_{SEL}
North East	198.1	181.0
South	196.9	180.4

Figure 4.6 and Figure 4.7 present the impact ranges from installing a 10 m diameter pile by impact piling at both northeast and south modelling locations. The contours show where the noise levels are expected to fall between 180 to 145 dB_{SEL}. The impact ranges for the two pile driving locations are also summarised in Table 4.11 and Table 4.12.

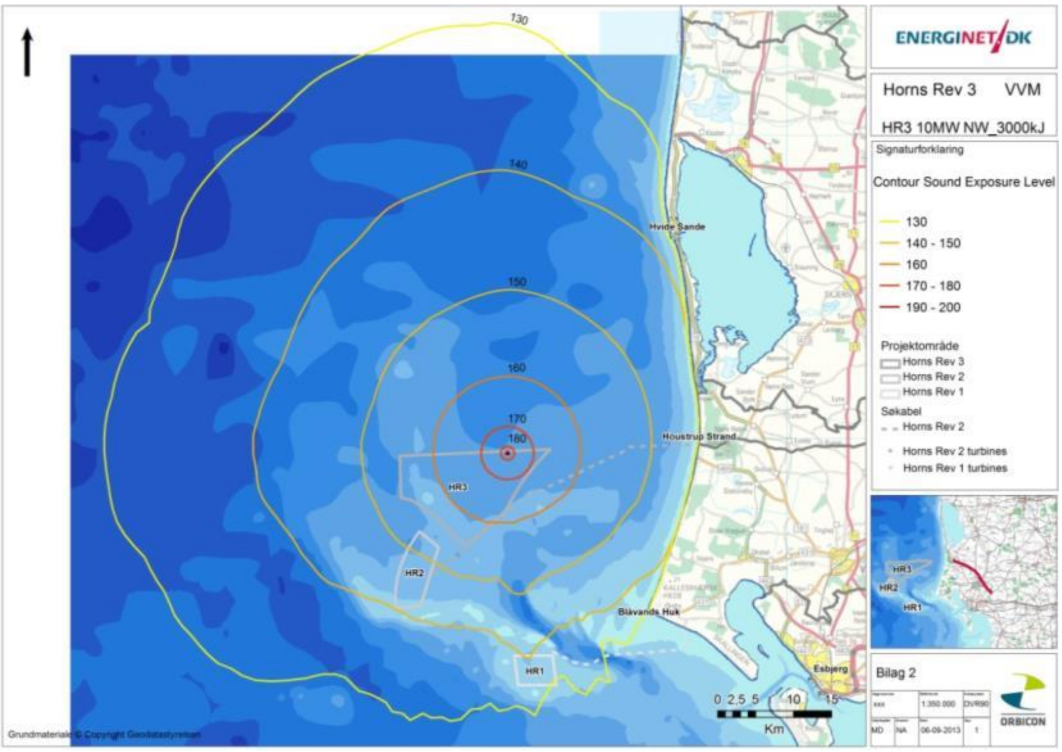

Figure 4.6: Noise contours from offshore pile driving of a 10 m monopile at a northeast position of Horns Rev 3 (Mason & Barham 2013). The noise emission is calculated for maximum effect from ramming at the end of piling.

Table 4.11: Estimated ranges for underwater noise transmission from installing a 10 m diameter pile at the Northwest (deep water) modelling location at Horns Rev 3 (Mason & Barham 2013).

Northeast	180 dB SEL	165 dB SEL	150 dB SEL	145 dB SEL
Max Range	840 m	6.2 km	21.5 km	28.8 km
Min Range	810 m	6.0 km	16.7 km	20.3 km

Mean Range	830 m	6.1 km	19.0 km	24.4 km

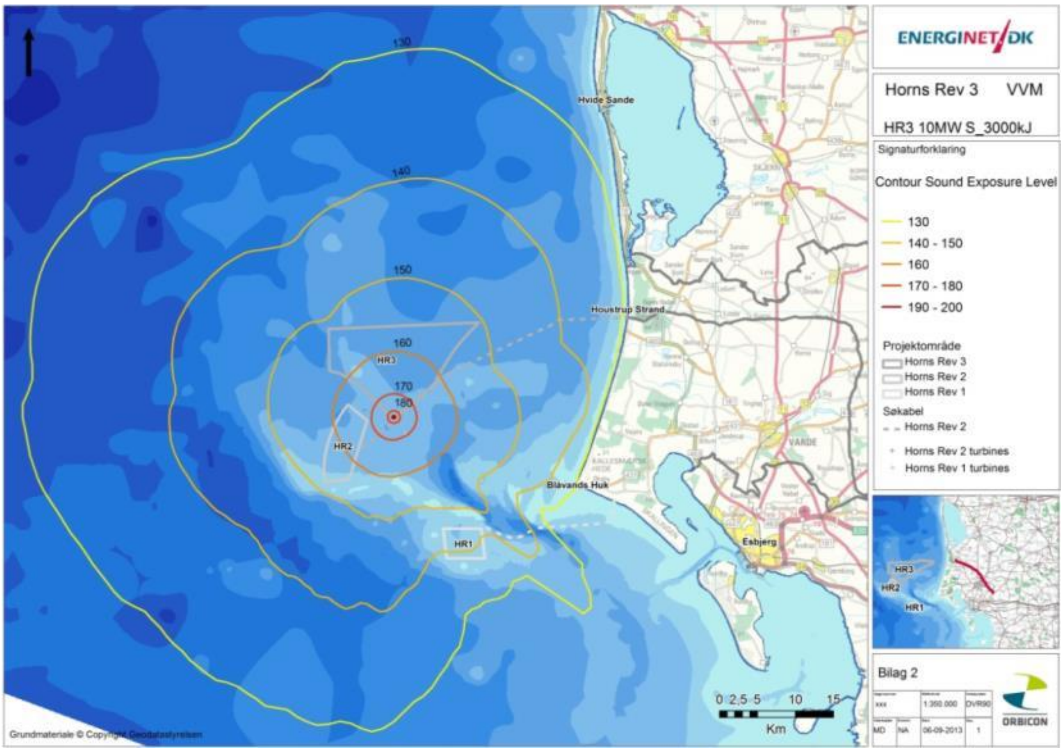

Figure 4.7: Noise contours from offshore pile driving of a 10 m monopile at a southerly position of Horns Rev 3 (Mason & Barham 2013). he noise emission is calculated for maximum effect from ramming at the end of piling.

Table 4.12 Estimated ranges for underwater noise transmission from installing a 10 m diameter pile at the south (shallow water) modelling location at Horns Rev 3 (Mason & Barham 2013).

South	180 dB SEL	165 dB SEL	150 dB SEL	145 dB SEL
Max Range	780 m	5.3 km	18.4 km	24.5 km
Min Range	750 m	4.9 km	12.3 km	15.5 km
Mean Range	770 m	5.1 km	15.7 km	20.5 km

4.4.2.1. Harbour porpoise

While comparing the sound propagation model (Figure 4.8 and Figure 4.9) with the modelled spatial distribution of harbour porpoises in the Horns Rev area (Figure 3.4 and Figure 3.5) an overlap between areas of high harbour porpoise density and higher sound levels becomes visible.

The sound propagation model maps were combined with the modelled spatial distribution in Figure 4.8 to Figure 4.11 and the number of harbour porpoises in the area exposed to at least 145 dB_{SEL} was extrapolated.

During the summer month the density of harbour porpoises in the Horns Rev area is very high. Large areas with densities of up to 20 porpoises/km² and more were modelled on the basis of aerial surveys with densities of up to 5 or more harbour porpoises inside the greater part of the Horns Rev 3 wind farm area.

Depending on the location of the pile driving activity the sound levels vary within different parts of the area. During pile driving close to the north-east corner of Horns Rev 3 porpoises in the high density area west of the wind farm Horns Rev 2 will partly be exposed to more than 145 dB_{SEL} (Figure 4.8). In the high density area north-west of Horns Rev 3 porpoises will be exposed to sound levels of more than 150 dB_{SEL}.

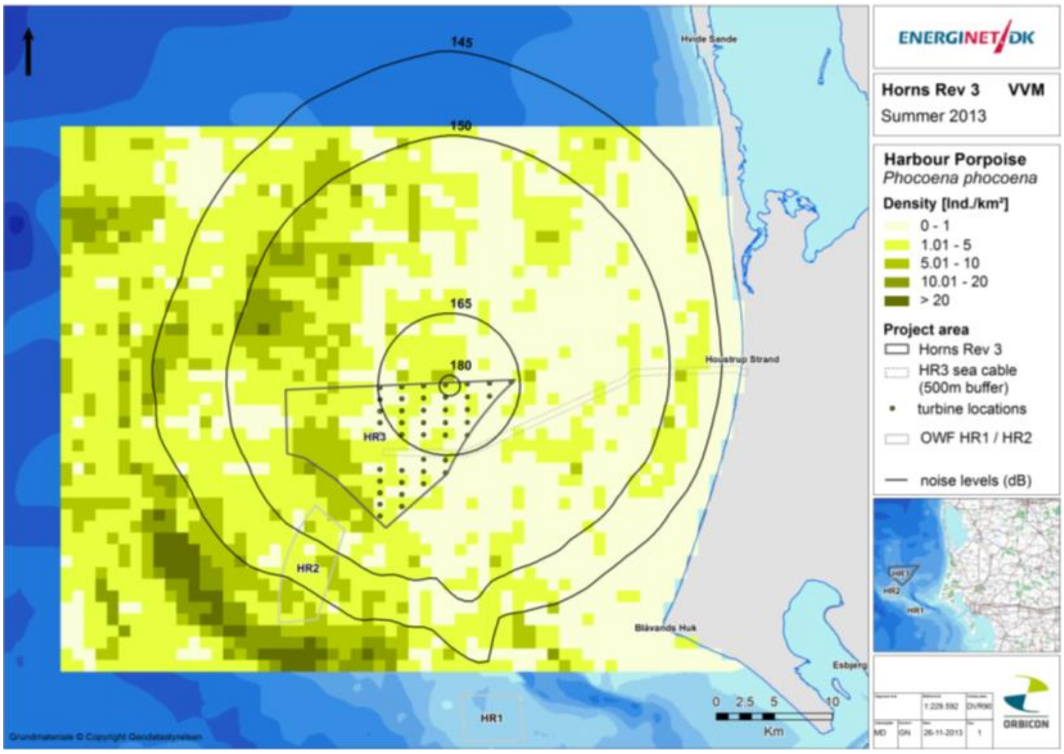

Figure 4.8: Summer spatial distribution model for harbour porpoise combined with sound propagation model during pile driving in the north-easterly part of the Horns Rev 3 offshore wind farm.

During winter the density of harbour porpoises in the area is much lower therefore the areas of highest density are smaller than in summer but more or less in the same positions.

Only small parts of a harbour porpoise high density area west of the wind farm Horns Rev 2 will be affected by sound of 145 dB_{SEL} or more during pile driving. Another smaller high density area north-west of Horns Rev 3 will be exposed to sound pressure levels of more than 150 dB_{SEL}. Inside the wind farm Horns Rev 3 densities of 1 to 10 porpoises/km² were modelled and would be exposed to 150 to 180 dB_{SEL}.

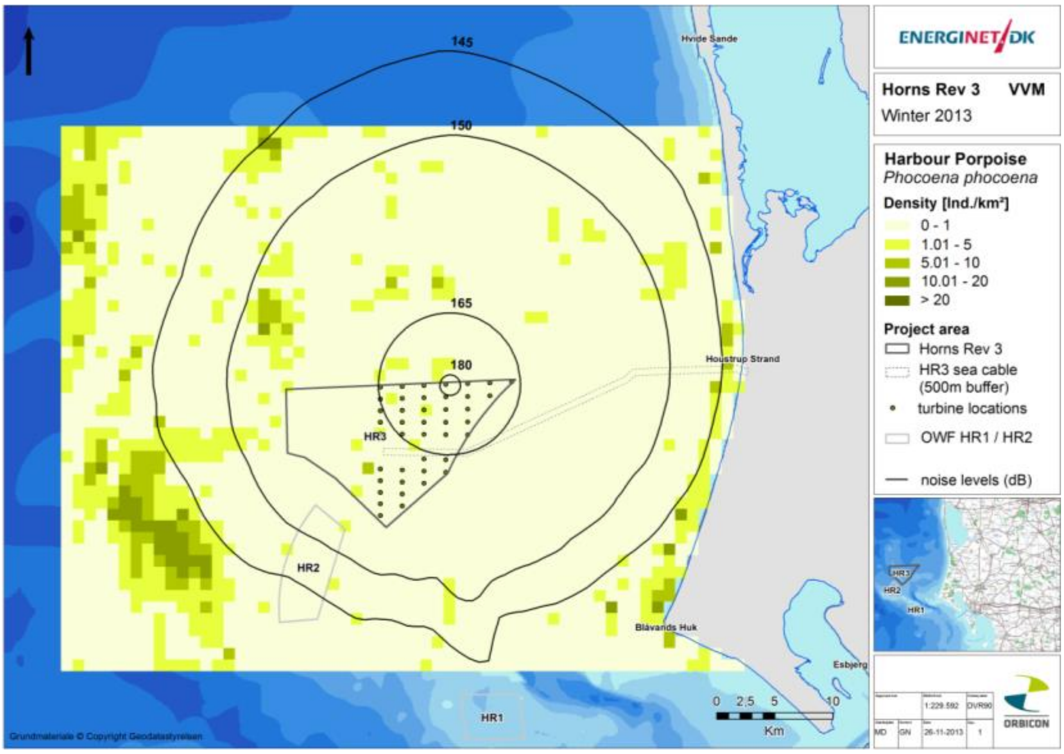

Figure 4.9: Winter spatial distribution model for harbour porpoise combined with sound propagation model during pile driving in the north-easterly part of the Horns Rev 3 offshore wind farm.

Pile driving at the south tip of Horns Rev 3 will move areas of high sound pressure levels toward the largest high density area of harbour porpoises. Therefore during the summer month the high density area west of Horns Rev 2 will be completely exposed to 145 and more dB_{SEL}. The high density area north-west of Horns Rev 3 will partly be exposed to more than 145 dB_{SEL}.

Harbour porpoise © Carline Höschle

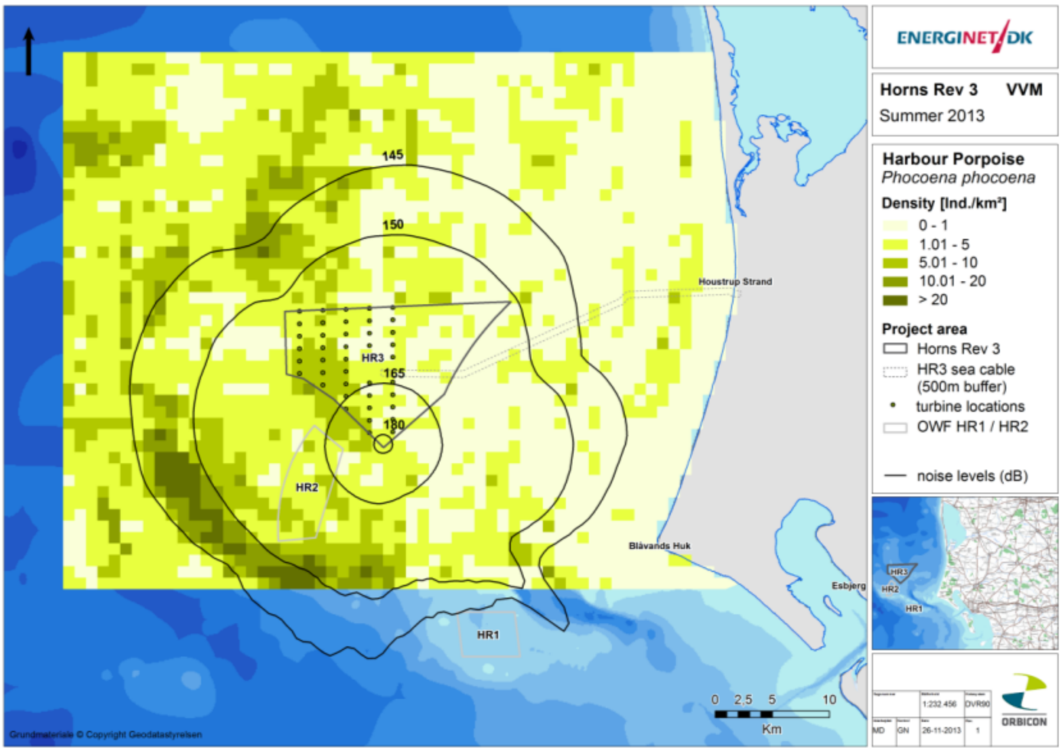

Figure 4.10: Summer spatial distribution model for harbour porpoise combined with sound propagation model during pile driving at the south tip of the Horns Rev 3 offshore wind farm.

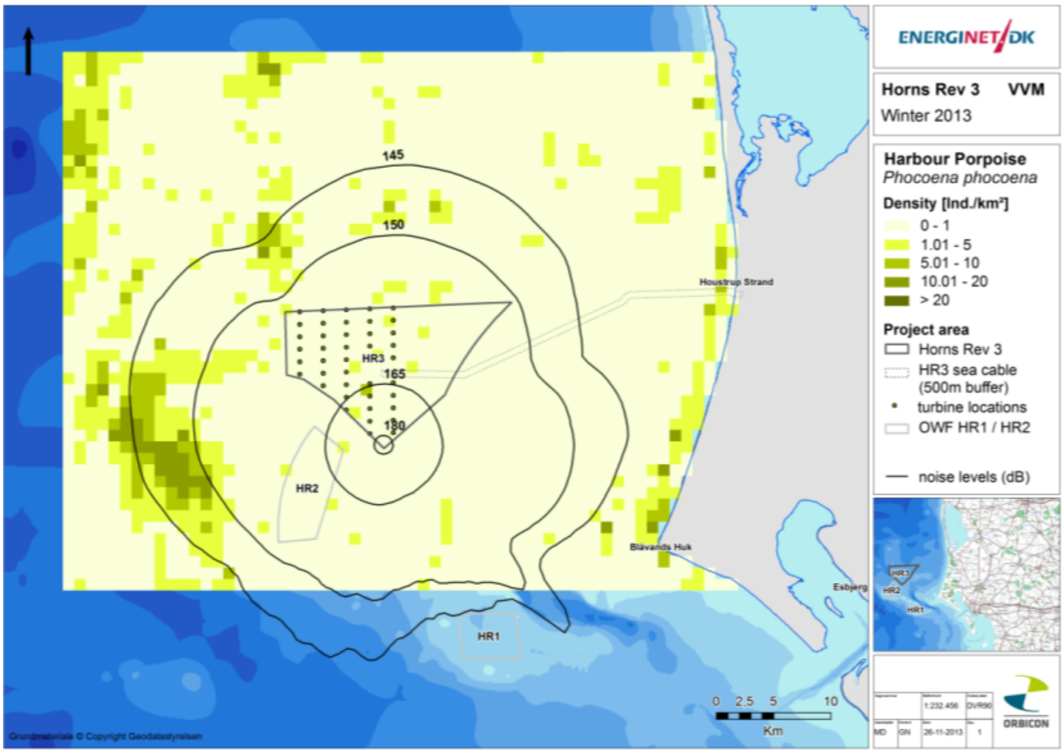

Figure 4.11: Winter spatial distribution model for harbour porpoise combined with sound propagation model during pile driving at the south tip of the Horns Rev 3 offshore wind farm.

