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VESTERHAV SYD

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ATR09 marine mammals

PROJECT

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1 SUMMARY

Vesterhav Syd is an offshore wind farm planned off the west coast of Denmark. It will be located within a project area of about 60 km² 4 – 10 km off the coast northwest of Hvide Sande. Water depths in the area vary between 15 and 25 m. The wind farm will have a maximum capacity of 200 MW. However, the final design is not yet defined. This includes various possibilities, from 66 smaller 3 MW wind turbines to large 10 MW wind turbines of which only 20 would be installed.

The aim of this study is to assess the environmental impact of construction, operation, decommissioning and cable laying processes on the three most common marine mammal species in the Vesterhav Syd area (harbour seal, grey seal and harbour porpoise). To perform the assessment we refer in this report to both existing literature and our own investigations. Since very little about the abundance and distribution of marine mammals in the Vesterhav Syd area was previously known, passive acoustic monitoring as well as aerial surveys were performed by IBL Umweltplanung.

In total, nine survey flights were conducted. Six flights at a height of 250 ft were performed for combined bird and mammal counts between November 2013 and April 2014 and another three flights at a height of 600 ft exclusively for monitoring mammals between May 2014 and July 2014. Overall 221 harbour porpoises, one unidentified whale, 25 harbour seals, 6 grey seals and 2 unidentified pinnipeds were recorded. This yields harbour porpoise densities between 0.06 and 1.96 individuals/km² (on average 0.67 ind./km²). The maximum was in May 2014. During surveys five calves and three subadults were seen. The results indicates that the area is not of importance for calving..

Passive acoustic monitoring (PAM) was conducted with C-PODs. Three of them were located at the central position of the wind farm in a “C-POD station”. As three PODs are deployed at the same position they are in principle redundant, but increase the likelihood of a continuous dataset. However, in May all C-PODs got lost, causing in principle a six week data gap. However, one Pod was found later on at the shore. Four weeks of data could be used for that analyzes reducing the data gap to only two weeks. The dataset available for analyses covers the period from 10 December 2013 to 11 October 2014. The C-PODs registered a regular presence of harbour porpoises in the area. The number of detections varied over seasons. On average 6.74 % of analyzed 10-minute-intervals contained detections of porpoises.

To judge by the field study data and a literature review the area is inhabited regularly by harbour porpoises, but does not represent an area with regular above-average densities or an area which has special functions for them (e.g. calving area). This conclusion is similar for both seal species, as the survey data and the literature based overview does not suggest high densities in this area and no haul-out sites are located in the proximity at the North Sea coast.

With regard to the impact assessment, the greatest effects are expected during the pile driving. The corresponding magnitude of impact is classified as moderate for the worst case of driving a 10 m diameter monopile without noise mitigation measures. Pile driving noise can cause hearing impairment in marine mammals resulting in a temporal (TTS) or permanent threshold shift (PTS). Additionally, noise can displace animals and may result in a temporary habitat loss.

Based on the worst case assumptions, PTS might occur in harbour porpoises within an affected area of 209 km², TTS within 1,655 km² as a result of the total amount of noise (cumulative) during the installa-

tion of one foundation. Behavioural reactions might occur within 1,680 km² after a single pile strike. Behavioral responses might occur in an even bigger area. In the event of TTS and avoidance behaviour the proportion of affected animals might exceed 1 % of the population and also the value of the potential biological removal (PBR) in the worst case. However, TTS and avoidance are reversible, non-lethal effects. Only PTS might have the potential to lower the fitness of affected animals. Following the “PCoD” (Population Consequences of Disturbance) approach, the long-term population decline due to the construction of Vesterhav Syd is estimated to be about 0.2 %.

Seals are assumed to be less affected than porpoises as the threshold limits for hearing loss are higher and the animals are more tolerant to noise.

The impact assessment also includes modelling of deliberately deterrence of porpoises and seals as part of the construction method in combination with reduction of worst case noise levels by 9.7 dB. With these requirements it can be assumed that no animals will experience permanent hearing damage (PTS – Permanent Threshold Shift)”.

As construction noise is the most important source of impact on marine mammals, deterrence measures before and noise mitigation measures during pile driving should be applied in order to prevent injuries and to reduce the displacement effect. For noise mitigation alternative foundation systems such as gravity based foundation or pile drilling can be considered. Alternatively, secondary noise mitigation systems such as bubble curtains or pile sleeves can be used to reduce noise emissions. Successful mitigation measures would reduce the magnitude of impact to minor. Consequences would also be less severe than described in the worst case scenario if for instance smaller piles or fewer strikes are used to install the piles.

Other impacts such as habitat loss, sediment spill, noise during operation, electromagnetic fields are considered to be minor or negligible. Additionally, structures that are being built resemble artificial reefs which might compensate for habitat loss. According to other studies, densities of harbour porpoises can recover during operation and reach the level they had before wind farm construction.

All marine mammal species are protected by the European Habitats Directive. The protection of harbour porpoises, harbour seals and grey seals is among the conservation objectives of various Natura 2000 sites in Danish waters and coastal regions. As the nearest of such protected areas are at least 60 km away from the intended wind farm, the implementation of the Vesterhav Syd project is expected to have no significant effect on the conservation objectives.