In winter large parts of the harbour porpoise high density area west of Horns Rev 2 will be exposed to more than145 dB_{SEL}. The same is true for the high density area north-west of Horns Rev 3.

Based on the spatial distribution models and the sound propagation models the number of harbour porpoises affected by ≥145 dB_{SEL} was calculated. The number of harbour porpoises was calculated for every single grid cell in the model and was added up to calculate an average number of harbour porpoises per km². Depending on the position of the pile driving activity an area in the north or in the south that was affected by noise was not covered by the distribution model. The expected harbour porpoise density for this area was calculated from the overall average calculated for the modelled area. The number of harbour porpoises affected by pile driving in different positions and in different seasons is given in Table 4.13.

Table 4.13: Number of harbour porpoises affected by ≥145 dB_{SEL} during pile driving (single strike) in the Horns Rev 3 area. The average number per km² was calculated on base of the modelled harbour porpoise distribution and was used to estimate the numbers in areas not covered by the model.

Pile driving position	season	Size of area affected by more than 145 dB_{SEL} in km²	Number of harbour porpoises affected	Average number of harbour porpoises/km^2
South	summer	1336,86	4876	3,5
	winter	1336,86	1015	0,8
North	summer	1880,80	3821	1,9
	winter	1880,80	689	0,4

A high number of harbour porpoises will be exposed to noise levels causing behavioural responses. Noise immissions in the northern part of the wind farm might cause behavioural reactions to nearly 700 harbour porpoises during the low density period in winter. The same piling would affect about 3800 harbour porpoises in the high density summer month. The numbers are higher in the southern part of the wind farm, where more than 1000 harbour porpoises in winter and about 4900 in summer would be affected.

In the course of a piling operation about 60% of the porpoise within the 145 dB_{SEL} contour are predicted to leave this area, thus total displacement from this area is estimated at maximal about 3000 porpoises for the southern location and 2300 for the northern location. Recovery time will be about 2 to 3 days in areas exposed to high noise levels but only last a few hours at the outer range of the impact area. Depending on the construction schedule it is possible, that recovery time lasts longer than the interval between two piling activities and is thus assumed that porpoise densities in the in construction area will be reduced over the whole construction period.

It is not possible to assess precisely how many porpoises will be exposed to higher noise levels which may induce hearing impairment, as porpoises will be deterred from the construction area and move further away as noise immissions increase. As the 165 dB_{SEL}-radius of a single strike ranges between 5.1 and 6.1 km it is likely that porpoises will be exposed to noise levels causing TTS, though numbers may be small as piling will start with low energy of the hammer and thus with reduced noise levels.

The 180 dB_{SEL}-contour for a single strike with full energy reaches a distance of about 800 m. If cumulation of high noise levels is taken into account the PTS-contour during the whole piling operation increases with the number of blows.

Ranges for cumulative received Sound Exposure Level (SEL) for a marine mammal over the entire piling operation have been modeled for a 6 h piling operation assuming that the receptor is fleeing from the noise at a speed of 1.5 m/s. The results of modelling a 10 m pile being installed with a maximum blow energy of 3000 kJ at Horns Rev 3 are summarised in Table 4.14. The propagation range is highly dependent on water depths and attenuation is stronger where the water is shallower. Therefore maximum and minimum and medium ranges were calculated with shorter ranges in the direction of shallow coastal waters and longer ranges in areas with greater water depths. Since harbour porpoises mostly avoid very shallow waters the calculated maximum range in deeper waters is more suitable to estimate the number of affected animals.

The model takes a soft-start with reduced piling energy and a gradual ramp-up procedure into account. It further assumes that porpoises flee from the noise source at a constant speed of 1.5 m/s. Even though harbor porpoises are certainly capable of swimming faster than 1,5 m/s, a moderate swimming is more appropriate for an impact assessment as it is not clear whether porpoise would swim directly away from the source. Further, mother-calve pairs may not reach a faster swimming speed as long as calves are small. From the present data it thus cannot be excluded that harbour porpoises would be exposed to noise levels causing PTS from cumulative exposures. The result of the model is that porpoises being within a range of 8.7 km for the northern location and 6.6 km for the southern location will receive a cumulative noise level inducing PTS. Although the model has to be regarded as being very conservative as it allows equal cumulation for high and low noise levels, the size of the impact ranges make it likely that at least part of the porpoises being present within these ranges will receive PTS during the piling operation of a 10 m monopile.

Table 4.14: Predicted impact ranges from cumulative exposures using the PTS criteria for marine mammals (Mason & Barham 2013).

PTS		Pinniped (186 dB SEL (M_{pw}) (cumulative))	Harbour porpoise (180 dB SEL (cumulative))
North East	Maximum	2.1 km	10.4 km
	Minimum	1.7 km	7.2 km
	Mean	1.9 km	8.7 km
South	Maximum	900 m	8.0 km
	Minimum	700 m	5.3 km
	Mean	800 m	6.6 km

The harbour porpoise is listed in Annex II and IV of the EU-habitat directive as an endangered species. In the Horns Rev area the density of harbour porpoises is very high in summer exceeding the very high importance level of >2 harbour porpoises/km^2 defined in

Table 2.5 and the area is used during mating and nursing periods. Cumulative noise levels may induce PTS in harbour porpoise. Therefore the severity of the impact is ranked as very high.

4.4.2.2. Harbour seal and grey seal

Large parts of the Horns Rev area including the Horns Rev 3 offshore wind farm will be affected by sound of more than 145 dB_{SEL}. This is the threshold for behavioural reactions in harbour porpoises and was defined as a precaution threshold for seals in this study (Table 4.5). The threshold defined for TTS in harbour seals is 171 dB_{SEL} (Southall et al. 2007). Depending on the water depth in which pile driving takes place the sound propagation model predicts the SEL to fall below 170 dB_{SEL} at a distance between 2,8 and 3.3 km from pile driving. Though seal density in the area is low it must be assumed that seals may be exposed to such noise levels. The PTS threshold is 186 dB_{SEL}. This level is exceeded at a distance of 1-2 km if cumulative exposure is considered. As the initial range of PTS-levels are very small it is considered unlikely that seals will be exposed to such levels during a piling operation.

Due to the low density or harbour seals in the area the number of seals that might be exposed to sound that could cause TTS or PTS will be small.

4.5. Impact of operation and structures

4.5.1.Habitat loss from footprint

The part of the Horns Rev 3 offshore wind farm that will be lost due to the footprint of the turbines and scour protection will be very small. Based on scour protection of 50 m diameter 40 turbines would cover an area of 0.079 km^2.

4.5.1.1. Harbour porpoise

Due to the small area that will be covered by the footprint of Horns Rev 3 only a small part of the harbour porpoise habitat will be lost. With an average harbour porpoise density of 1.9 to 3.5 per km^2 in summer and 0.4 to 0.8 porpoises/km^2 in winter 0.03 to 0.27 harbour porpoises could be affected.

The loss of 0.079 km^2 soft bottom habitat is not likely to cause larger changes to the benthic community but the introduction of artificial structures will alter the species composition by providing settlement structures for hard bottom species (see chapter 4.5.2). While the loss of small parts of soft sediment habitat are not likely to affect the food availability of harbour porpoises the artificial reef structure is likely to have positive effects on the fish community and therefore can provide better food sources for harbour porpoises.

4.5.1.2. Harbour seal and grey seal

The size the footprint of the wind farm Horns Rev 3 is expected to be 0.079 km^2 and therefore covers 0.003 % of the survey area. This loss is considered to be negligible.

4.5.2.Habitat change and artificial reef effects

All habitat changes have the potential to cause temporary or permanent behavioural changes in marine mammals. Changes to foraging areas or in the case of seals haul-out places can cause distributional changes and might affect fecundity and survival.

The main habitat change during operation of Horns Rev 3 will be the structures of piles and scour protection.

Anthropogenic structures are known to be colonized by a large number of different invertebrate organisms and in suitable light conditions macrophytes. Therefore the introduction of piles and scour protection of Horns Rev 3 will increase the structural complexity and will allow new species to settle in the generally soft bottom area. This provides enhanced feeding conditions for fish and will increase abundance and diversity of fish species (Langhamer 2012). The new structures can function as spawning and nursery areas for different fish species during the operational phase of the wind farm. Therefore it is likely that the prey composition of marine mammals in the area will change and that the food availability might increase with higher abundance at and around the artificial structures. Lindeboom et al. (2011) observed not only a higher biodiversity of benthic organisms inside the Dutch offshore wind farm Egmond aan Zee but a higher acoustic activity of porpoises inside the wind farm compared to reference areas outside the wind farm (Scheidat et al. 2011). The higher acoustic activity points to a higher number of porpoises present in the area which the authors assumed would be caused by increased food availability (due to artificial reef effects) and the exclusion of fisheries and reduced vessel traffic inside the wind farm (shelter effect) (Scheidat et al. 2011).

Therefore the effect of habitat change due to operation of the wind farm Horns Rev 3 is likely to be negligible or even positive for harbour porpoises, harbour seals and grey seals.

4.5.3.Hydrographical changes from wind farm structures

The presence of 40 to 136 wind turbines as permanent structures in the Horn Rev 3 area will cause hydrographical changes. The physical changes in structures or seabed can have potential effects on the water level, currents, salinity, temperature and waves.

The effects of hydrodynamical changes on marine mammals in the Horns Rev 3 area will mainly be related to distributional changes of prey species. Therefore changes in these variables might cause distributional changes. The effects are expected to be small scale and no strong sensitivity of harbour porpoises, harbour seals and grey seals regarding these features is expected.

4.5.4.Noise from operation

The noise emitted during operation of the wind farm will be on a much lower level than during construction but on the other hand it will be permanently emitted over the whole operational period of 20 or more years.

The frequency range and sound level emission of the turbine depends on the foundation and on wind speeds. Norro et al. (2009) measured sound pressure levels in the vicinity of wind turbines and at a greater distance which was considered to represent the background noise level. The authors found clear differences between 5 MW concrete gravity foundations that added about 8 dB to the background noise while 3 MW steel monopile foundations increased the noise level by 20 to 25 dB. Both turbine types emitted most energy at the low frequency range between 100 Hz to 1 kHz (Norro et al. 2009).

Tougaard et al. (2009) measured operational noise from three different offshore wind farms (450 kW, 500 kW and 2 MW) and found that only frequencies below 500 Hz were detectable above background noise levels. They measured sound pressure levels of 109 to 127 dB re 1µPa at distances between 14 and 20 m from the turbines. It was concluded that harbour porpoises would be able to detect the turbine noise at distances between 20 to 70 m while harbour seals with better hearing ability at the low frequency range could hear the noise in a range from less than 100 m to several kilometers (Tougaard et al. 2009).

Harbour porpoises and harbour seals have been observed in operating offshore wind farms (Tougaard et al. 2006a, Tougaard et al. 2006b, Diederichs et al. 2008a, Scheidat et al. 2011, Teilmann et al. 2012) in comparable or even higher numbers as before installation of the wind parks and therefore the noise emitted by operating offshore wind farms is assessed as negligible.

4.6. Decommissioning

The expected operational time for offshore wind farms is 20 years. Afterwards they will be decommissioned by removing the structures above the sea bed. Due to the long life time of offshore wind farms and fast technical progress in the field detailed plans for decommissioning are not available yet. So far it is expected that dredgers will be used to remove scour protection and that the piles will be cut above the sea bed by water jet cutters.

Decommissioning will therefore cause comparable effects as the construction of the wind farm regarding ship traffic and dredging. In contrast to the construction phase with very high noise levels due to pile driving noise levels during decommissioning will be much lower.

Disturbance of harbour porpoises, harbour seals and grey seals due to decommissioning are expected to be local and short term.

4.7. Protected areas and species

4.7.1. Assessment of strictly protected species

Article 12 of the Council Directive 92/43/EEC on the protection of species states that:

1. Member States shall take the requisite measures to establish a system of strict protection for the animal species listed in Annex IV (a) in their natural range, prohibiting:

   a) all forms of deliberate capture or killing of specimens of these species in the wild;
   b) deliberate disturbance of these species, particularly during the period of breeding, rearing, hibernation and migration;
   c) deterioration or destruction of breeding sites or resting places.

2. For these species, Member States shall prohibit the keeping, transport and sale or exchange, and offering for sale or exchange, of specimens taken from the wild, except for those taken legally before this Directive is implemented.
3. The prohibition referred to in paragraph 1 (a) and (b) and paragraph 2 shall apply to all stages of life of the animals to which this Article applies.

Member states are further requested to establish a system to monitor the deliberate capture or killing of species listed in Annex IV (a) and to make sure that this will not impair the conservation status of these species. The demands from the Habitats Directive concerning the strictly protected species have been transposed into national law in Denmark (Naturbeskyttelsesloven). Further guidance on the application of the regulation of Article 12 is provided by the EU (http://ec.europa.eu/environment/nature/conservation/species/guidance/index_en.htm).

4.7.2. Deliberate capture or killing of specimens, including injury

Pile driving of the transformer platform and 10 m monopiles emit underwater noise which might cause PTS in a distance of some hundred meters to several kilometres. Due to regular presence of harbour porpoises and other cetacean species in the area this poses a relevant risk to induce PTS to this species which might lead to a violation of the obligations from Art. 12. The risk of inducing PTS to harbour porpoises and other species thus needs to be securely reduced by mitigation measures (see below) and soft start procedures.

As described in chapter 4.4, noise levels potentially causing PTS in harbour porpoise reach about 800m at the first blow and rapidly increase over the piling process. The radius with a cumulated noise immission exceeding 180 dB_{SEL} would grow to 5 to 10 km over a full piling operation even when a soft-start procedure is taken into account. It is concluded that the range is so large that exposure to noise immissions which may induce PTS cannot be excluded.

Mitigation measures by deterrents are not considered to be sufficient to safely exclude the risk of inducing PTS as the range of efficient deterring is much smaller than the range in which PTS may be induced.

It is thus concluded that construction works is likely to lead to injury of harbour porpoises species of the area and that the obligation of Article 12 habitat directive are violated by the project unless active noise mitigation is applied in order to reduce noise levels during pile driving.

4.7.3. Deliberate disturbance

Noise immissions from construction activities lead to rather large-scale (20 km) disturbance with a short duration. The impacts from pile driving are considered to be fully reversible in short time. Though the number of harbour porpoises affected from noise immissions causing behavioural responses is rather large, no impacts lasting longer than a few days after end of construction are expected..

It is thus concluded that construction work will not lead to significant disturbance of the local population of harbour porpoises in the area and that the obligations of Article 12 habitat directive are not violated by the project.

4.7.4.Natura 2000 impact assessment

The closest Natura 2000 area where marine mammals are defined as conservation targets is the SCI DK00VA347 Sydlige Nordsø. The harbour porpoise is listed in the standard data form.

Noise levels of 150 – 145 dB_{SEL} overlap with a small part of the protected area. Noise immissions will cause minor disturbance in the area where noise immissions exceed 145 dB_{SEL} which will be short duration and not last longer than the piling. Piling in the northern part of the Horns Rev 3 wind farm will not result in noise levels causing disturbance in the SCI.

It is thus concluded that pile driving for the Horns Rev 3 wind farm will not result in significant impacts in the SCI Sydlige Nordsø.

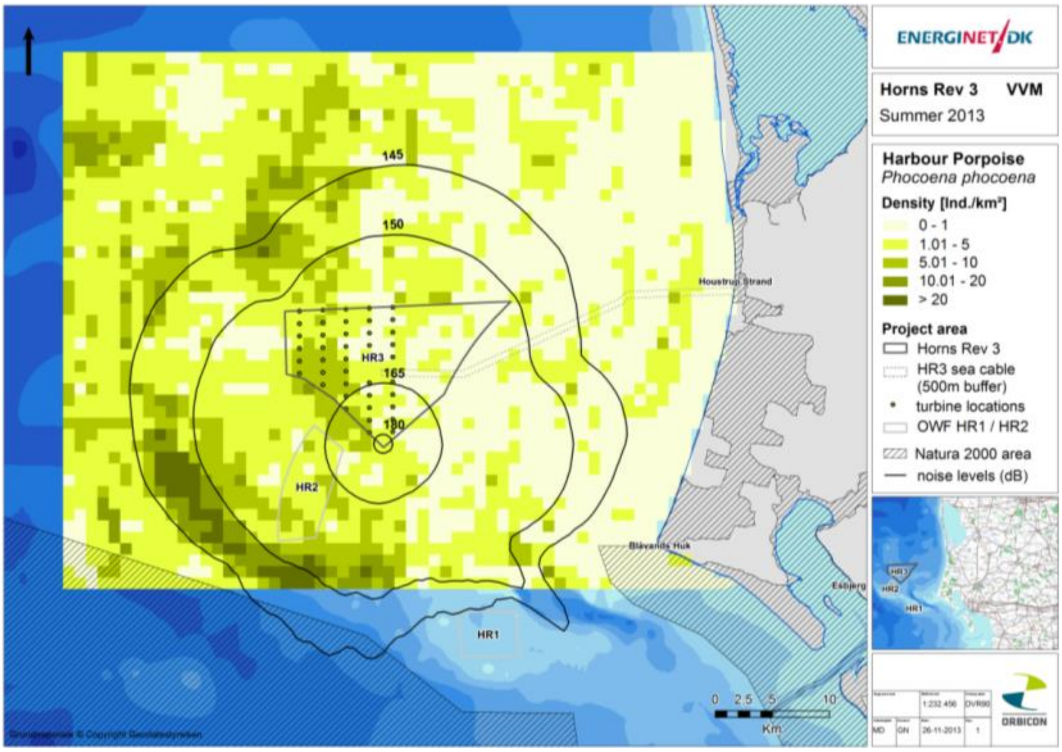

Figure 4.12: Summer spatial distribution model for harbour porpoise. The map shows the overlap of noise immissions with SCI Sydlige Nordsø. The noise emission is calculated for maximum effect from ramming at the end of piling.

4.8. Assessment of cumulative impacts

Cumulative may be relevant from nearshore wind farms and German wind farms. For the planned nearshore wind farms in Denmark no parallel construction is expected as the two nearshore wind farms in the North Sea are in a different stage of planning. For German wind farms, active noise mitigation is mandatory so that noise immissions are small and no cumulative impacts will occur. Even there are some projects close to Danish waters which might be constructed in the same time as the Horns Rev 3 wind farm, due to active noise mitigation to 160 dB_{SEL} at 750 m, impacts from these projects will be very small and not induce disturbance.

4.9. Summary of impact assessment

4.9.1. Harbour porpoise

4.9.1.1. Temporary effects

The construction of the planned offshore wind farm Horns Rev 3 will have temporary effects on harbour porpoises. Increased presence and activity of different kinds of boats during construction is likely to cause behavioural and small scale distributional changes for the duration of construction work.

Sediment spills caused by preparation of the sea bed, pile driving and installation of scour protection is not likely to affect harbour porpoises directly. The effects that sediment spill will have on prey species of harbour porpoise are expected to be local and insignificant for the fish population in the area. Therefore the effect of sediment spill on harbour porpoises is considered to be negligible.

The main effect during construction will be the noise emitted by pile driving that will affect large areas. Injuries or permanent threshold shift in harbour porpoises are expected at SELs that exceed 180 dB. If cumulative effects are taken into account the range for PTS in harbour porpoises could rise to 8.7 km for the northern location and 6.6 km for the southern location of pile driving.

The area affected by noise of 180 dB_{SEL} or more is expected to expand to a distance of 830 to 890 m from pile driving activities. Temporary threshold shift in harbour porpoises is expected to occur at SELs of ≥165 dB. This level will be exceeded at distances of 5.3 to 6.2 km from pile driving and therefore harbour porpoises present in this range are at risk to suffer TTS.

Although the model has to be regarded as being very conservative as it allows equal cumulation for high and low noise levels, the size of the impact ranges make it likely that at least part of the porpoises being present within these ranges will receive PTS during the piling operation of a 10 m monopile.

Minor behavioural reactions are expected at SELs of 145 d. The area being affected by at least 145 dB adds up to about 1300 to 1900 km² (depending on the position of pile driving). Considering the high density of harbour porpoises in the area about 3800 to 4900 porpoises in summer and 690 to 1000 in winter will be exposed to sound that might cause behavioural reactions.

The harbour porpoise is listed in Annex II and IV of the EU-habitat directive as an endangered species. In the Horns Rev area the density of harbour porpoises is very high in summer exceeding the very high importance level of >2 harbour porpoises/km^2 defined in Table 2.5 and the area is used during mating and nursing periods. Temporary impacts on harbour porpoises due to pile driving during construction of the Horns Rev 3 offshore wind farm are therefore considered to be very high.

4.9.1.2. Permanent effects

Permanent effects will be caused by the presence of the wind farm structures. Considering the layout with 40 turbines of 10 MW only a small part of about 0.08 km² of the harbour porpoise habitat will be covered by the wind turbines and scour protection which is not likely to cause noticeable effects. The structures have the potential to cause changes in currents, water level, salinity, temperature and waves. While direct effects on harbour porpoises are not expected from the presence of the structures indirect effects are likely due to effects on prey species of harbour porpoises. Effects on fish populations are considered to be local and minor and therefore indirect effects on harbour porpoises are expected to be negligible.

Operational noise from offshore wind turbines only exceeds the background noise level at frequencies below 500 to 1000 Hz which is outside the range of best hearing in harbour porpoises. The sound pressure levels are relatively low and it is expected that harbour porpoises can detect the turbine sound only in a range of maximal 70 m and behavioural reactions might appear, when they are very close to the turbines (Tougaard et al. 2009). Harbour porpoises have been observed in different operational offshore wind farms indicating usage of the wind farm in the same way as surrounding areas.

The Horns Rev area is dominated by soft bottom sediment. Artificial structures such as the wind turbines and scour protection will enable hard substrate species to settle in the area which will lead to a higher biodiversity and abundance in invertebrates and consequently in e.g. fish species benefiting from better food resources. While there is no information on direct effects of artificial reef structures on harbour porpoises it is likely that they will benefit from better food availability in the wind farm. Additionally the exclusion of fisheries and reduced vessel traffic inside the wind farm might have positive effects on harbour porpoises.

4.9.2. Harbour seal and grey seal

4.9.2.1. Temporary effects

During construction of the Horns Rev 3 offshore wind farm seals are likely to be temporarily affected by increased presence and activity of different kinds of boats. Small scale distributional and behavioural changes are expected during construction. Due to the large distance to the next haul-out sites of harbour seals disturbance of resting seals is not expected. Haul-out sites for grey seals are not present in the Danish Wadden Sea so far.

Sediment spills caused by preparation of the sea bed, pile driving and installation of scour protection are not likely to affect seals directly. The spill could have local and insignificant effects on the fish population in the area and therefore have indirect effects on seals as mainly fish eating predators. The effect of sediment spill on seals is considered to be negligible.

The main effect during construction will be the noise emitted by pile driving that will affect large areas. Injuries and permanent threshold shifts in seals are expected at SELs of 186 dB. The SEL dropped to about 180 dB at 750 m from pile driving activity. Therefore seals need to get notably closer to the pile than 750 m to suffer injury or PTS. Temporary threshold shift in seals is expected at levels of at least 171 dB_{SEL}. SELs of 170 dB were modelled for distances of about 3.3 km from pile driving activity which is the range in which seals can suffer TTS. Minor behavioural changes are expected at SELs of ≥145 dB. The area being affected by at least 145 dB_{SEL} adds up to about 1300 to 1900 km² (depending on the location).

The Horns Rev area is considered to be of no special importance to harbour seals and numbers of observed harbour seals were relatively low. Therefore the number of seals that might be exposed to sound that could cause TTS or PTS or behavioural changes will be small.

No grey seal was identified in the area during survey flights in 2013 but it is possible that some or all of the 15 unidentified seals during surveys were grey seals. The Horns Rev area is considered to be of no special importance to grey seals and the number of grey seals will be low.

Temporary impacts on harbour seals and grey seals due to pile driving during construction of the Horns Rev 3 offshore wind farm are therefore considered to be of medium severity.

4.9.2.2. Permanent effects

The presence of the wind farm structure will have permanent effects on the wind farm area although the footprint of the turbines and scour protection is likely to cover only an area of 0.08 km². This footprint of the wind farm is not expected to have any noticeable effect on seals in the area. The structures have the potential to cause changes in currents, water level, salinity, temperature and waves. While these hydrographical changes are not likely to have a direct influence on seals they are likely to affect prey species and therefore indirectly the seals itself. Effects on fish populations are considered to be local and minor and therefore indirect effects on harbour and grey seals are expected to be neglectable.

The sound emitted by offshore wind turbines only exceeds the background noise level at frequencies below 500 to 1000 Hz. The hearing ability of seals at lower frequencies is relatively good with hearing threshold around 80 dB re 1µPa. They will likely be able to detect the turbine sound at distances up to 100 m to several kilometers (Tougaard et al. 2009). While seals will be able to detect the sound over a wider range they seem to be more tolerant to underwater noise than harbour porpoises (Tougaard et al. 2009). Behavioural reactions cannot be excluded at a range of a few hundred meters but harbour seals have been observed using the area of wind farms (Tougaard et al. 2006c)

Stronger reactions in seals are not expected and the effects of operational noise on seals is considered to be negligible

The wind turbines and scour protection will act as artificial reef structures that will be fouled by hard substrate species that could so far not settle in the prevailing soft bottom substrate at Horns Rev. This will lead to a higher biodiversity and abundance in invertebrates and consequently in e.g. fish species benefiting from better food resources.

While there is no information on direct effects of artificial reef structures on harbour and grey seals it is likely that they will benefit from better food availability in the wind farm. Additionally the exclusion of fisheries and reduced vessel traffic inside the wind farm might have positive effects on seals.

Piling of monopiles at Horns Rev 2 Offshore Wind Farm

5. MITIGATION DURING PILE DRIVING

With respect to exposure of marine mammals to high noise levels there are two strategies for mitigation of impacts of pile driving:

1. To deter marine mammals out of an area where they might be exposed to harmful noise levels.

2. Active mitigation of noise immission in order to reduce impact radii.

In the absence of specific noise thresholds, active noise mitigation would only be required if deterrence would not secure that no protected species are exposed to noise levels causing physical injury or if disturbance would cause large-scale impacts which would be regarded as significant in respect to protected areas or local populations. However, for the assessed worst case scenario for installation of 10 MW turbines it cannot be excluded at this stage that harbour porpoises may be exposed to cumulative noise levels which may induce PTS in this strictly protected species. Therefore active noise mitigation is considered as mandatory for the project.

In order to reduce the exposure of marine mammals to levels causing hearing impairment, active noise mitigation, soft start inducing an early displacement of animals and ramp up procedures should be applied. Seal scarer and adequate deterrence devices shall be established to assure reduced noise levels and displacement of animals from the piling site.

5.1. Active noise mitigation

Underwater noise from pile driving can be efficiently reduced by various methods such as bubble-curtain, noise mitigation screen and others (Nehls et al. 2007, Koschinski & Lüdemann 2013, Pehlke et al. 2013).

Though there is no state of the art technique available at the moment which would allow a defined degree of noise reduction, development of noise mitigation techniques is developing fast as noise mitigation is mandatory in Germany and Belgium in relation to defined thresholds which would be generally exceeded without mitigation. A mitigation of at 10 dB can be achieved with a bubble-curtain and other techniques as well. This would reduce impact radii to ¼ of initial size and is regarded as sufficient for the project.

5.2. Acoustic Deterrent procedures and devices

Acoustic deterrent devices (ADDs) are made specifically for displacing marine mammals, e.g., protecting fishing nets from hunting seals. These devices use powerful underwater sounds and can be distinguished by the emitted sound level (SMRU Ltd 2007):

- Pingers: devices in which the source level is lower than 185 dB re 1 µPa @ 1m
- Seal scrammers or Seal scarer: devices in which the source level is higher than 185 dB re 1 µPa @ 1m

5.2.1. Pingers

Pingers are mainly used in aquaculture and fisheries, to keep marine mammals away from the nets and reduce cetacean bycatch. These devices operate within mid-high frequencies (2.5-100 kHz) and with higher harmonic frequencies of up to 180 kHz. Though devices are proven to be effective, habituation of species has been documented and are a main concern regarding the use of pingers (Cox et al. 2001, Gordon & Northridge 2002; Teilmann et al. 2006b). Considering the inter-specific differences in hearing sensitivity in marine mammals, the output of these devices must be specifically designed for the target species.

On the basis of the available literature, every study on the effects of pingers on harbour porpoises has shown a sustained and substantial degree of exclusion, even if some reports provide apparently contradictory observations of habituation followed by the extensive use of pingers (Gordon & Northridge 2002).

On pinnipeds on the other hand, pingers appear to have few negative effects (SMRU Ltd 2007).

5.2.2.Seal scarer

The efficacy of these devices is derived from their high power levels within the seals' best hearing sensitivity (8-17 kHz).

Harbour porpoise showed strong aversive responses to seal scarers up to a range of 1-2 km (Johnston 2002, Olesiuk et al. 2002, Brandt et al. 2011b, Robertson et al. 2004). An almost complete displacement can be assumed for a range of 1 km.

Surprisingly, there are no peer reviewed articles that proof an effective displacement of seals. This might be owed to the fact, that ADDs used at fish farms or fish traps to demotivate seals to approach the nets, are often continuously active and left active for long periods of time. Additionally, they are usually in proximity to a resource that seals are highly motivated to acquire.

Nevertheless, a combination of a time-delayed activation of a pinger and seal-scarer followed by ramp-up and reduced energy ramming is recommended as an appropriate deterrence procedure.

5.3. Surveillance during pile driving

It is common practice to monitor the risk zone in which marine mammals may be exposed to harmful noise levels for the presence of marine mammals. This is often done by visual observations from a ship by so-called Marine Mammal Observers. As pile driving may be conducted during night or weather conditions, which do not allow making observations from a ship this method has a high risk of not providing the information which is needed. It is thus recommended to use a passive acoustic monitoring technique (PAM) instead, either by towed or by stationary hydrophones.

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7. APPENDIX

7.1. Model diagnostic plots

7.1.1.Harbour porpoise – summer model

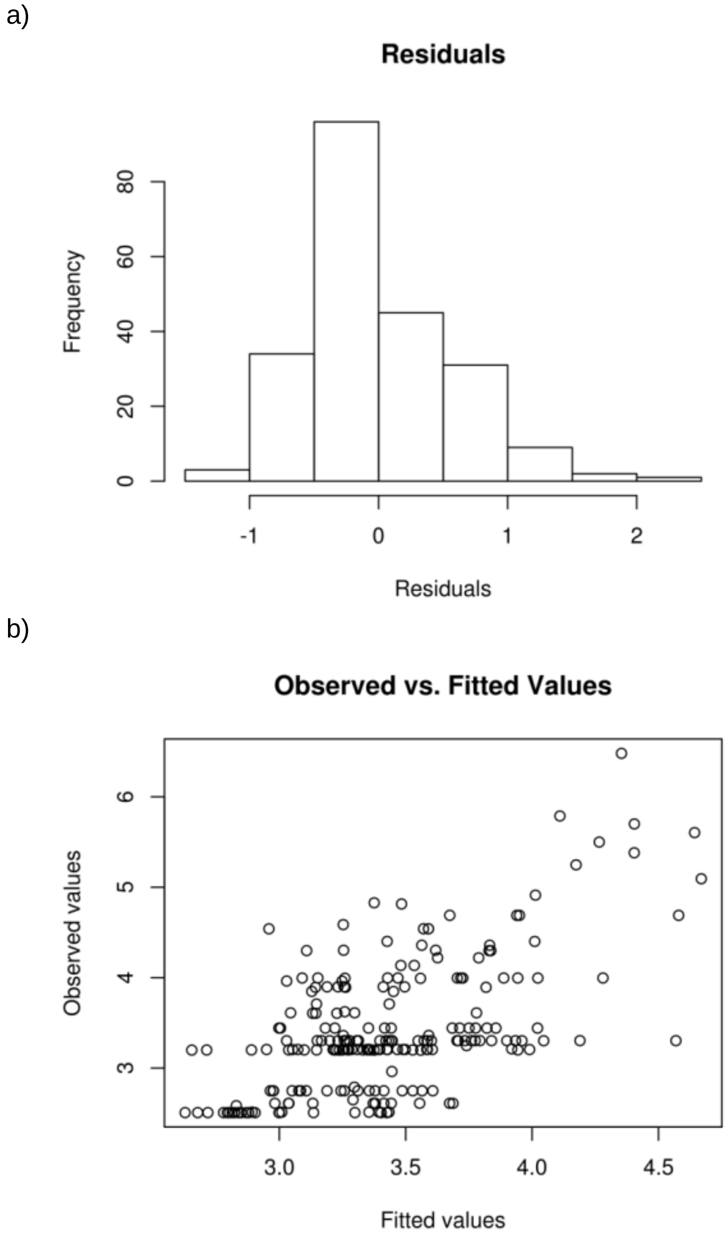

Figure 7.1: Diagnostic plots for the positive part of the two-part random Forest summer model for the harbour porpoise. A histogram of the residuals is displayed in (a) and the fitted against the observed values are displayed in (b).

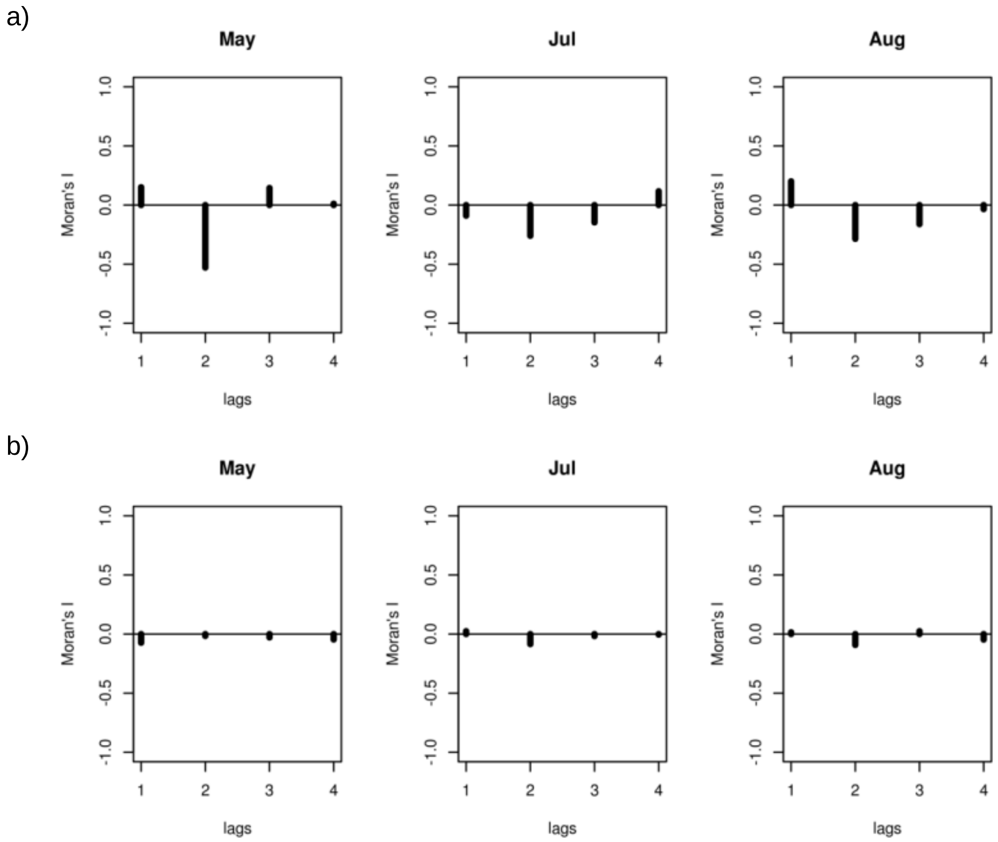

Figure 7.2: Spatial correlograms displaying the spatial autocorrelation in the residuals for the two-part Random Forest summer model for the harbour porpoise (a) indicates the positive part and b) indicates the presence and absence part). The bars show twice the square root of the variance from the estimated Moran's I value. 1 lag equals the defined nearest neighbourhood of 20,000 meters.