The harbour porpoise is a strictly protected species listed on annex IV of the Habitats Directive and is thus subject to an assessment in relation to Article 12. The construction of Vesterhav Syd is not expected to violate the provisions in article 12 (1) (b) concerning prohibition of significant disturbance at population level because the potential impact is temporary and fully reversible. However, based on the worst case scenario it cannot be excluded that the prohibition of killing individuals of strictly protected species (Art. 12 (1) (a)) will be violated if no noise mitigation measures are applied. In the vicinity of pile driving sites the porpoise mortality risk might increase due to a lowered fitness caused by permanent hearing damage (PTS).

A recent study indicates that the PTS onset level might be considerably higher than the value used for the evaluation. In this case the risk of PTS would be much lower and Article 12 (1) (a) would not be violated. The same holds true for noise emissions below the worst case scenario, if for instance smaller piles or fewer strikes are used to install the piles.

2 INTRODUCTION

In 1996 the Danish government issued a policy statement on the development of sustainable Danish energy production, called “Energy 21”, undertaking to reduce emission of the greenhouse gas CO2 by 20 % in 2005 compared to 1988. A follow up on Energy 21 in 1999 contains further reductions. Within the Kyoto Protocol, Denmark has once more committed itself to reducing greenhouse gas emissions by 21 % in the period 2008-2012 relative to the level of 1990. Since 1990 the Danish adjusted carbon emissions have fallen by more than 13 %. As a central strategy in progressing towards a further CO2 reduction, Denmark is promoting the development of wind energy. The overall aim is an increase in the contribution of wind energy to as much as 50% of the total national consumption of electricity in 2020 (Klima-, Energi- og Byggeministeriet 2013).

Vindeby in the Danish Baltic Sea was the first wind farm. For more than 20 years of operation time (since 1991), the importance of offshore wind farms in Danish waters has increased continually. Until 2013 a total of 5,196 wind turbines with an overall capacity of 4,823 MW were installed. In 2013 these turbines produced 9,466 GWh electricity, which is almost 30 % of the national/domestic electricity supply (DEA 2013).

On 22 March 2012 a broad political majority of the Danish Parliament agreed on the energy policy for the period 2012-2020. Establishment of near shore wind farms, generating up to 450 MW of energy, will ensure part fulfillment of the overall taget of 100% renewable energy in the energy and transport sectors by 2050. On 28 November 2012 the Danish government specified six sites around Denmark which are to be subject to pre-investigations prior to their development, including turbines, submarine cables and cable landfall. The selected sites are: Bornholm, Smålandsfarvandet, Sejerø Bugt, Sæby, Vesterhav Syd and Vesterhav Nord. The Danish Energy Agency (DEA) is responsible for the procurement of the 450 MW wind power for the six near shore wind farm areas. The six projects are divided into two packages. Package 1, including Bornholm, Vesterhav Syd and Vesterhav Nord, is to be considered as a whole and studies on resting and migrating birds/bats are to be performed in parallel by the same consultants (NIRAS, IBL Umweltplanung GmbH). Hereby, data for joint analyses are available. NIRAS Consortium is responsible for the Environmental Statements of the three wind farm sites. This report on marine mammals will be annexed to the main Environmental Statement report for Vesterhav Syd offshore wind farm. Energinet.dk is responsible for the EIA process related to the projects.

This report presents the details of the Environmental Impact Assessment for marine mammals. The impacts and influences on marine mammals of the offshore elements differentiated according to installation, operation, decommissioning and cable laying are assessed and potential mitigation and monitoring options are provided.

The final layout of the wind farm is not yet defined, but the turbines will be distributed within a pre-investigation area that is referred to as “development area” in this report.

2.1 Objectives

Before any impact assessment of the planned wind farm "Vesterhav Syd" on marine mammals can be performed, basic knowledge about marine mammals' use of this area needs to be appraised and potential disturbances have to be explained. In this report the occurrence, abundance and distribution of harbour porpoise, grey seal, harbour seal and other relevant marine mammal species which might occur in the development area are presented in order to document the importance of the area. For further information about species specific behavior due to influences like noise, traffic and habitat changes existing literature is reviewed. Additionally, data from standardized aerial and passive acoustic surveys during the pre-construction phase have been collected. These data, used to assess possible impacts, are presented in this report. Furthermore, available information and data from other studies conducted in both adjacent and distant areas are considered to describe the abundance and distribution of marine mammals in this area.

The specific objectives of this assessment were to

- describe and evaluate the importance of the area of the proposed wind farm Vesterhav Syd for marine mammals;
- determine the potential impacts of the installation, operation and decommissioning of the offshore elements of the proposed wind farm Vesterhav Syd on the species and to predict the significance of those impacts;
- present a Habitats Regulations Assessment for the proposed development, including the Natura 2000 screening process and an assessment of the conservation obligations for strictly protected species according to the Habitats Directive.
- identify the potential for cumulative effects with other developments.

3 PROJECT DESCRIPTION

Vesterhav Syd offshore wind farm comprises the establishment of a nearshore wind farm, inter-array and export cables as well as cable landfall facilities including cable termination station (and additional substations) on land. The entire development area is shown in Figure 1.

The wind farm will be located within a 60 km² development area 4 – 10 km off the coast northwest of Hvide Sande. Water depths in the area vary between 15 and 25 m. The wind farm will possibly have a maximum capacity of 200 MW.

The export cables from the wind farm to the mainland may be installed in two 500 m broad corridors, running from the northern part of the wind farm to the coast near Klegod and Tyvmose, both sites located north of Hvide Sande (Figure 1).

Figure 1: Development area of the wind farm Vesterhav Syd.

A description of the project and construction methods for the installation offshore is presented in a separate report (Energinet.dk 2015).