Table 7.1: Test statistics for Moran I for the harbour porpoise summer model. None of the tests revealed the presence of spatial autocorrelation (all P-values were > 0.05) with exception of the month of August for the positive part of the model (P < 0.05).

Month	Positive	Presence/ Absence
May	1.49	-0.43
July	0.15	1.18
August	2.79	0.78
September	0.60	-0.22

7.1.2.Harbour porpoise – winter model

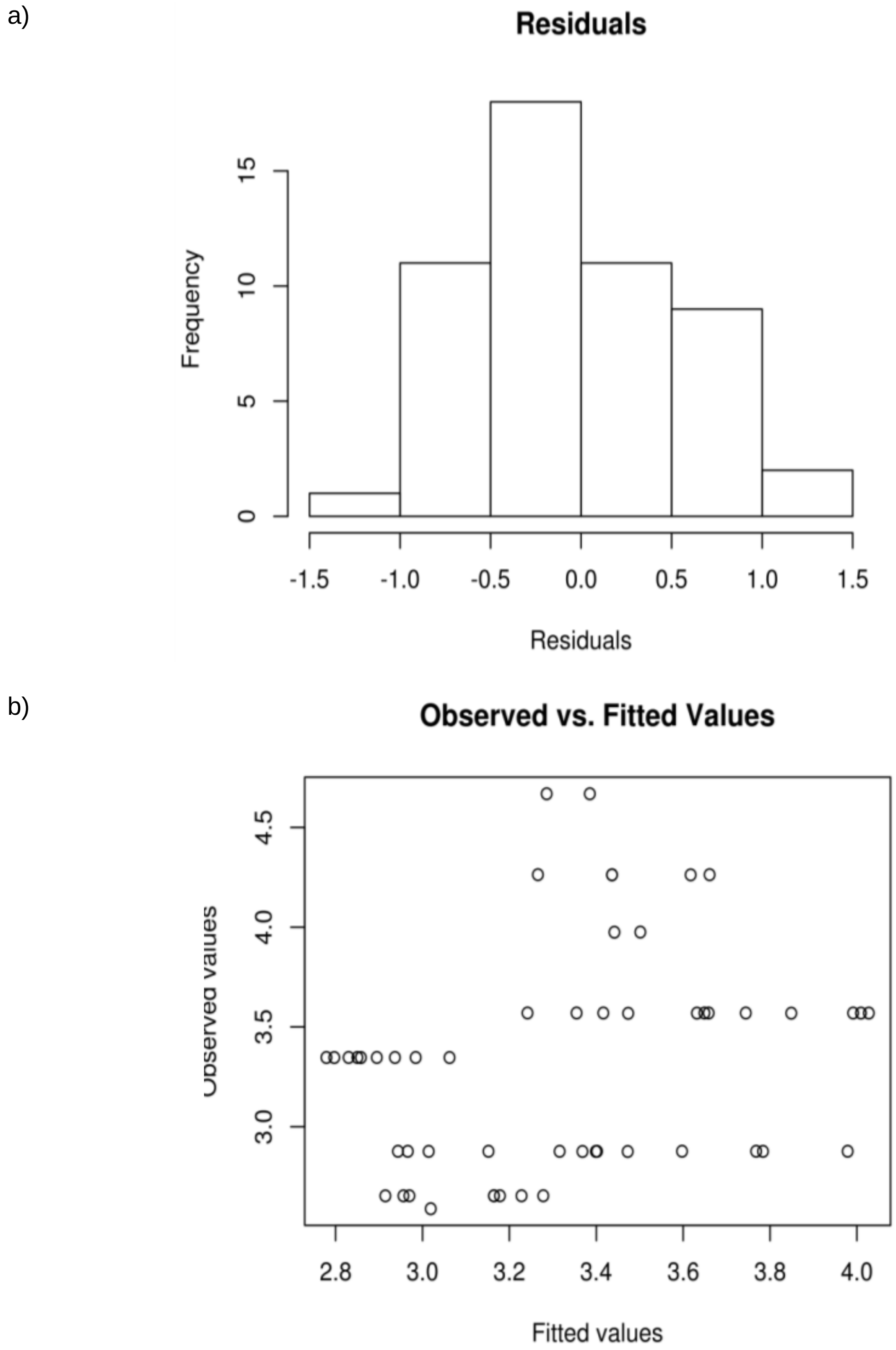

Figure 7.3: Diagnostic plots for the positive part of the two-part random Forest winter model for the harbour porpoise. A histogram of the residuals is displayed in (a) and the fitted against the observed values are displayed in (b).

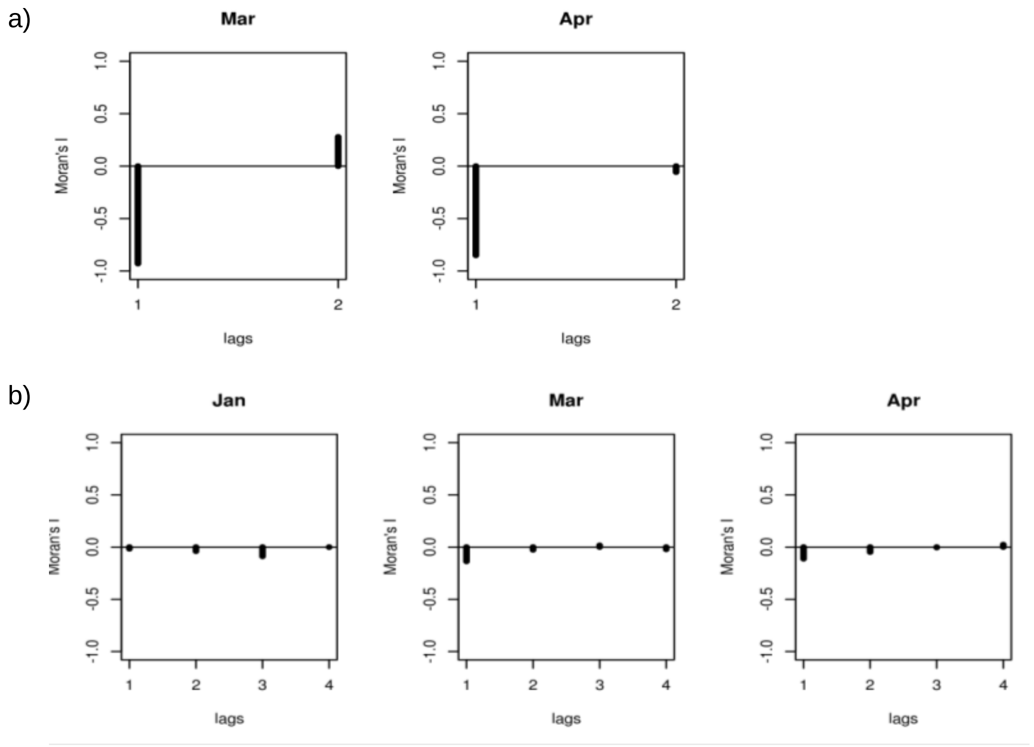

Figure 7.4: Spatial correlograms displaying the spatial autocorrelation in the residuals for the two-part Random Forest winter model for the harbour porpoise (a) indicates the positive part and b) indicates the presence and absence part). The bars show twice the square root of the variance from the estimated Moran's I value. 1 lag equals the defined nearest neighbourhood of 20,000 meters.

Table 7.2: Test statistics for Moran I for the harbour porpoise winter model. None of the tests revealed the presence of spatial autocorrelation. All P-values were > 0.05.

Month	Positive	Presence/ Absence
January	-	0.26
March	-0.56	-0.79
April	0.00	-0.86

7.2. Passive acoustic monitoring

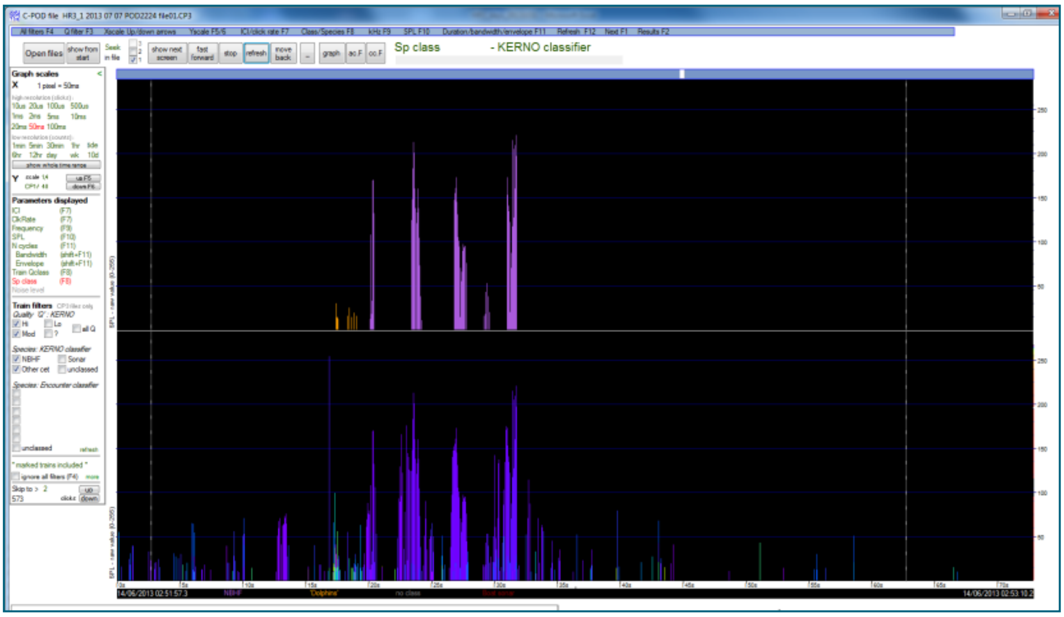

Figure 7.5: C-POD.exe: Visualisation of processed data (upper graph) click trains assigned to dolphins (orange) and harbour porpoises (purple: Narrow band high frequency click trains) in comparison to unprocessed data (lower graph); height of bars indicates sound pressure level.

Table 7.3: Post-hoc comparison between months: Pairwise Wilcoxon-Test of porpoise activity illustrated as detection positive 10-minute-intervals per day per PAM-station (p-values corrected after Bonferroni, NA = no data; * significant; ** highly significant)

'Horns Rev 3 – 1'	2012 12	2013 01	2013 02	2013 03	2013 04	2013 05	2013 06	2013 07	2013 08	2013 09	2013 10	2013 11
2013 01	NA	-	-	-	-	-	-	-	-	-	-	-
2013 02	NA	NA	-	-	-	-	-	-	-	-	-	-
2013 03	NA	NA	NA	-	-	-	-	-	-	-	-	-
2013 04	NA	NA	NA	NA	-	-	-	-	-	-	-	-
2013 05	1.0000	NA	NA	NA	NA	-	-	-	-	-	-	-
2013 06	0.0009 **	NA	NA	NA	NA	0.0051 **	-	-	-	-	-	-
2013 07	0.0001 **	NA	NA	NA	NA	0.0001 **	0.0164 *	-	-	-	-	-
2013 08	0.0001 **	NA	NA	NA	NA	0.0001 **	0.0001 **	0.2824	-	-	-	-
2013 09	0.4284	NA	NA	NA	NA	0.5350	1.0000	0.0056 **	0.0001 **	-	-	-
2013 10	0.7157	NA	NA	NA	NA	1.0000	1.0000	0.0029	0.0001 **	1.0000	-	-
2013 11	1.000	NA	NA	NA	NA	1.0000	1.0000	1.0000	0.7414	1.0000	1.000	-
2013 12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

'Horns Rev 3 – 2'	2012 12	2013 01	2013 02	2013 03	2013 04	2013 05	2013 06	2013 07	2013 08	2013 09	2013 10	2013 11
2013 01	1.0000	-	-	-	-	-	-	-	-	-	-	-
2013 02	1.0000	1.0000	-	-	-	-	-	-	-	-	-	-
2013 03	1.0000	1.0000	1.0000	-	-	-	-	-	-	-	-	-

'Horns Rev 3 – 2'	2012 12	2013 01	2013 02	2013 03	2013 04	2013 05	2013 06	2013 07	2013 08	2013 09	2013 10	2013 11
2013 04	0.6063	1.0000	1.0000	1.0000	-	-	-	-	-	-	-	-
2013 05	0.1016	0.2405	1.0000	1.0000	1.0000	-	-	-	-	-	-	-
2013 06	0.0034 **	0.0070 **	0.0864	0.0839	0. 2230	1.0000	-	-	-	-	-	-
2013 07	0.0001 **	0.0001 **	0.0001 **	0.0001 **	0.0001 **	0.0001 **	0.0234 *	-	-	-	-	-
2013 08	0.0001 **	0.0001 **	0.0001 **	0.0001 **	0.0001 **	0.0089 **	0.4629 8	1.0000	-	-	-	-
2013 09	0.0005 **	0.0002 **	0.0072 **	0.0267 *	0.0064 **	1.0000	1.0000	0.0012 **	0.1378	-	-	-
2013 10	0.0001 **	0.0001 **	0.0001 **	0.0058 **	0.0001 **	0.6581	1.0000	0.1033	1.0000	1.0000	-	-
2013 11	0.0001 **	0.0001 **	0.0001 **	0.0015 **	0.0001 **	1.0000	1.0000	0.0566	1.0000	1.0000		-
2013 12	0.8031	0.6783	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

'Horns Rev 3 – 3'	2012 12	2013 01	2013 02	2013 03	2013 04	2013 05	2013 06	2013 07	2013 08	2013 09	2013 10	2013 11
2013 01	1.0000	-	-	-	-	-	-	-	-	-	-	-
2013 02	0.0001 **	0.2705	-	-	-	-	-	-	-	-	-	-
2013 03	0.0107 *	1.0000	0.0275 *	-	-	-	-	-	-	-	-	-
2013 04	0.0005 **	1.0000	0.6830	1.0000	-	-	-	-	-	-	-	-
2013 05	0.0045 **	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-	-	-
2013 06	0.0442 *	1.0000	0.0012 **	1.0000	1.0000	1.0000	-	-	-	-	-	-
2013 07	0.0001 **	0.0055 **	0.5611	0.0003 **	0.0010 **	0.0741	0.0001 **	-	-	-	-	-
2013 08	0.0001 **	0.0009 **	0.0113 *	0,0001 **	0.0001 **	0.0119 *	0.0001 **	1.0000	-	-	-	-
2013 09	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
2013 10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-
2013 11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
2013 12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

'Horns Rev 3 – 4'	2012 12	2013 01	2013 02	2013 03	2013 04	2013 05	2013 06	2013 07	2013 08	2013 09	2013 10	2013 11
2013 01	1.0000	-	-	-	-	-	-	-	-	-	-	-
2013 02	1.0000	1.000	-	-	-	-	-	-	-	-	-	-
2013 03	1.0000	1.0000	NA	-	-	-	-	-	-	-	-	-
2013 04	0.0028 **	0.0002 **	1.0000	0.0004 **	-	-	-	-	-	-	-	-
2013 05	1.0000	0.2063	1.0000	1.0000	1.0000	-	-	-	-	-	-	-
2013 06	1.0000	1.0000	1.0000	1.0000	0.0001 **	0.5647	-	-	-	-	-	-
2013 07	0.1306	1.0000	1.0000	0.0043 **	0.0001 **	0.0001 **	0.0300 *	-	-	-	-	-
2013 08	0.0825	0.8821	1.0000	0.0065 **	0.0001 **	0.0001 **	0.0203 *	1.0000	-	-	-	-
2013 09	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
2013 10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-
2013 11	1.0000	1.0000	1.0000	0.0554	0.0001 **	0.0014 **	0.6494	1.0000	1.0000	NA	NA	-

2013 12	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	NA	NA	1.0000

'Horns Rev 3 – 5'	2012 12	2013 01	2013 02	2013 03	2013 04	2013 05	2013 06	2013 07	2013 08	2013 09	2013 10	2013 11
2013 01	0.7377	-	-	-	-	-	-	-	-	-	-	-
2013 02	0.0015 **	1.0000	-	-	-	-	-	-	-	-	-	-
2013 03	1.0000	1.0000	0.0102 *	-	-	-	-	-	-	-	-	-
2013 04	0.0467 *	1.0000	0.5610	1.0000	-	-	-	-	-	-	-	-
2013 05	1.0000	0.0915	0.0001 **	0.1138	0.0003 **	-	-	-	-	-	-	-
2013 06	1.0000	0.0584	0.0001 **	0.2332	0.0001 **	1.0000	-	-	-	-	-	-
2013 07	1.0000	1.0000	0.0979	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
2013 08	0.0001 **	0.0197 *	1.0000	0.0001 **	0.002 **	0.0001 **	0.0001 **	0.0013 **	-	-	-	-
2013 09	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
2013 10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-
2013 11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
2013 12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