Owing to the fact that the foundation type is not confirmed yet, a short description of all possible foundation variations is included. Furthermore, other parts of the installation procedures, which might be relevant for the impact assessment e.g. scour protection and cable laying procedure, are described briefly in this report.

3.1 Turbines

Turbine size and dimension has not been finally determined. The wind farm area is planned for a total rated power of 200 MW consisting of either 20 turbines of 10 MW or 66 turbines of 3 MW (198 MW). The technical specifications of 3 MW and 10 MW turbines are given in Table 1. Possible and likely layouts for those two scenarios have been developed by DTU Wind Energy, Department of Wind Energy (DTU 2014). They are presented in Figure 2. According to DTU Wind Energy bigger turbines on the edge of the wind farm leads to lower wake losses, since there will be fewer turbines on the edges.

Table 1: Technical specifications of 3 MW and 10 MW wind turbines.

Turbine capacity	Rotor diameter	Total height	Hub height	Max. number
3 MW	112 m	137 m	81 m	66
10 MW	190 m	220 m	125 m	20

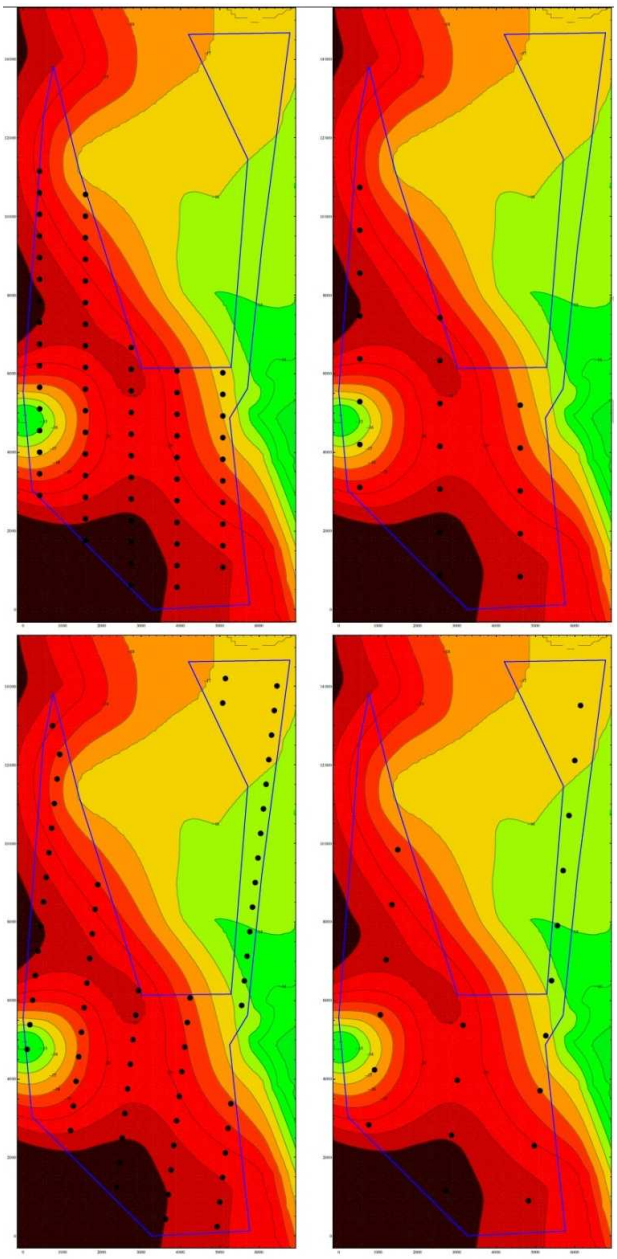


Figure 2: Suggested layouts for the 3.0 MW turbines (left) and 10 MW turbines (right). The bathymetry is depicted with 1 m intervals ranging from purple to dark red, with red being the deepest (Source: DTU 2014).

3.2 Foundations

The turbines will be fixed in the seabed by one of the foundation types listed below. Foundation types are dependent on turbine size, water depth and sediment characteristics. Since some of these parameters are not defined yet, all calculations are made for dimensions on either a 3 MW or 10 MW turbine and an average water depth of 20 m.

- Driven steel monopiles
- Concrete gravity bases

- Jacket foundations
- Suction buckets

3.2.1 *Driven steel monopile*

Monopiles have been installed at a large number of wind farms in the UK and in Denmark in e.g. Horns Rev I and II and Anholt OWF's. The monopile foundation is a steel pile of a diameter in a range 6 – 9.5 meters, which is driven into the seabed at a depth of about 23 - 39 m. Penetration depth and pile diameter depend on turbine size and sediment characteristics. Dimensions of a monopile for either a 3 or 10 MW turbine and scour protection (if necessary) are listed in Table 2.

Table 2: Estimated dimensions of the two suggested monopile types.

MONOPILE	**3.0MW**	**10.0MW**
Outer diameter at seabed level*	4.0-6.0 m	6.0-9.5 m
Pile length	35-55 m	50-80 m
Ground penetration (below mud line)	15-30 m	20-39 m
Outer diameter (based on a conical shaped monopile)	3.5-5.5 m	5.5-7.5 m
Foot print area per foundation (+/-100 m^2)	1,500 m^2	2,000 m^2
Total foot print scour area (20 turbines)	30,000- 32,000 m^2	40,000- 42,000 m^2
Total foot print scour area (66 turbines)	99,000- 105,600 m^2	132,000- 138,600 m^2

3.2.2 *Concrete gravity base*

Concrete gravity bases have been used successfully for wind farms since the early 90s, e.g. Vindeby in the Danish Baltic Sea (the world´s first wind farm, in operation since 1991). In the North Sea gravity bases are used as foundations in Thornton Bank wind farm in Belgium (in operation since 2009). Gravity base foundations are held in place mainly by their mass. Additionally, foundation bases are filled with material such as sand or gravel to withstand the extraordinary forces of the offshore environment and the wind turbines. Prior to the installation of concrete gravity bases, seabed preparations are required such as the removal of ground material and replacement by a stone bed (Figure 3).