'Horns Rev 3 – 6'	2012 12	2013 01	2013 02	2013 03	2013 04	2013 05	2013 06	2013 07	2013 08	2013 09	2013 10	2013 11
2013 01	1.0000	-	-	-	-	-	-	-	-	-	-	-
2013 02	1.0000	1.0000	-	-	-	-	-	-	-	-	-	-
2013 03	0.0162 *	1.0000	0.0956 *	-	-	-	-	-	-	-	-	-
2013 04	1.0000	1.0000	1.0000	0.0374 *	-	-	-	-	-	-	-	-
2013 05	0.1266	1.0000	0.5491	1.0000	0.2079	-	-	-	-	-	-	-
2013 06	0.0696	1.0000	0.5597	1.0000	0.4201	1.0000	-	-	-	-	-	-
2013 07	0.2906	1.0000	0.9700	1.0000	0.2648	1.0000	1.0000	-	-	-	-	-
2013 08	1.0000	1.0000	1.0000	0.0837	1.0000	0.3269	0.4404	0.1081	-	-	-	-
2013 09	0.0052 **	1.0000	0.0265 *	1.0000	0.0096 **	1.0000	1.0000	1.0000	0.0212 *	-	-	-
2013 10	0.1475	1.0000	0.9088	1.0000	0.4335	1.0000	1.0000	1.0000	0.2338	1.0000	-	-
2013 11	1.0000	1.0000	1.0000	0.0052 **	1.0000	0.0290 *	0.0210 *	0.1277	1.0000	0.0019 **	0.0625	-
2013 12	1.0000	1.0000	1.0000	0.0320 *	1.0000	0.1222	0.1395	0.3199	1.0000	0.0225 *	0.2503	1.0000

7.3. Distribution maps of harbour porpoise from aerial surveys

NERI harbour porpoise flights (only depicted with a minimum of 18 sighted animals)