The Table 3 below specifies the estimated dimensions for the biggest (10 MW) and the smallest (3 MW) turbine type. Since water depth in the Vesterhav Syd area is between 15 - 22 m, dimensions are calculated with an average depth of 20 m.

Table 3: Estimated dimensions of gravity bases for the two suggested layouts of Vesterhav Syd.

GRAVITY BASE	3.0MW	10.0MW*
Shaft diameter	3.5-5.5 m	5.0-7.0 m
Area of base	280 – 440 m²	400 – 600 m²
Type of ballast	Infill sand	Infill sand
Ballast volume per unit (m^3)	700-1,100 m³	1,200-2,800 m³
Seabed preparation		
Material excavation (per base)	1,000-1,600 m³	1,600-3,200 m³
Stone replaced into excavation (per base) – stone bed	100-180 m³	160-400 m³
Scour protection (per base)	600-1,000 m³	1,100-2,000 m³
Foot print area (per base)	800-1,300 m²	1,400-2,600 m²

3.2.3 Jacket foundation

Wind turbines can be erected on a jacket foundation. Jacket foundations are widely applied as they are often used in the oil and gas industry. They are therefore also applicable in deeper water. The jacket foundation itself has three or four main piers or legs. These are stabilized with cross struts forming a lattice. The whole construction then has the form of a lattice tower resembling a cage. The legs have to be secured to the sea bottom. For this purpose different techniques are available. However, all of them involve some kind of pile driving. The dimension of the jackets varies with the size of the mounted wind turbines and would be up to 20 x 20 metres for the smaller 3.6 MW wind turbines and 40 x 40 metres for the larger 10 MW wind turbines. On top of the jacket is a transition mount on which the wind turbine can be erected. Scour protection would be necessary in the Versterhav Syd area.

Table 4: Estimated dimensions of jacket foundations for the two suggested layouts of Vesterhav Syd.

Jacket	3.0MW	10.0MW*
Distance between legs at seabed	15 x 15 - 18 x 18 m	32 x 32 - 40x 40 m
Pile length	30-50 m	40-70 m
Diameter of pile	0.95 – 1.5 m	1.2 – 1.8 m
Scour protection volume per foundation (+/-150 m^3)	800-900 m^3	2,500-2,600 m^3
Foot print area per foundation (+/-100 m^2)	700-800 m^2	1,600-1,700 m^2

3.2.4 Suction bucket

The bucket foundation is a relative new foundation type. It combines the main features of a gravity foundation and a monopile foundation. It consists of a cylindrical steel foundation which is open at the lower end. Suction buckets are drawn to the ground by using jet and suction. Soil enclosure gives further stability to the foundation. Suction buckets can be used in water depth up to 40 m. Unobstructed ground conditions are necessary. This foundation type can be designed for various conditions, if homogeneous ground conditions e.g. sand, silts and clay are prevalent. Suction buckets are used offshore for supporting met masts at Horns Rev 2 and Dogger Bank and for a 3 MW turbine in a polder near Frederikshavn in Denmark.

3.3 Scour protection

Depending on the type of foundation used, ground conditions and hydrodynamics, a scour hole of different size can be formed around the base. If the seabed is erodible and the flow is sufficiently strong, a scour hole is formed. Where the seabed consists of erodible sediments there will be a risk of scour hole development around the foundation structure(s) due to impact from waves and current. Development of scour holes can affect the foundation structure's stability.

In order to ensure the stability of the offshore wind plants and to prevent serious damage, a scour protection technique will be installed. There are two different types of scour protection which can be installed. One is to allow for scour in the design of the foundation (thereby assuming a correspondingly larger water depth at the foundation), or to install scour protection around the structure. Scour protection regularly consists of stones, mats or sand bags. For a piled foundation structure the scour protection will be installed around the piles. The scour protection may consist of a two-layer system comprising a filter layer and an armour layer. These layers can consist of stones, mats, sand, backs or other material. The decision, on which kind of scour protection will be installed, will be made by the constructor.

Depending on the hydrodynamic environment the diameter of the armour layer for monopile foundations can be between 10 and 15 meters with a thickness between 0.7 and 1.5 m. Filter layers are usually 0.7 - 0.9 m thick and extend up to 2.5 m further than the armour layer.

Scour protection for other foundation types such as jackets, suction buckets or concrete gravity bases may be necessary, depending on the soil properties at the installation location. The design for scour protection may include a ring of rocks around the structure (Figure 3). It is anticipated that the scour protection applicable to bucket foundations is included and placed below the surface of the seabed. Depending on the exact foundation design scour protection may not be necessary.

In the event of scour protection installation, the material, such as rocks, stones or sand, will be graded and loaded onto a suitable rock-dumping vessel and dropped directly onto the seabed via a bucket grab or via a telescopic tube.

The decision on whether to install scour protection will be made during a detailed design phase. The magnitude in terms of changes in ground structure and resulting habitat changes will be included in the impact assessment.