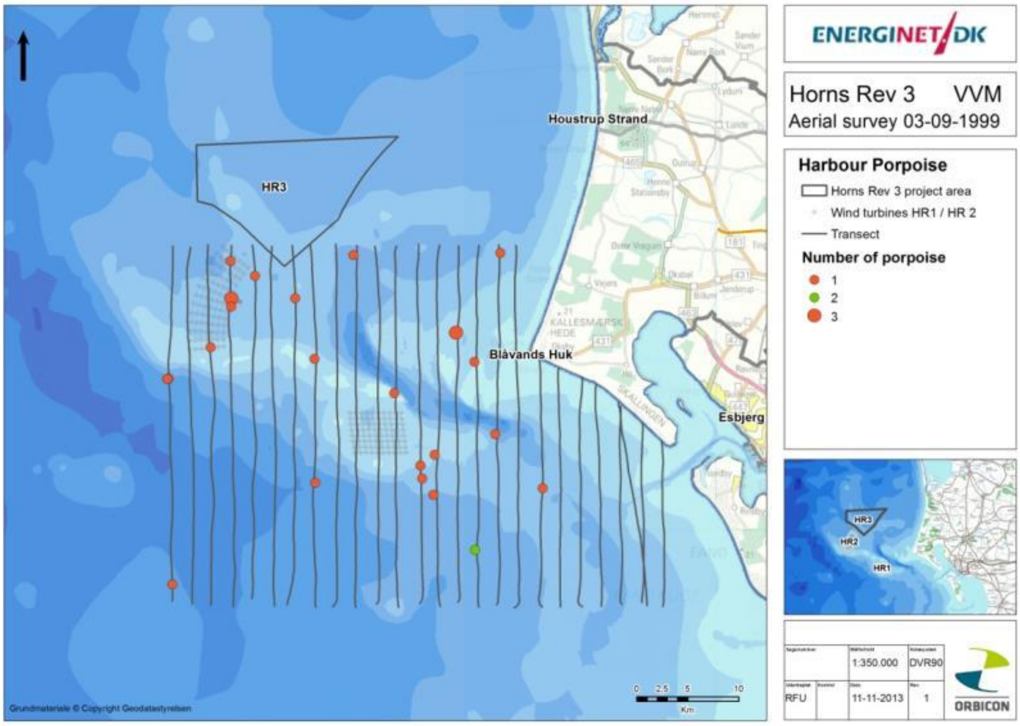

Figure 7.6: NERI aerial survey from summer 1999 (03.09.1999) with n=29

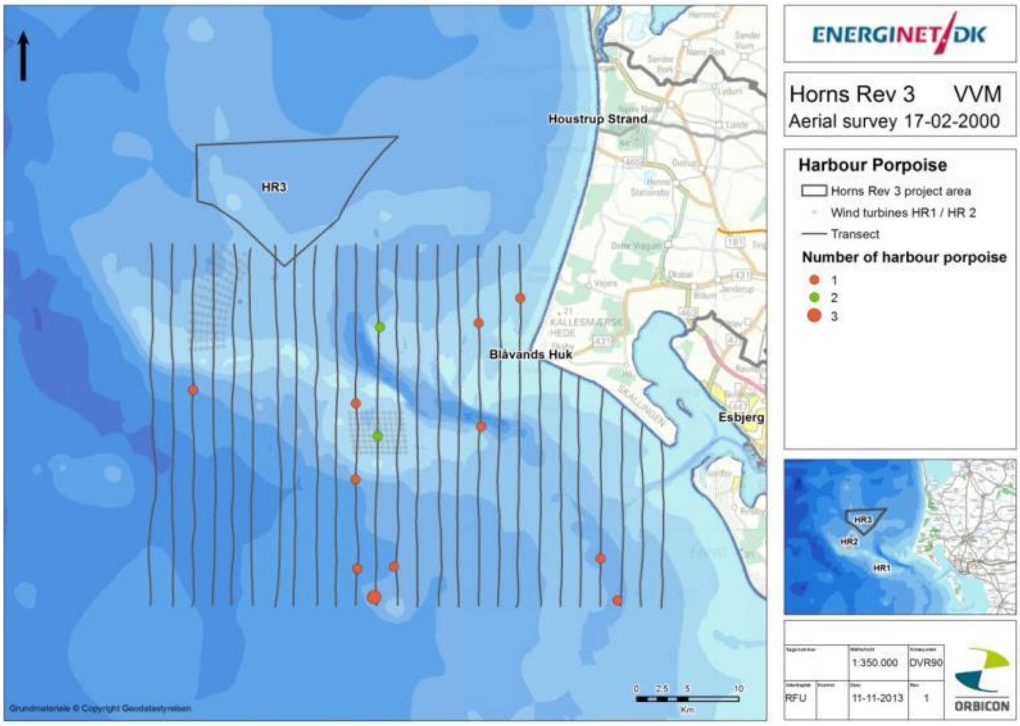

Figure 7.7: NERI aerial survey from winter 2000 (17.02.2000) with n=18

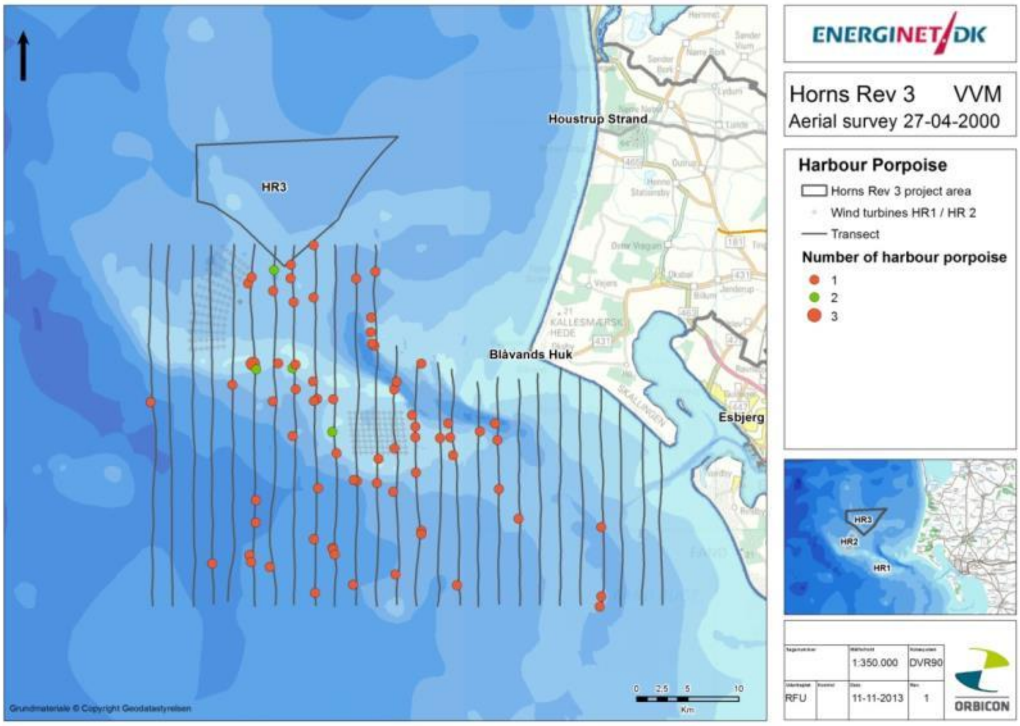

Figure 7.8: NERI aerial survey from spring 2000 (27.04.2000) with n=80

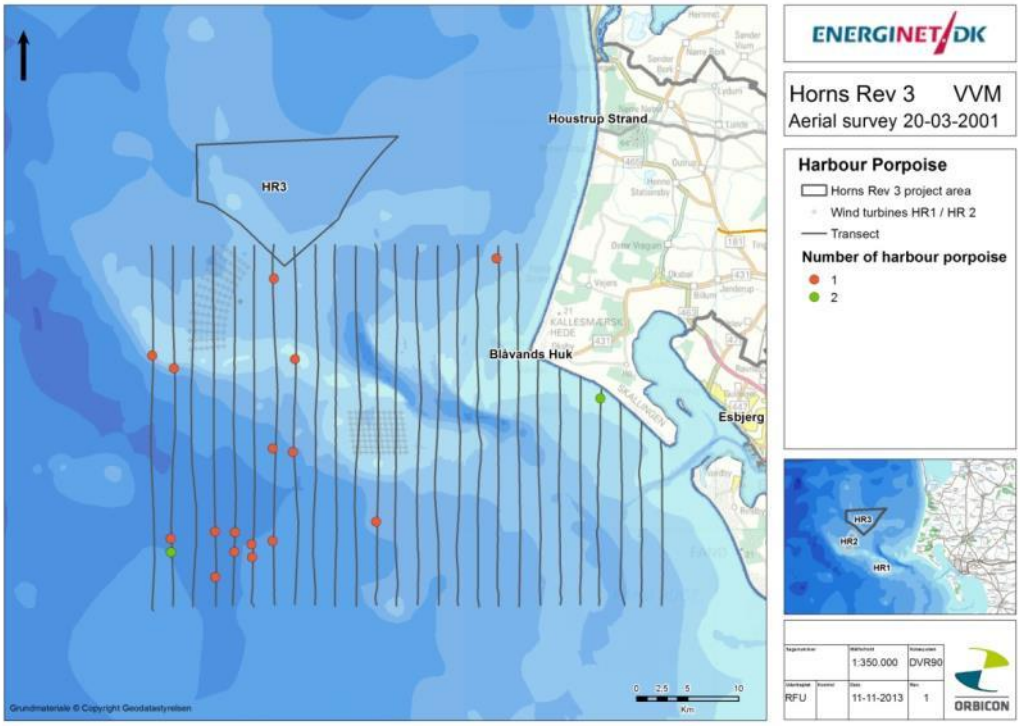

Figure 7.9: NERI aerial survey from spring 2001 (20.03.2001) with n=20

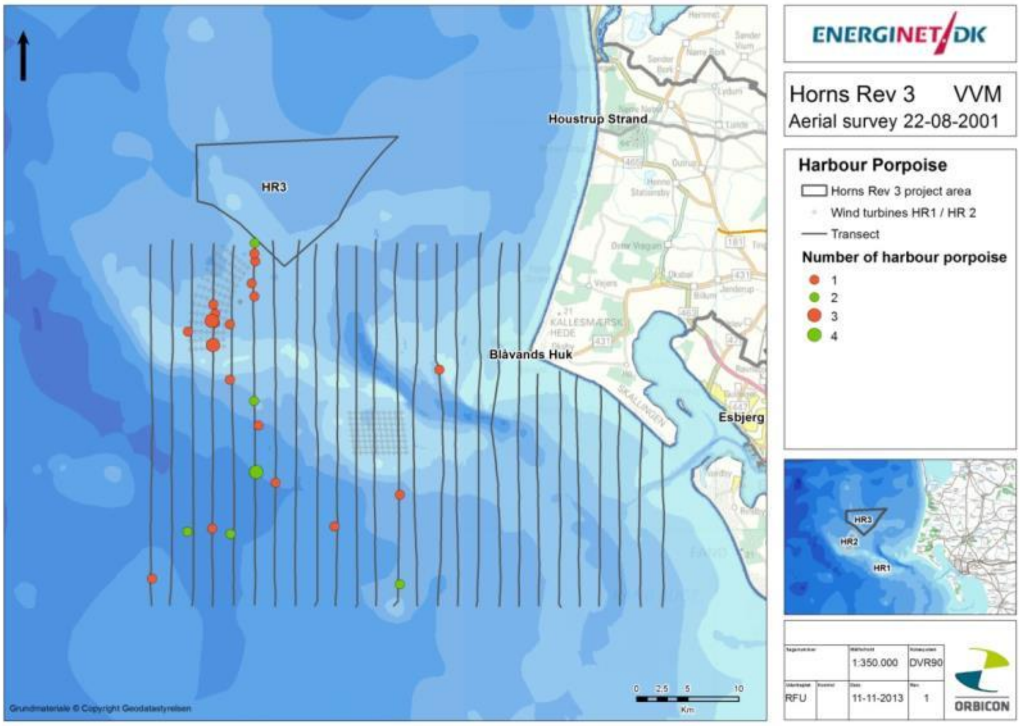

Figure 7.10: NERI aerial survey from summer 2001 (22.08.2001) with n=37

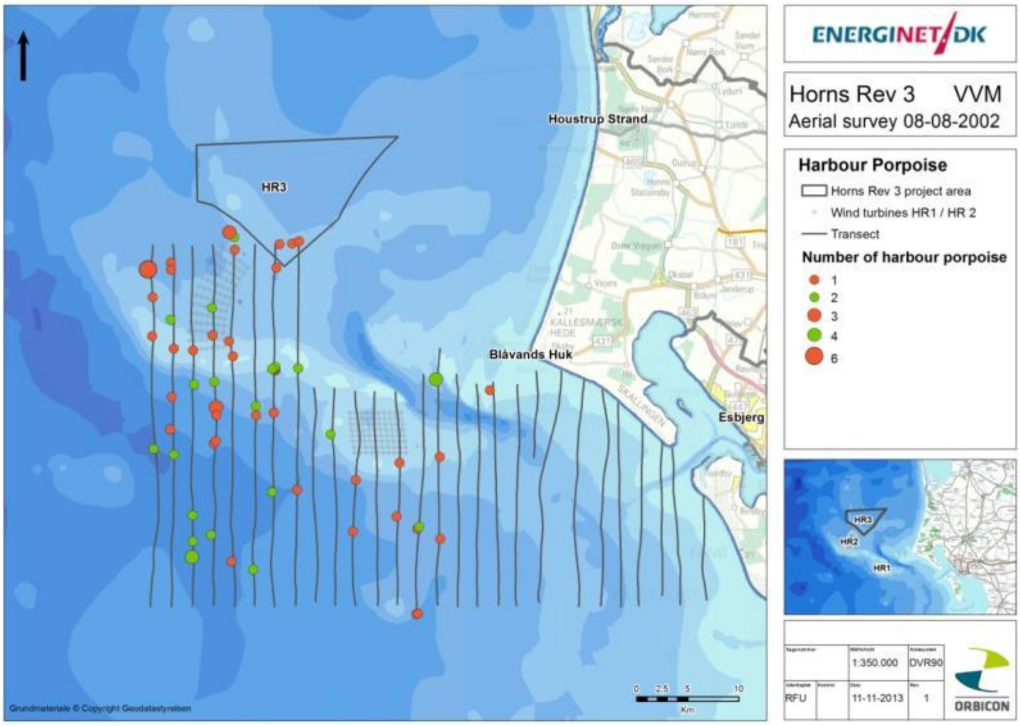

Figure 7.11: NERI aerial survey from summer 2002 (08.08.2002) with n=95

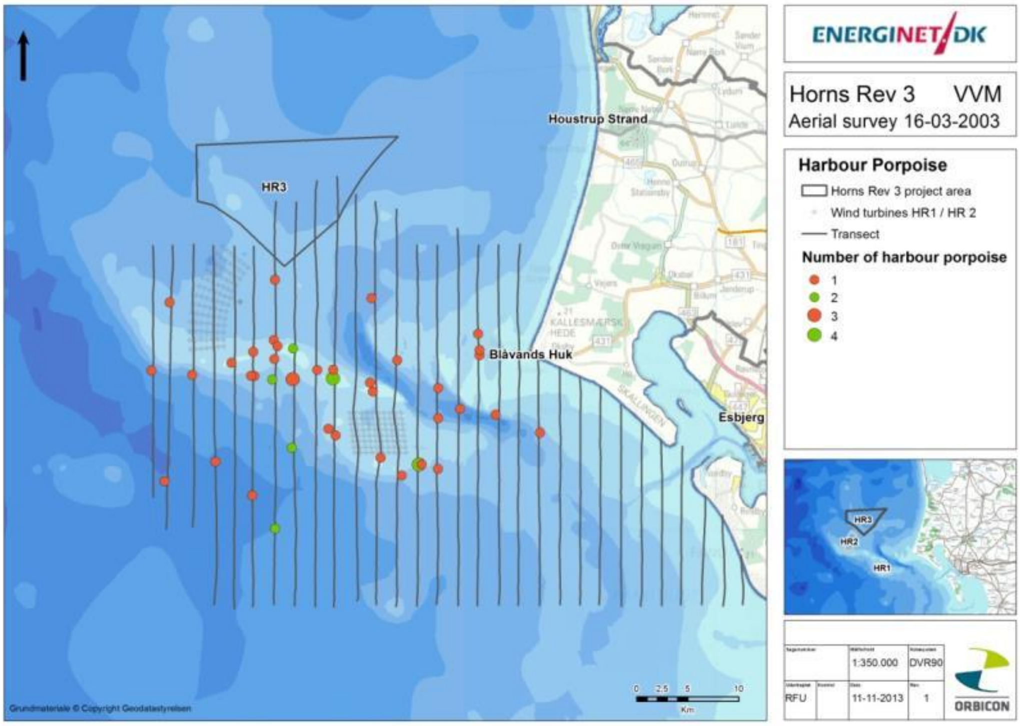

Figure 7.12: NERI aerial survey from winter 2003 (16.03.2003) with n=54

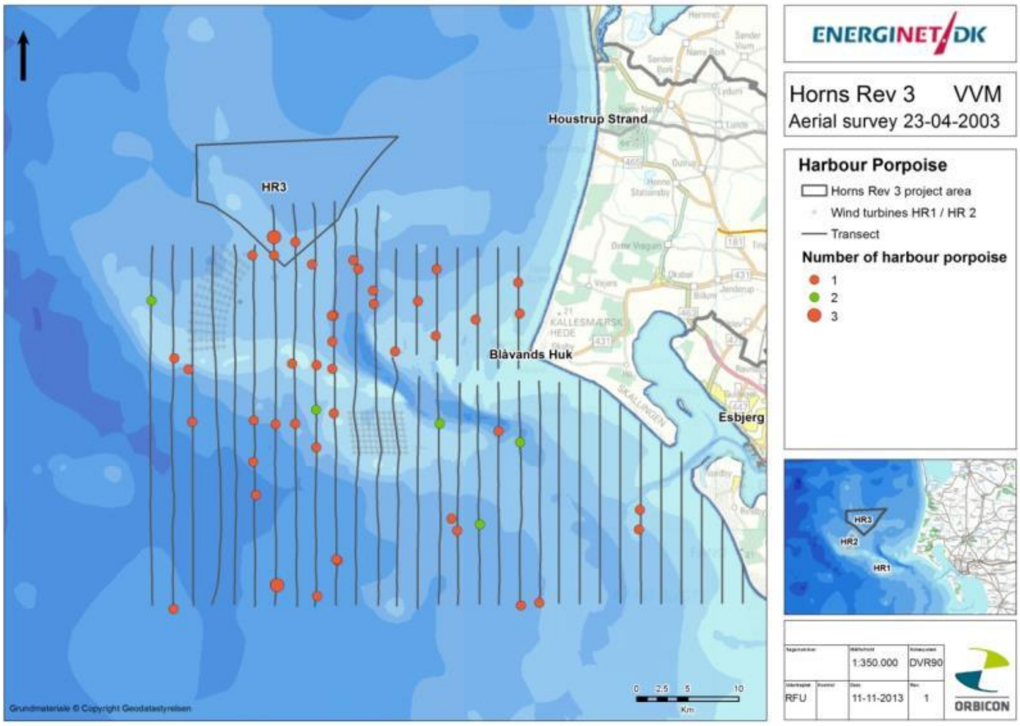

Figure 7.13: NERI aerial survey from spring 2003 (23.04.2003) with n=58

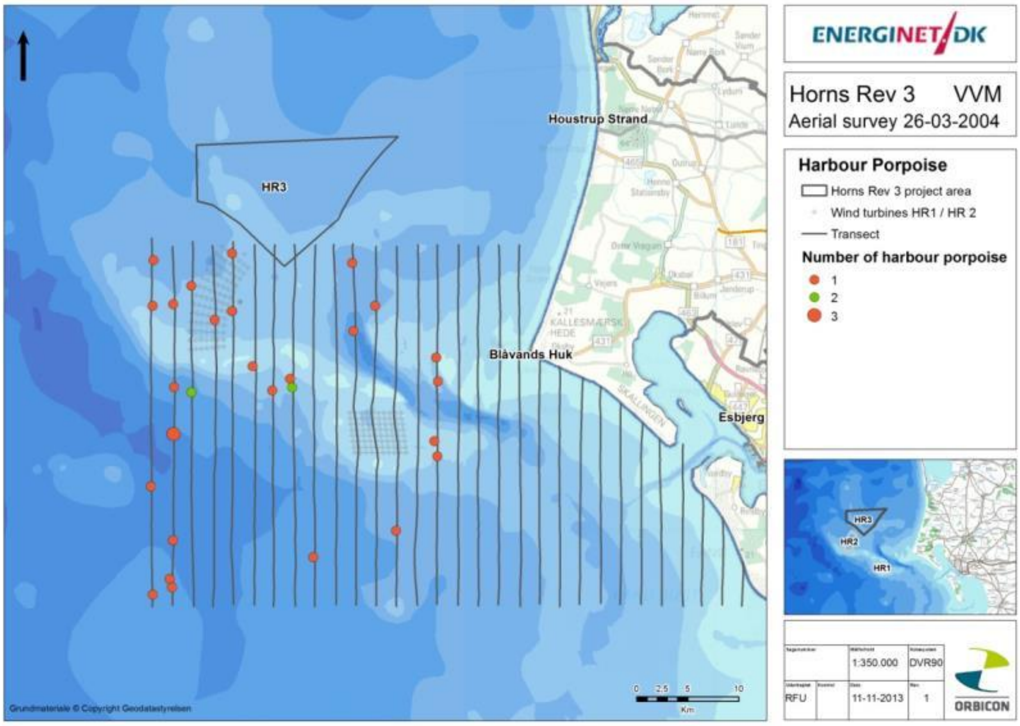

Figure 7.14: NERI aerial survey from spring 2004 (26.03.2004) with n=34

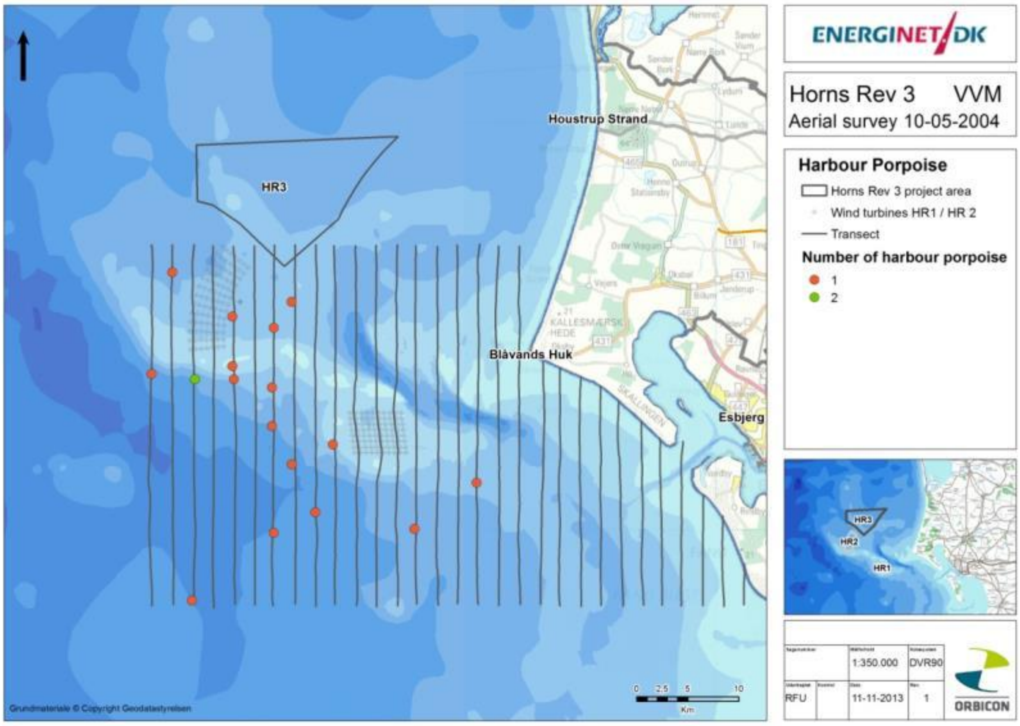

Figure 7.15: NERI aerial survey from spring 2004 (10.05.2004) with n=18

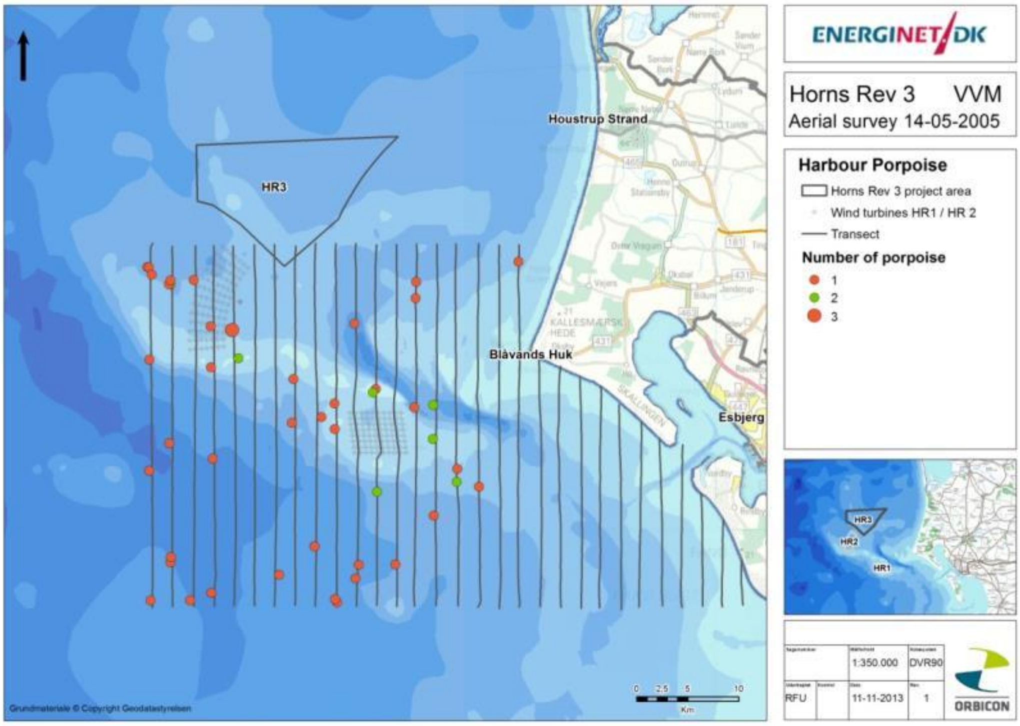

Figure 7.16: NERI aerial survey from spring 2005 (14.05.2005) with n=56

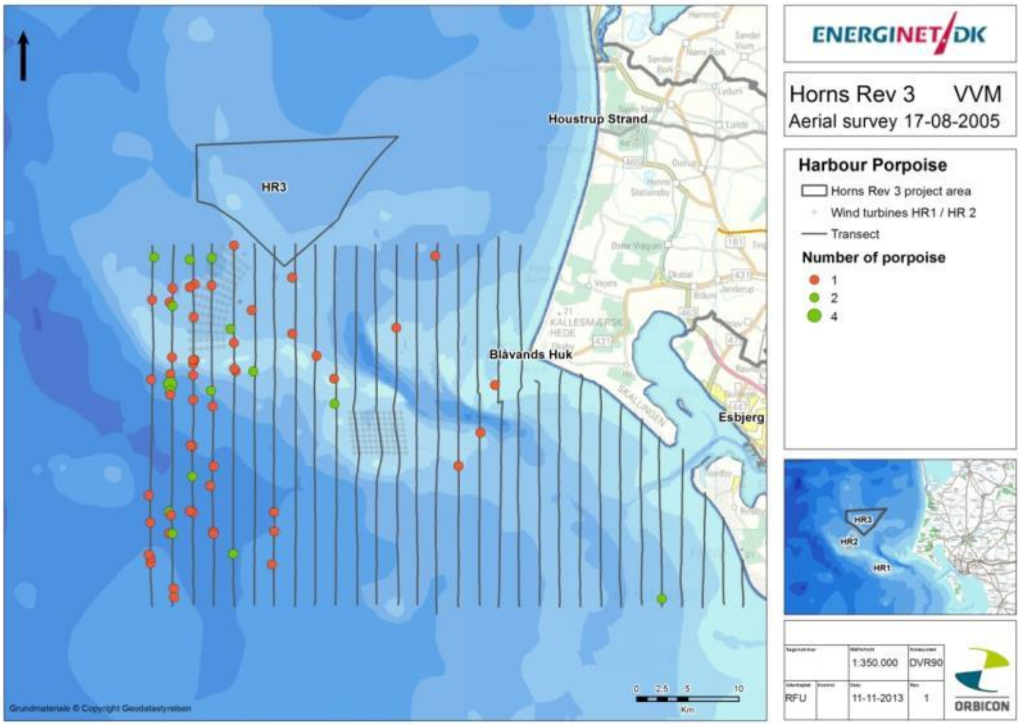

Figure 7.17: NERI aerial survey from summer 2005 (17.08.2005) with n=83

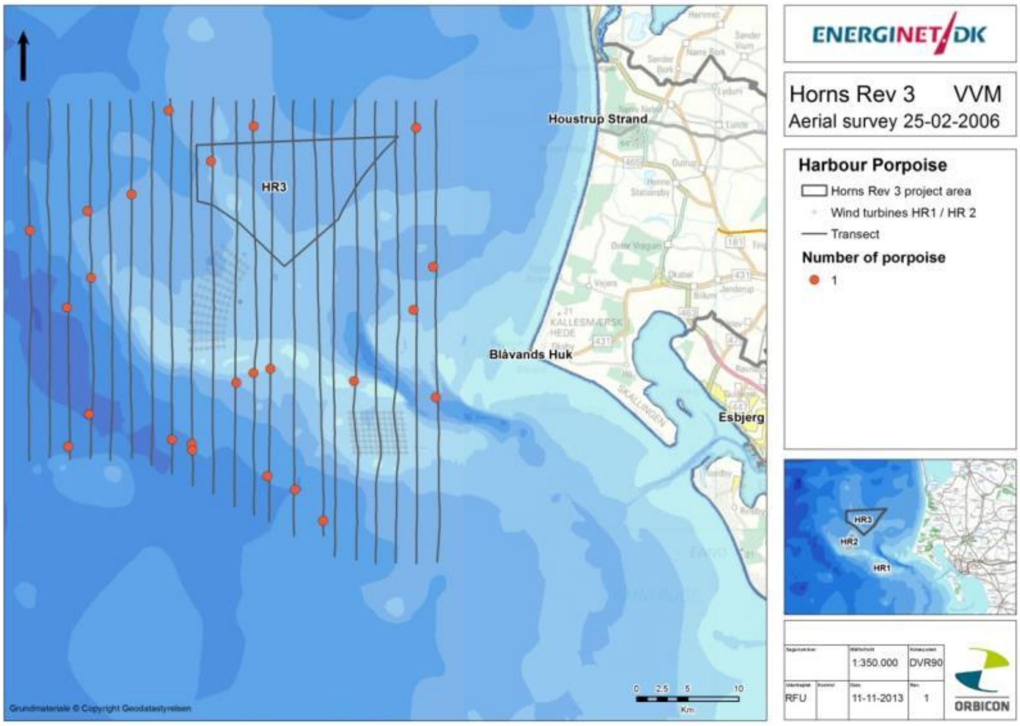

Figure 7.18: NERI aerial survey from winter 2006 (25.02.2006) with n=24

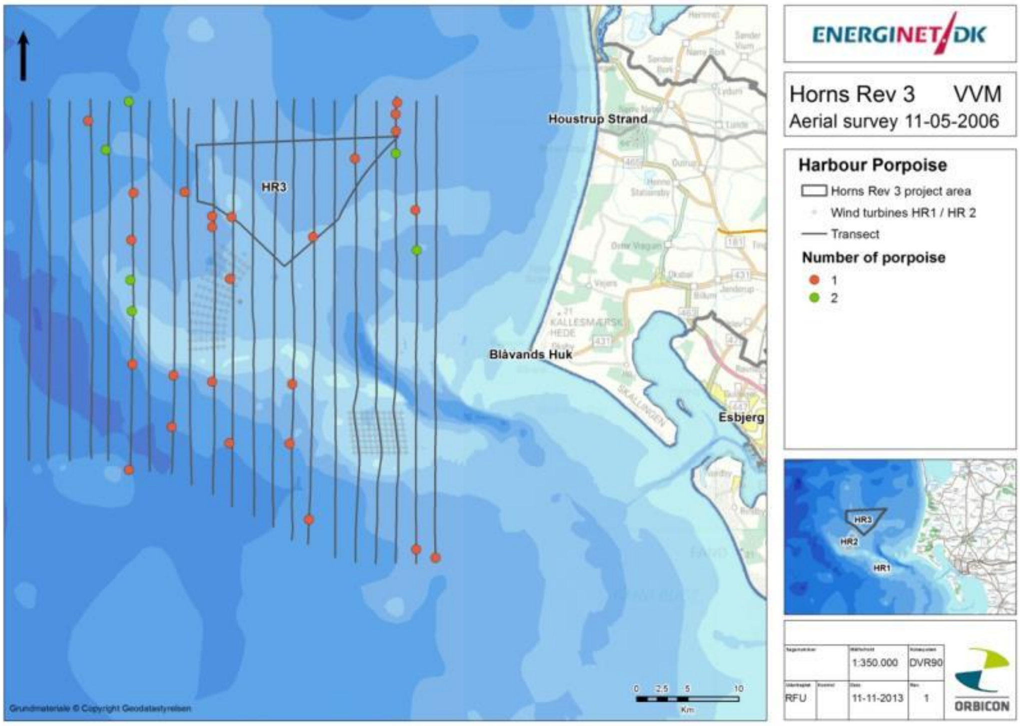

Figure 7.19: NERI aerial survey from spring 2006 (11.05.2006) with n=37