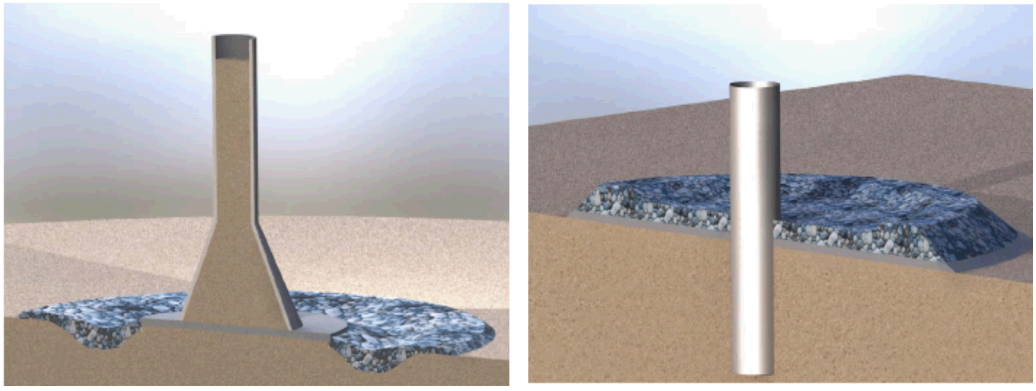


Figure 3: Example of scour protection techniques for either concrete gravity bases (left) or monopile foundations (right) (drawings by Rambøll).

3.4 Subsea cables

Subsea cables are necessary to connect the wind turbines and to conduct the electricity to the land. For this inner-array cables are necessary as well as export cables. The network of inner-array cables depends heavily on the number of wind turbines, as they can be 20 or as many as 66. One cable will connect 8-10 wind turbines in one row. Export cables could lie parallel to each other and run directly to the shore. Alternatively, a transformer platform could be installed where inner-array cables join. From the transformer platform one cable could lead to the shore.

All cables, both inter-array cables as well as export cables will be jetted into the seabed to protect the cables from damage from fishery tools or anchors. Cables are buried to a depth of 1 to 1.5 metres. In detail, different procedures are possible that are all carried out by specialized vessels. Cables could also be protected by rock dumping. Therefore, medium sized rocks will be used. The width of this corridor would be 2-3 metres.

4 METHOD

To estimate the distribution and abundance of (mainly) harbour porpoises, grey seals and harbour seals in the study area, overall standardized aerial surveys were used. In addition, passive acoustic monitoring was used to detect the acoustic activity of harbour porpoises.

4.1 Aerial surveys

Aerial surveys were conducted using a standard method for Environmental Impact Assessment for offshore wind farms. This line transect method is used in several EIA monitoring programms, e.g. Horns Reef (Nehls et al. 2014). It follows the methodology of the distance sampling approach (Buckland et al. 2001).

4.1.1 Survey design and data collection

Overall 9 survey flights were conducted in the period from November 2013 to July 2014 along 18 transect lines at 2 km intervals with an average track length of 28 km and a total length of 500 km (see Figure 4). Thus, a survey area of 950 km² was covered. The cruising speed was approximately 185 km/h (100 knots). The first 6 flights were executed at an altitude of 76 m (250 feet) to record birds and mammals simultaneously. The last 3 flights in May, June and July 2014 were conducted at 183 m (600 ft) altitude exclusively for observing marine mammals. The dates of the nine surveys and the general weather conditions during the flights are presented in Table 4. Detailed information on weather was noted at the beginning of each transect and at any change of conditions.

Table 4: Weather conditions during each of the nine survey flights.

Date	Altitude	Sea-state	Visibility (km)	Wind speed (Bft)	Wind direction (°)	Cloud cover (x/8)	Rain	Temperature (°C)
25.11.2013	250 ft	2-3	10	2	360	1-3	no	5
03.02.2014	250 ft	2-3	5-10	4	135	1	no	5
11.02.2014	250 ft	1-3	8-10	2	225	1-6	no	3
11.03.2014	250 ft	1-2	10	2	50	0-1	no	8
25.03.2014	250 ft	1-3	10	2	230	1-2	no	6
16.04.2014	250 ft	2-3	10	3	240	3-6	no	7
18.05.2014	600 ft	1-2	10	2	315	1-5	no	12
11.06.2014	600 ft	2-3	5-10	2	230	1-4	no	17
07.07.2014	600 ft	1-2	10	3	250	4-5	no	15

Figure 4: Investigation area with transect lines for aerial surveys.

The latitudes and longitudes of the western and the eastern end of each transect line are listed in Table 25 in the Appendix.

Marine mammals and birds were counted by two experienced observers, one on each side of a twin-engined “Brittan Norman BN2” equipped with bubble windows (Figure 5). Various parameters such as species, number, behaviour, transect band and time were recorded. The observation conditions, i. e. seastate, turbidity, visibility, glare and other parameters, were also recorded. Furthermore, each observer made a subjective assessment summing up the observation conditions on his side as ‘good’, ‘moderate’, ‘poor’ or ‘unacceptable’. This classification is a rough guess as to the probability with which a marine mammal can be visually detected under the given conditions.

Figure 5: Aircraft used for surveys: “Brittan Norman BN2” with bubble windows (Photo by Michael Joost/IBL-Umweltplanung).

For each survey the effort was calculated as valid kilometer covered on each side, e.g. a 10 km track line covered by both observers results in 20 km survey coverage. Based on the total transect length of 500 km the total effort is around 1,000 km if analysis is possible on both sides of the airplane. However, on most survey flights some sections had to be excluded from evaluation due to invalid observation conditions (see next chapter). The residual valid effort is listed in Table 26 in the Appendix for each flight.

4.1.2 *Data analyses*

In calculating porpoise densities from aerial survey data the following factors are needed: the observation distance covered under valid conditions, the number of sightings under valid conditions, the 'effective strip width' (ESW) and the detection probability g(0).

The ESW was calculated using the distance sampling software DISTANCE 6.0 (Thomas et al. 2010). It is determined by the detection function that describes the distribution of the sightings. The latter typically shows a non-linear decline with increasing perpendicular distance from the transect line (Buckland et al. 2001). (The distances to the transect line are calculated via a sine function, based on the angle of the sightings.) Because a minimum of 60 – 80 sightings is needed for a proper calculation of the ESW (Buckland et al. 2001) the data from the two projects 'Vesterhav Syd' and 'Vesterhav Nord' were pooled for the analyses and a global detection function was determined for the entire dataset of the 250 ft and 600 ft flights respectively. As the 'Vesterhav Syd' and 'Vesterhav Nord' surveys were performed within the same time period (mostly only a few days between surveys in the respective months) with the same aircraft and the same observers, this approach is reasonable and justified. In this way the statistical power of the analyses is increased.

The software adjusts a detection function using variations of key parameters (cosine, hazard rate) and adjustment terms if necessary (uniform, half-normal). The detection function for the altitude of 250 ft is given in Figure 47 (hazard rate key function) and Figure 48 in the Appendix shows the function for the altitude of 600 ft (half normal key function). During the flights at 250 ft the focus was on resting birds (see report on resting birds, Wendeln in prep.). The birds were counted in strips with a focus on strips A to C, where A starts at 44 m distance from the transect line. Therefore, the number of observations of marine mammals in close proximity to the transect line is relatively low (Figure 47), whereas detection at the transect line during surveys at 600 ft (surveys on mammals) is high and can be regarded as 100 %. The best fitted function was chosen by the smallest AIC (Akaike Information Criterion) value. The effective strip width (ESW) for each flight altitude (250 ft and 600 ft) is summarized in Table 27 in the Appendix. Besides the mean ESW, 95 % confidence intervals are also calculated as a measure of possible variation in densities of animals. Detection functions were estimated using the conventional distance sampling engine (CDS). Densities are calculated on the basis of 2 x 2 km grids.

The detection probability g(0) defines the proportion of actually sighted individuals among the entirety of present animals within the ESW. It corrects for the proportion of porpoises that are non-visible in deeper water (availability bias) or overlooked by observers (perception bias). The availability bias depends on the proportion of time the porpoises spend in the upper water column where they can be seen (down to 2 m below surface). On the basis of transmitter data, Teilmann et al. (2013) calculated mean percentages of 'near surface time' for each month (Figure 6). The authors also give correction values for the site and the period of the day. For the Skagerrak / North Sea area and the period 9:00 to 15:00 hrs. the monthly mean percentages of surface time (0-2 m depth) as listed in Table 28 in the Appendix are taken into account as availability bias.

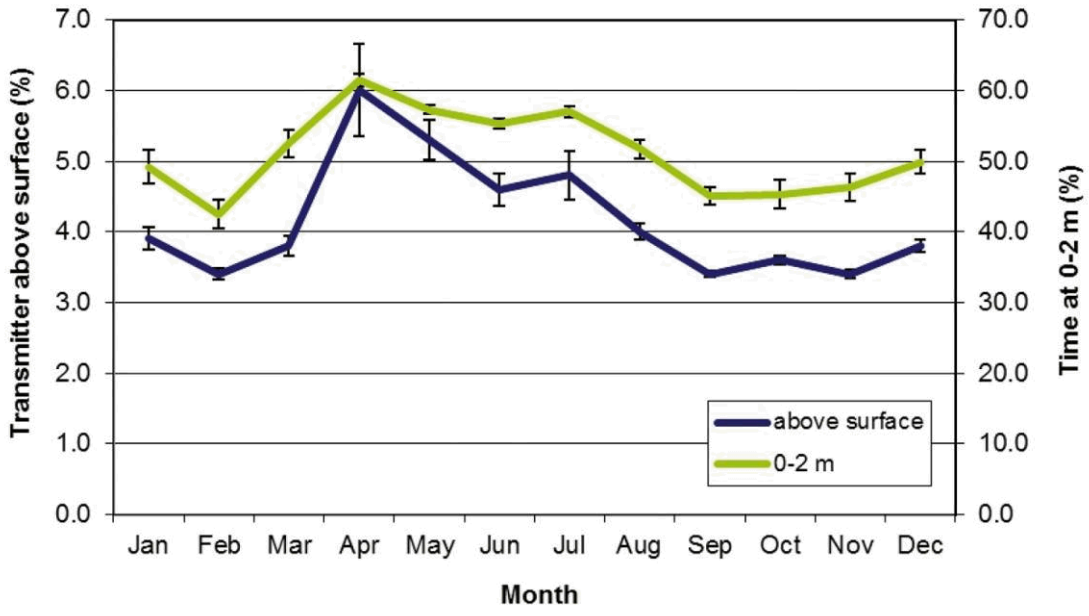


Figure 6: Monthly mean percentages of time spent at surface (Source: Teilmann et al. 2013).