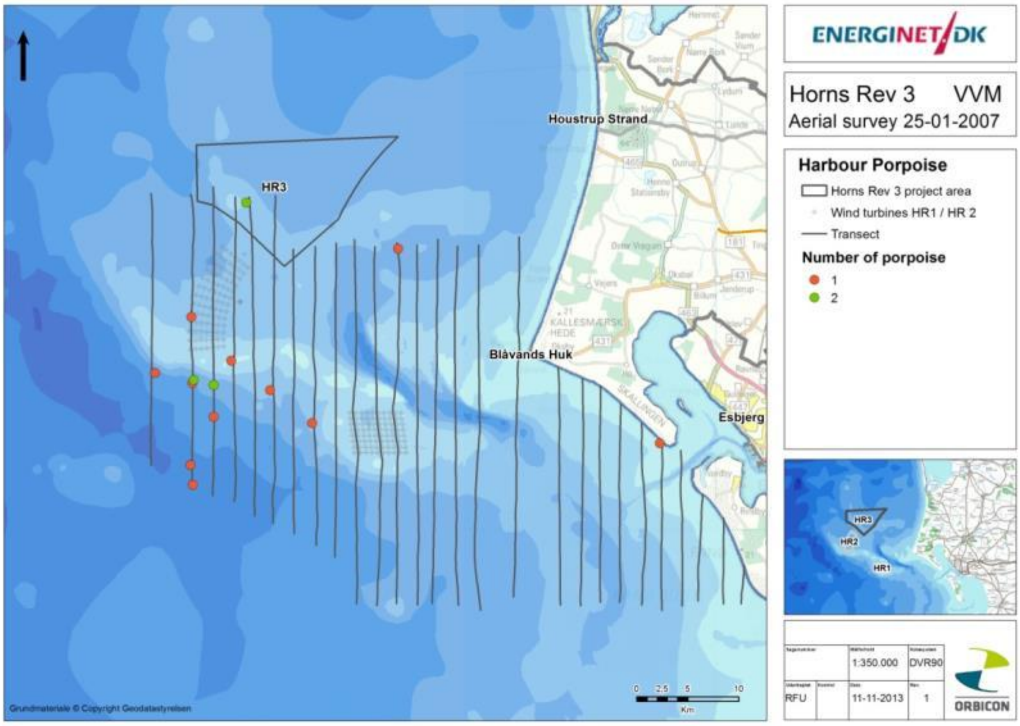

Figure 7.20: NERI aerial survey from winter 2007 (25.01.2007) with n=18

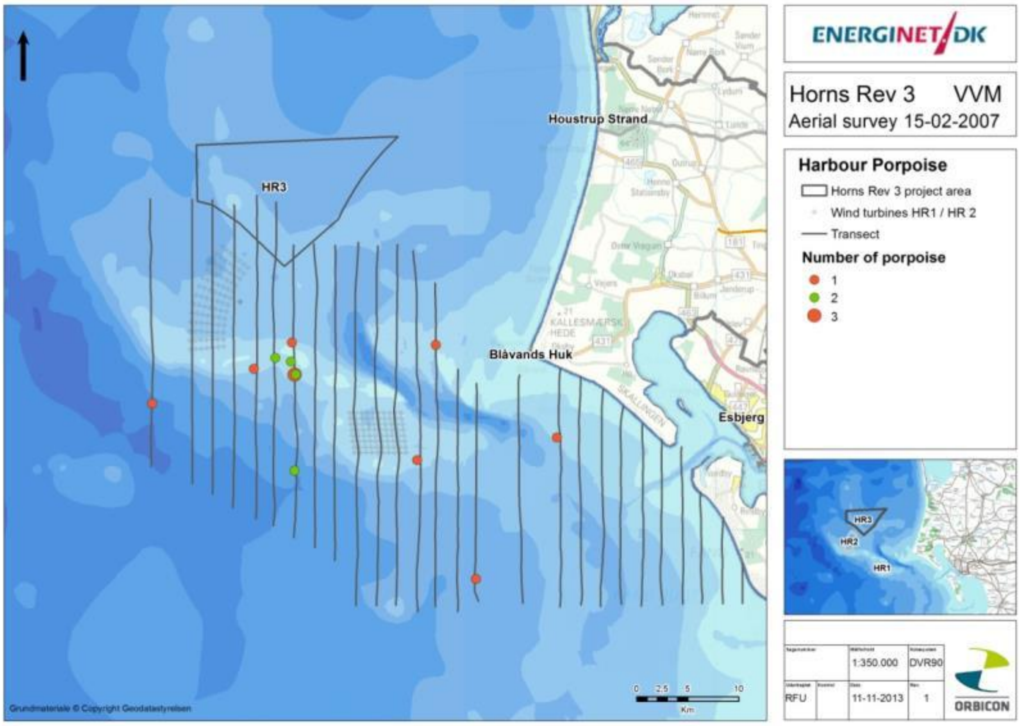

Figure 7.21: NERI aerial survey from winter 2007 (15.02.2007) with n=18

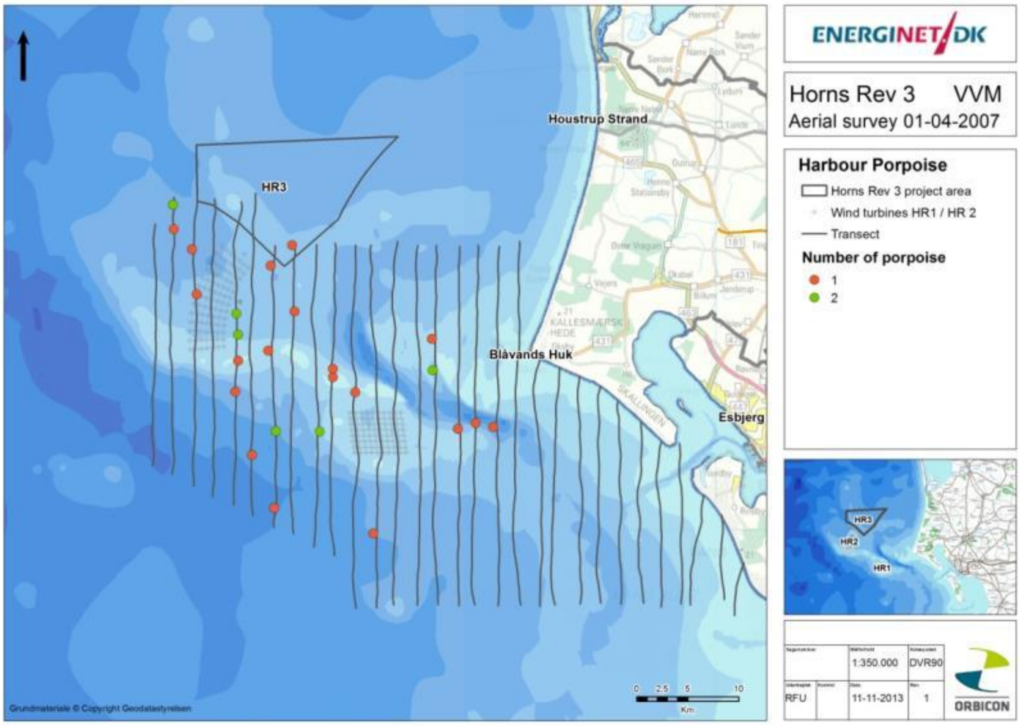

Figure 7.22: NERI aerial survey from spring 2007 (01.04.2007) with n=31

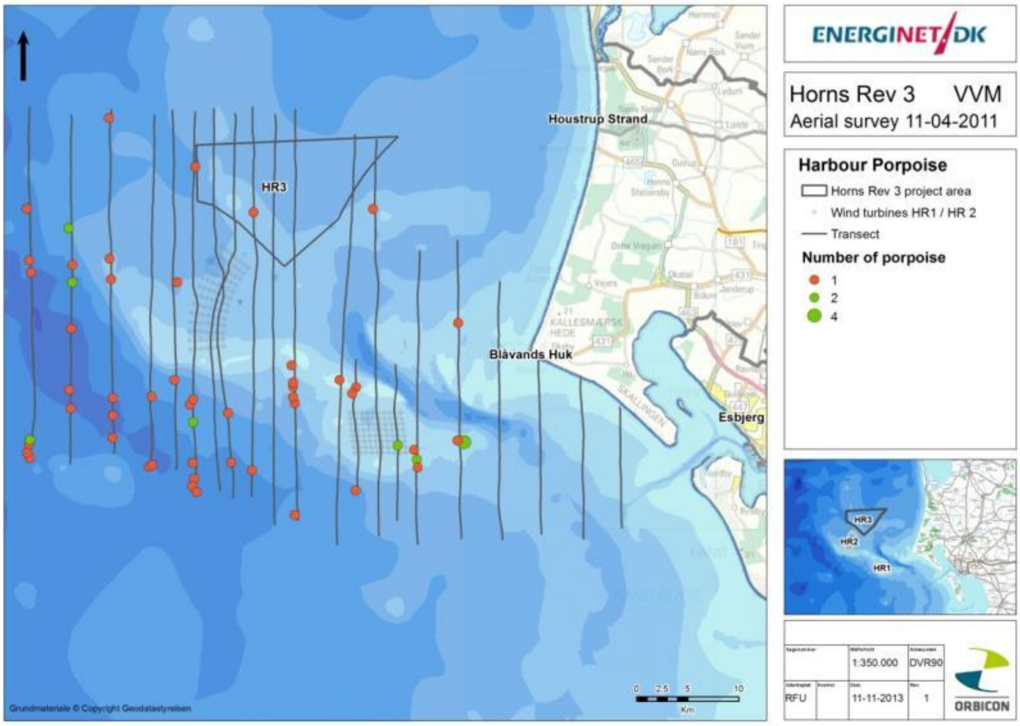

Figure 7.23: NERI aerial survey from spring 2011 (11.04.2011) with n=64

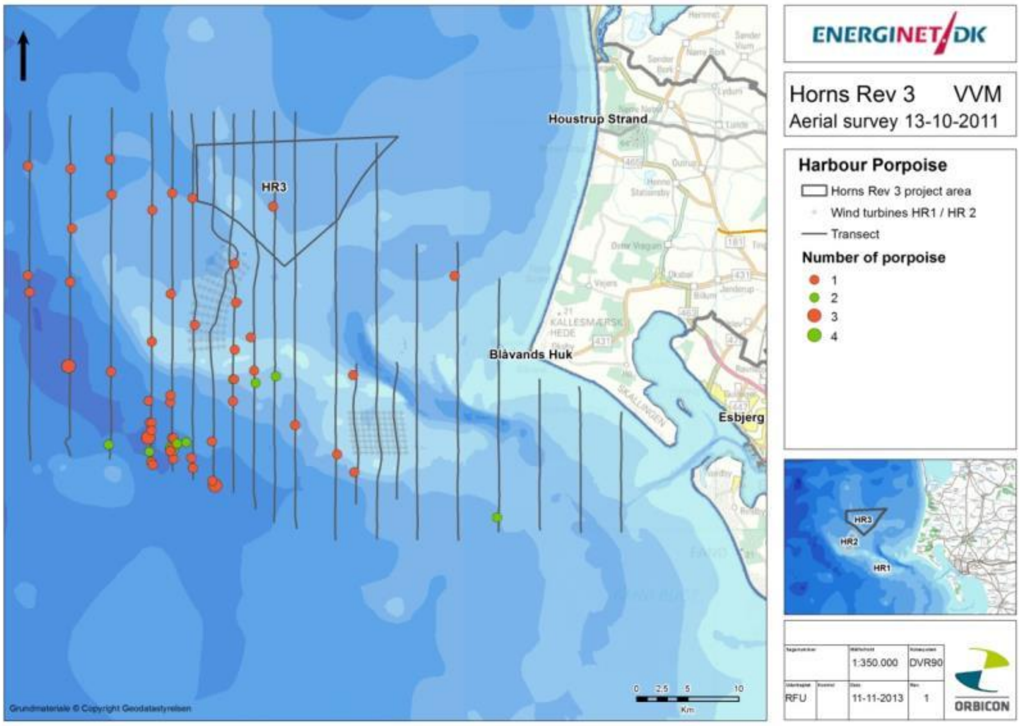

Figure 7.24: NERI aerial survey from autumn 2011 (13.10.2011) with n=76

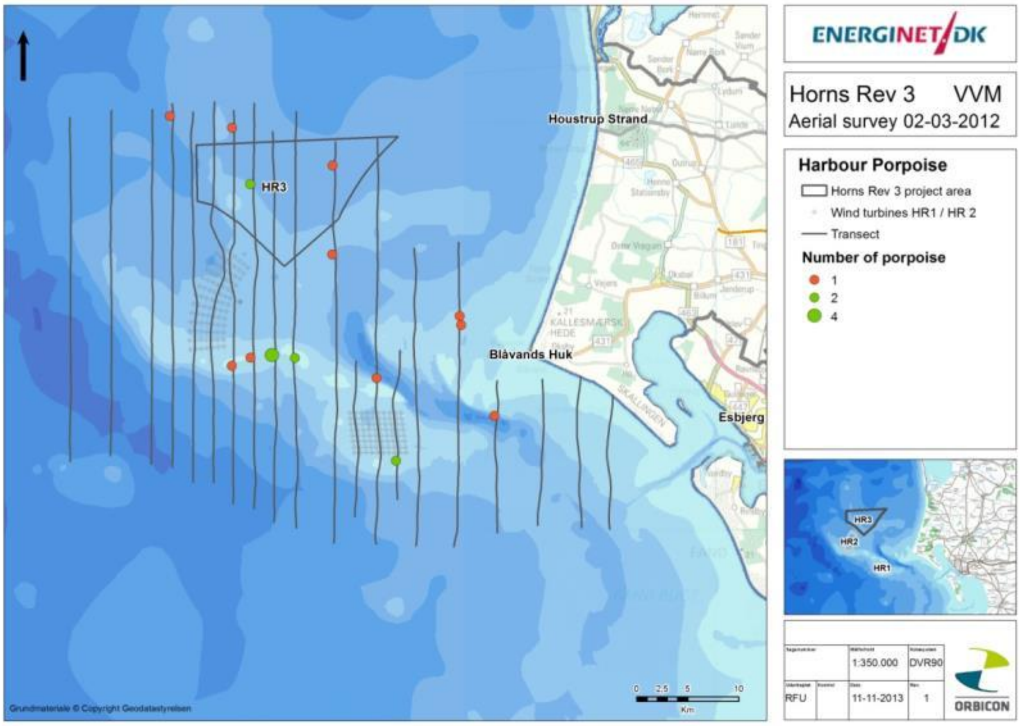

Figure 7.25: NERI aerial survey from winter 2012 (02.03.2012) with n=20

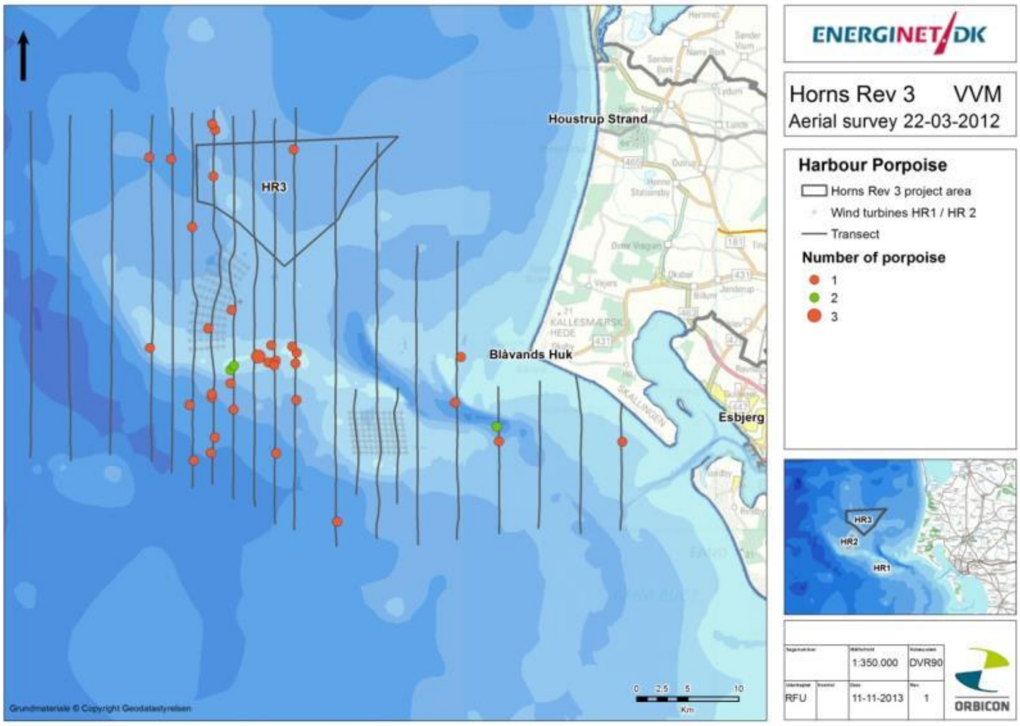

Figure 7.26: NERI aerial survey from spring 2012 (22.03.2012) with n=41

Table 7.4: NERI aerial surveys 1999 – 2007 and 2011 -2012 with number of total sighted harbour porpoises

Survey date	Harbour porpoises
19990803	5
19990903	29
19991112	9
20000217	18
20000221	14
20000319	8
20000427	80
20000821	8
20001006	4
20001222	4
20010209	3
20010320	20
20010421	10
20010822	37
20020107	8
20020312	7
20020409	6
20020808	95
20030213	2
20030316	54
20030423	58
20030905	16
20031204	9
20031230	3
20040229	8
20040326	34
20040510	18
20040909	13
20050308	3

Survey date	Harbour porpoises
20050309	13
20050402	10
20050514	56
20050817	83
20051118	23
20051119	6
20060202	10
20060225	24
20060312	16
20060415	15
20060511	37
20070125	18
20070215	18
20070303	12
20070401	31
20110301	14
20110326	10
20110411	64
20111013	76
20111117	5
20120115	13
20120208	4
20120302	20
20120322	41
20120411	2

7.4. Distribution maps of seals from aerial surveys

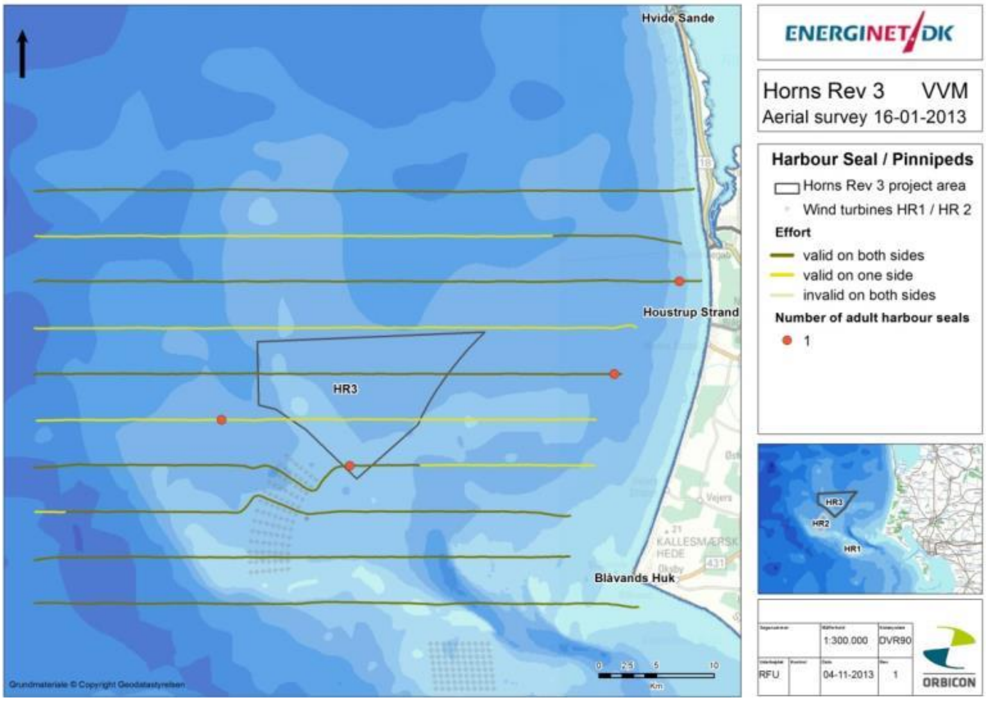

Figure 7.27 Sightings of harbour seals in January 2013 (16.01.2013) with n=4

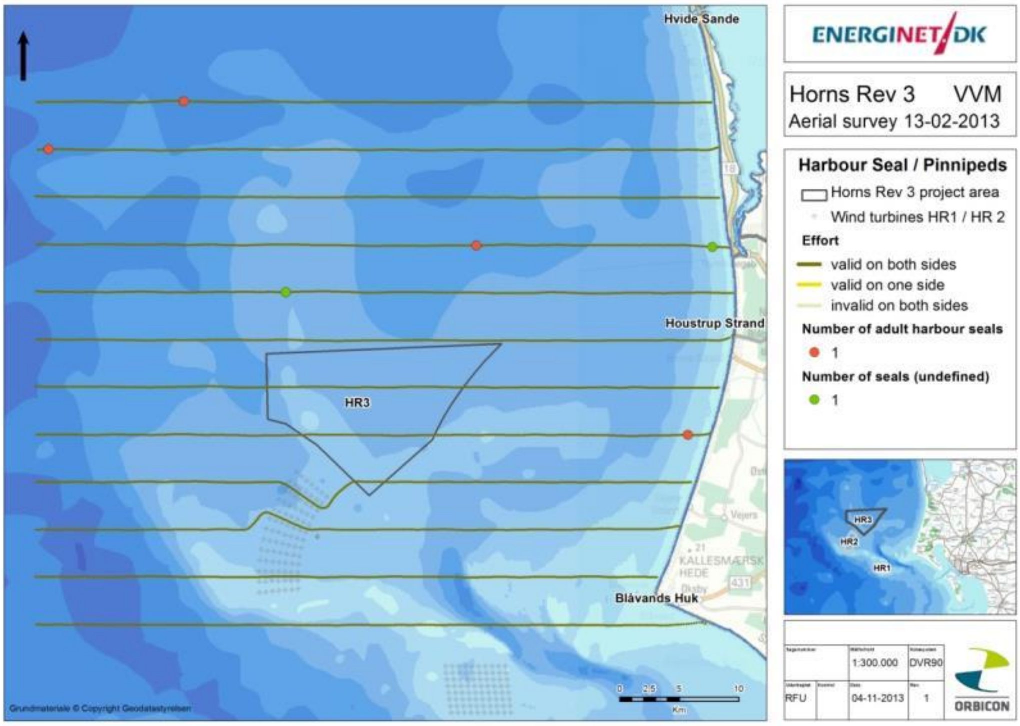

Figure 7.28 Sightings of harbour seals in February 2013 (13.02.2013) with n=8, and unknown seals with n=2

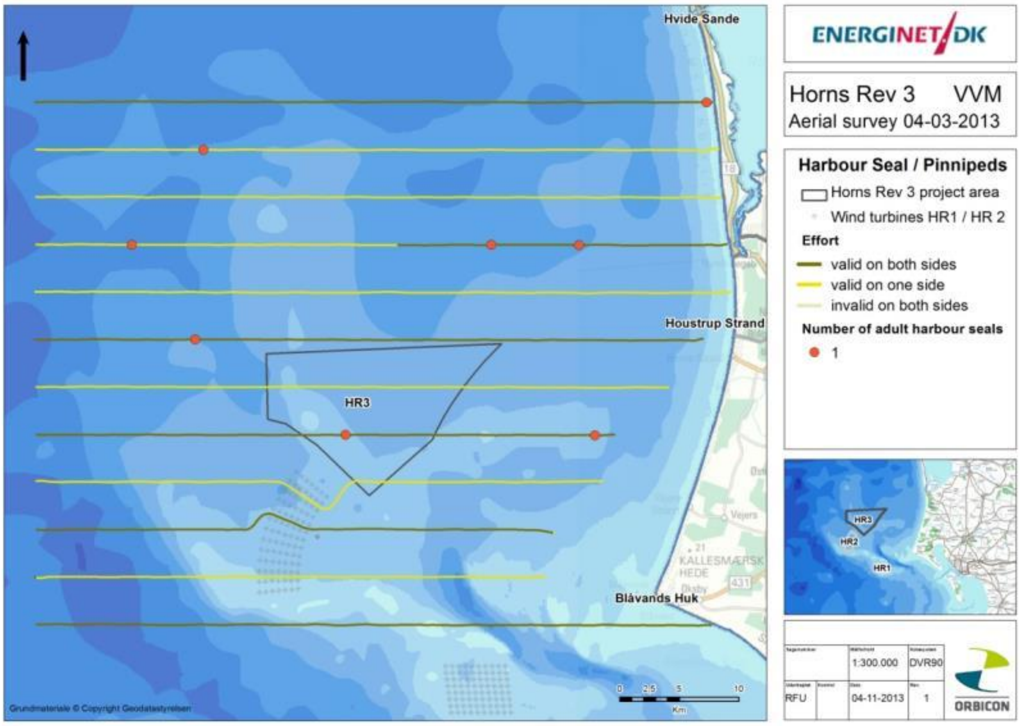

Figure 7.29 Sightings of harbour seals in March 2013 (04.03.2013) with n=8

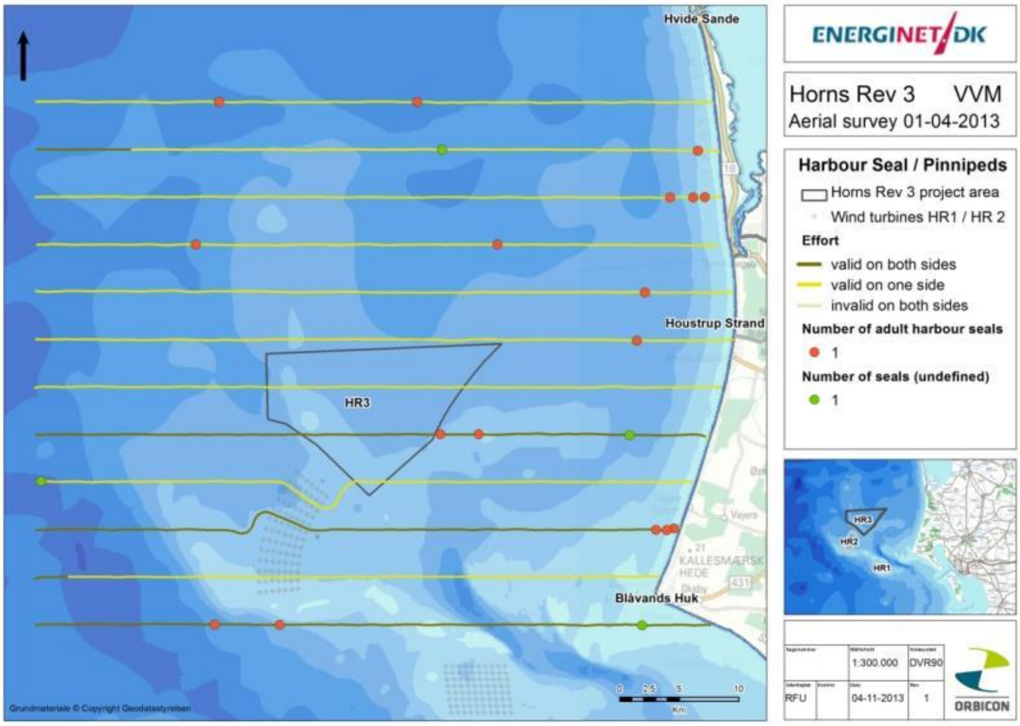

Figure 7.30 Sightings of harbour seals in April 2013 (01.04.2013) with n=17, and unknown seals with n=4

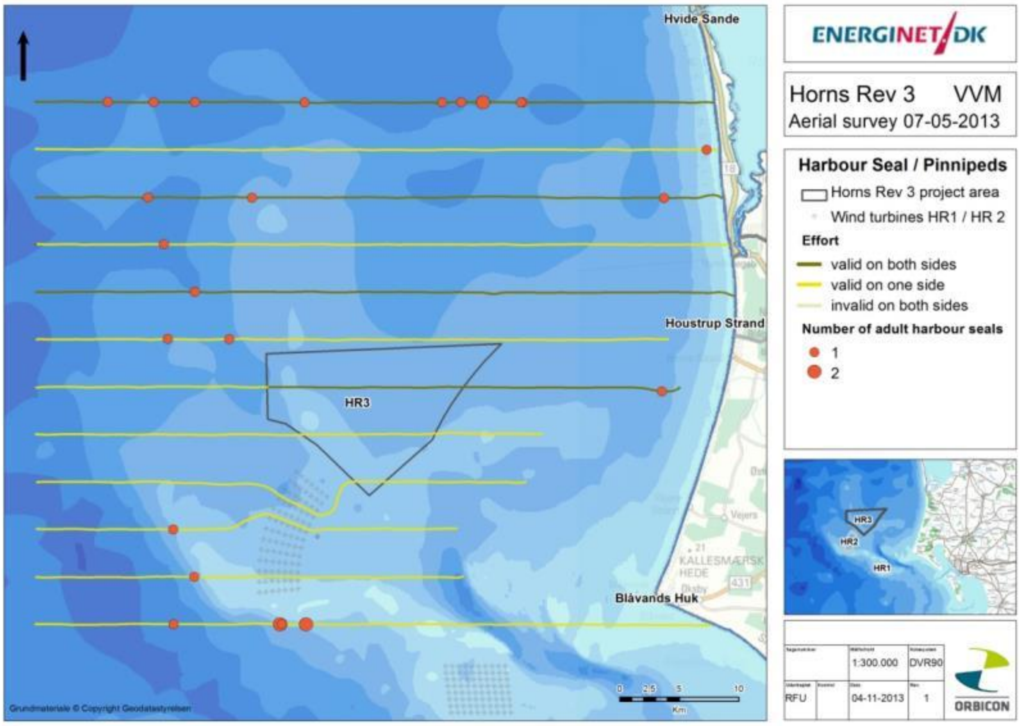

Figure 7.31 Sightings of harbour seals in May 2013 (07.05.2013) with n=27

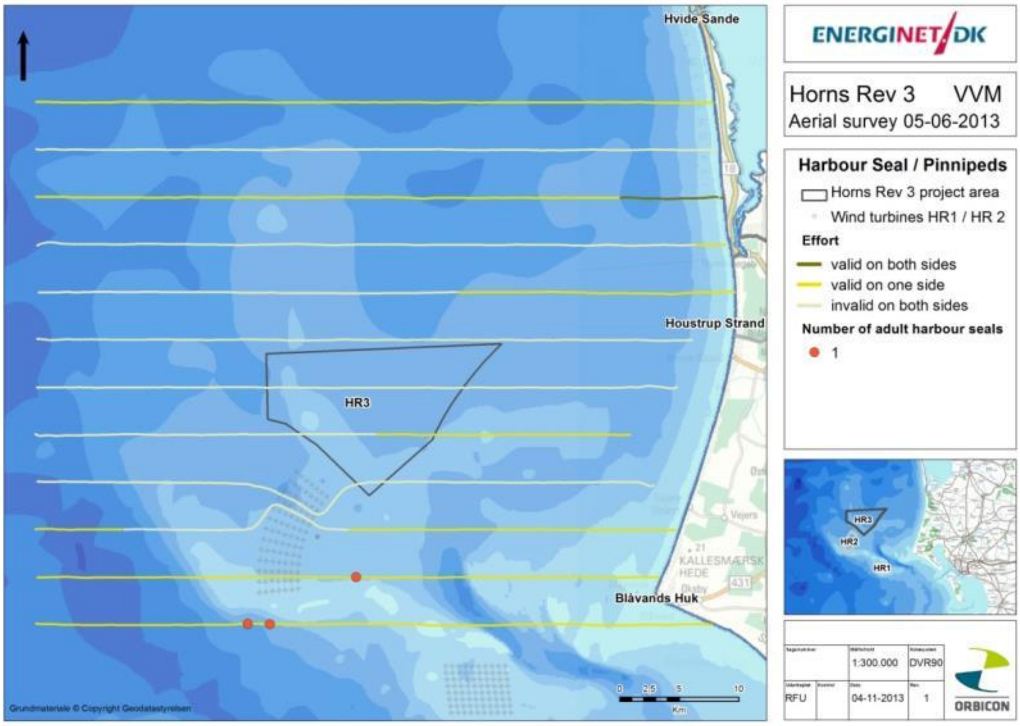

Figure 7.32 Sightings of harbour seals in June 2013 (05.06.2013) with n=3

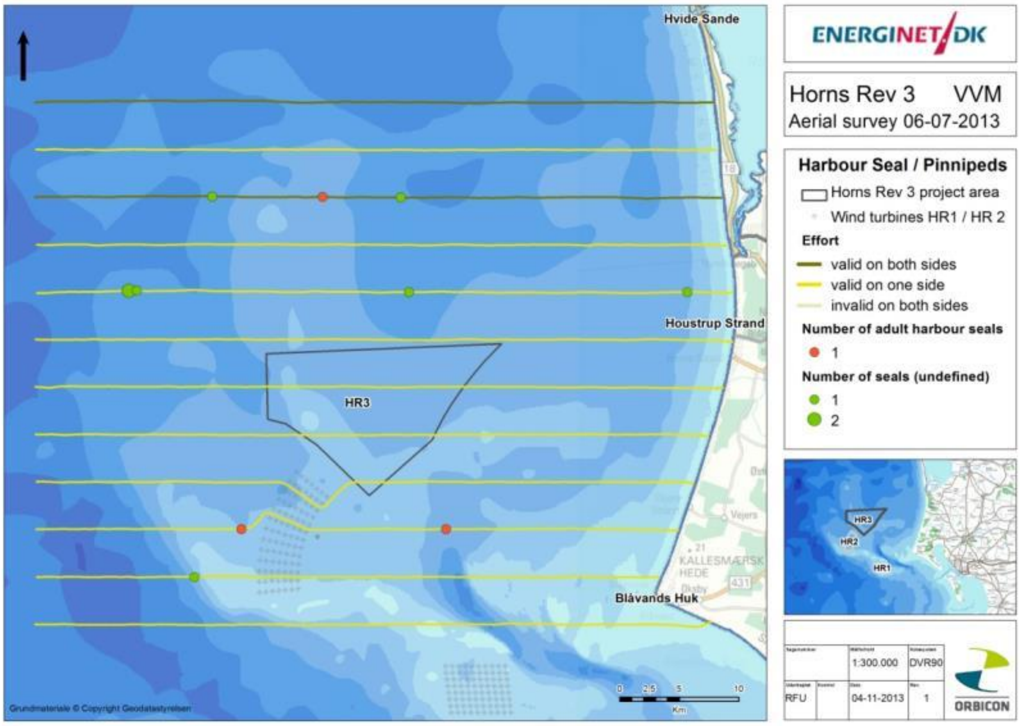

Figure 7.33 Sightings of harbour seals in July 2013 (06.07.2013) with n=3, and unknown seals with n=8

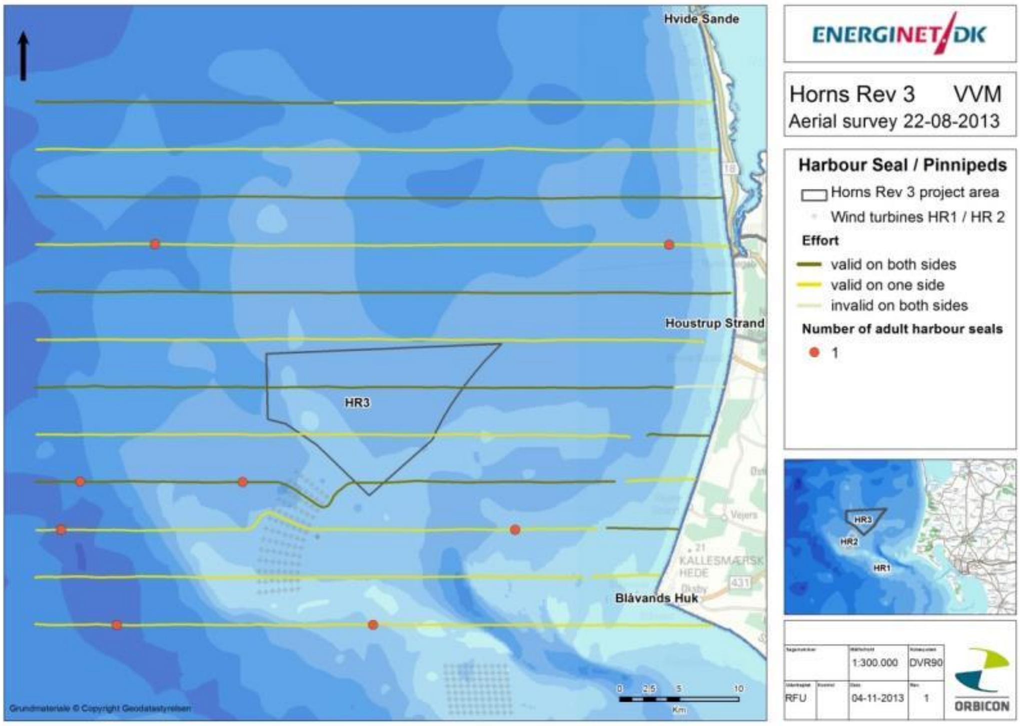

Figure 7.34 Sightings of harbour seals in August 2013 (22.08.2013) with n=8