The perception bias can be determined by the proportion of recaptured sightings when flying the same transect section twice within a short time span ('circle back' method) or when a control observer is deployed ('double platform' method). The latter method has been used on several projects and has found the recapture rate (e.g. double sightings by both main and control observer within the 'detection zone overlap') usually to be 50-60% for both altitudes in 'good' and 'moderate' conditions. Because the number of flights for the Vesterhav Syd project is critically small for calculating a value for the detection bias, the flights were conducted without a control observer and fell back on the 'IBL perception bias' for the density calculations. Based on more than 650 control observer sightings since 2010, the mean IBL perception bias is 59.8 % for 250 ft flights and 53.4 % for 600 ft flights in the main detection zone overlap. (In line with Diederichs et al. (2010a) the range from 45° to 70° vertical viewing angle was chosen as the relevant detection zone overlap for the recapture rate calculation.)

The detection probability g(0) is the product of the perception bias and the availability bias. The monthly g(0) values are listed in Table 28 in the Appendix, according to the mixed model availability bias estimation of Teilmann et al. (2013).

Alongside the mean values for the perception bias and the ESW, a flight-specific correction of the density calculations is also given by considering only data which was recorded under comparatively 'good' and 'moderate' observation conditions; transect sections and sightings that were subject to very unfavorable conditions not being taken into account. This applies to perception conditions which the observer subjectively assessed as 'poor' or 'unacceptable' for various reasons (fog, low clouds, strong glare, reflection of clouds, dense turbidity etc.) and in general to a seastate of level 4 and above.

From flight data porpoise densities and porpoise distribution are determined. Independent from flight data, the impact area of construction work (especially noise during pile driving) can be calculated on a theoretical background. This is the information required to calculate the number of affected porpoises. This again allows to run two approaches to assess the impact of construction work on population level:

the “Potential Biological Removal” (PBR) and the “Interim Population Consequences of Disturbance” (PCoD)

The potential biological removal (PBR) is the maximum loss rate of a population that would not lead to a population decline. The significance of project-related impacts can be assessed in relation to the PBR. The PBR is defined as

$$PBR = N_{min} * 0.5 * R_{max} * FR \text{ (Taylor et al. 2000).}$$

Hereby, N_{min} is the minimum population estimate, R_{max} is the maximum population growth rate and FR is the recovery factor for a depleted population.

However, both approaches consist of models that can still be refined. The main focus in the PBR is to present a simple model where variables are easily available. The outcome presents a number of animals that can die of all human activities including fishing. Wind farm construction is only one of these factors. The PCoD model targets more specifically the impact of the construction of one wind farm and the model is requisited with many population specific parameters. However, these parameters are not yet all known but are currently often based on expert judgement. This means that the outcome of the model presents a scenario what could happen but is not a secure prediction of future population development.

4.2 Passive acoustic monitoring

4.2.1 Survey design and data collection

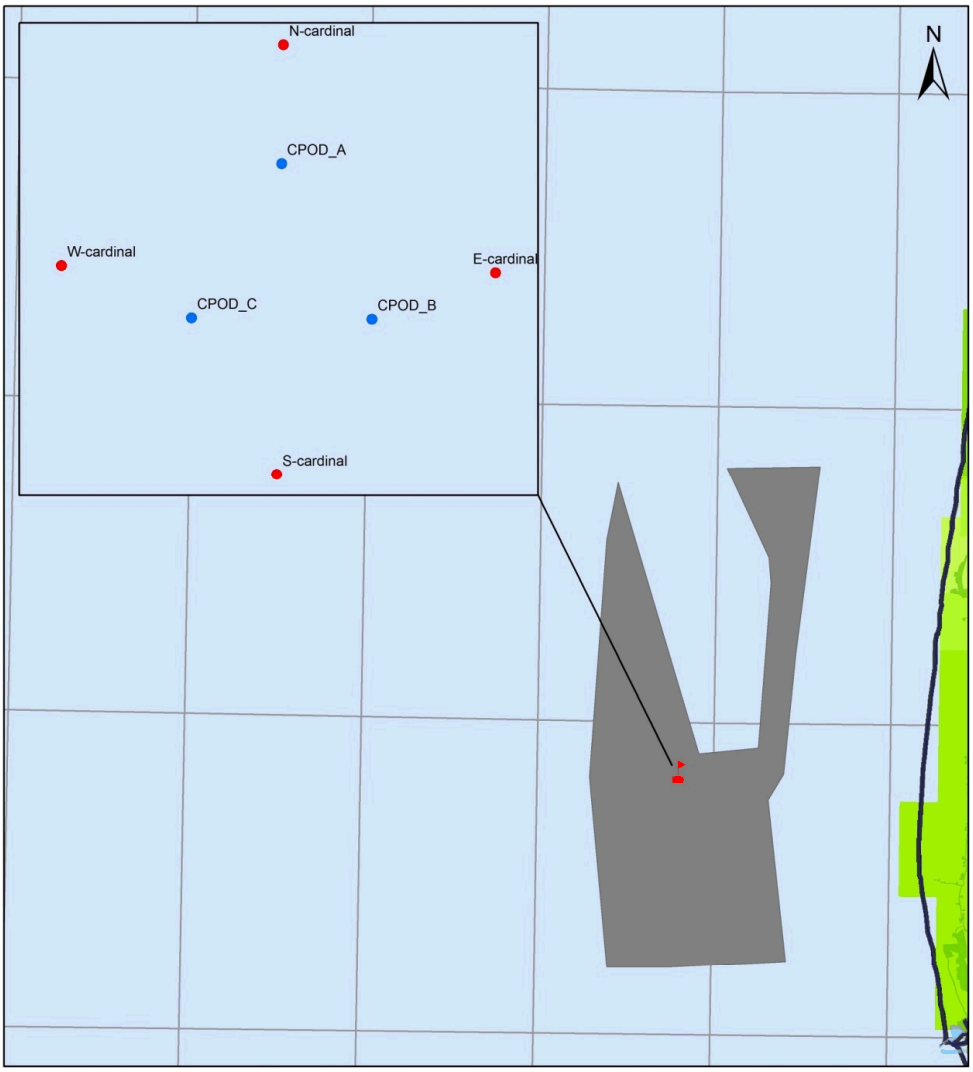
Acoustic monitoring methods are compared to visual monitoring methods independent of weather and light conditions. Underwater passive acoustic monitoring with fixed hydrophones in automated click-detectors such as C-PODs and T-PODs has become an important standard method for detecting the small-scale distribution and relative abundance of odontocetes in the wild (Gordon & Tyack 2002, Evans & Hammond 2004). Since harbour porpoises emit echolocation clicks almost continuously (Linnenschmidt et al. 2012), passive acoustic data is a very suitable source for evaluating temporal variations in harbour porpoise presence as an indicator for the habitat use. However, the detection range is limited (approx. 300m, Tregenza 2011) and highly variable depending on the ambient noise level and the orientation of clicking porpoises. Therefore the data is not suitable for calculating absolute densities, although correlations between detection rates and absolute densities have been found (Kyhn et al. 2012).

In this study C-PODs (Cetacean Porpoise Detectors) were used to detect the acoustic activity of harbour porpoises in the proposed wind farm area. The C-POD is commonly used in european studys (e.g. Dähne et al. 2013b). It consists of a hydrophone, a sound converter, a digital timer, frequency filters, a 4 GB SD-card memory unit and batteries. The C-POD detects click sounds in the frequency range between 20 and 145 kHz (Version 0) or 170 kHz (Version 01) (www.chelonia.co.uk). These clicks may not only originate from odontocete whales but also from other ambient noise sources. Subsequently, the porpoise clicks have to be filtered out by the ‘CPOD.exe’ software (see chapter ‘data analyses’ below).

Since a high variation of porpoise activity inside the relatively homogenous wind farm site was not expected and because Vesterhav Syd is a coastal area with intensive fishery activity it was decided to

deploy the C-PODs in a group as a ‘C-POD station’ in the centre of the intended wind farm site. The centre of the station is located at 56°04.221’N / 7°59.037’E at a water depth of about 20 m. The distance to land is 7 km.

The C-POD station consists of three C-PODs (positions A, B, C) which are anchored at a distance to each other of 150 m, and marked with buoys (Figure 7). This C-POD triangle is surrounded by a rhomb of cardinal buoys, equipped with sea lanterns and radar reflectors. As three C-PODs were deployed together to form one C-POD-station three datasets are available if all devices are working and all are recovered, producing a redundancy of two data sets. However, in an area with elevated risk of material and data losses (fishery, severe coastal waves and currents) the C-POD station design with redundant data sets has advantages. In the case of C-POD losses, back-up datasets are available. Featuring four big cardinal light buoys the C-POD station is clearly visible even at night and easily detectable for radar devices. However, the design does not provide protection against negligence, intentional damage or heavy storms.



Vesterhav Syd

CPOD - Positions

GEBIET	TYPE	LAT_WGS84, GM	LON_WGS84, GM	LAT_WGS84, GD	LAT_WGS84, GD	LAT_ETRS89_Z32	LON_ETRS89_Z32	CODE_LIGHT
Vesterhav Syd	N-cardinal	0759,036	5604,323	07,98393	56,07205	0436748,970	6214563,250	Q
Vesterhav Syd	E-cardinal	0759,212	5604,220	07,98687	56,07033	0436929,100	6214369,820	Q(3)10s
Vesterhav Syd	S-cardinal	0759,036	5604,126	07,98393	56,06877	0436743,290	6214198,300	Q(6)+LFl.15s
Vesterhav Syd	W-cardinal	0758,857	5604,220	07,98095	56,07034	0436560,420	6214375,850	Q(9)15s
Vesterhav Syd	CPOD_B	0759,112	5604,198	07,98520	56,06996	0436824,160	6214330,340	
Vesterhav Syd	CPOD_A	0759,036	5604,268	07,98393	56,07114	0436747,360	6214462,240	
Vesterhav Syd	CPOD_C	0758,964	5604,197	07,98273	56,06996	0436670,830	6214331,620	

Figure 7: Position of the C-POD station Vesterhav Syd.

Usually the stored data is transferred to land via the SD card after this is replaced by a fresh one. For the replacement of SD cards and batteries the POD station is serviced every one or two months. The service vessel crew also replaces lost material if losses are known before a cruise starts. The location of the C-POD station is near transect line 10, so the survey flight crew also had it in view and controlled its condition with each flight.

The C-POD station Vesterhav Syd was established on 10 December 2013 and recovered on 11 October 2014. Table 5 gives an overview of the service dates and the maintenance.

Table 5: Maintenance of the C-POD station Vesterhav Syd.

Date	Cruise n°.	Vessel	Maintenance
10.12.2013	NI-13-01	Arne Tiselius	Setup of POD station Vesterhav Syd. Deployment of C-PODs A, B and C at the planned positions (see Figure 7)
26.02.2014	NI-14-03	Reykjanes	Replacement of batteries / SD cards at position B, replacement of lost C-POD and mooring gear at position C, no replacement of lost C-POD A
30.03.2014	NI-14-04	Reykjanes	Replacement of batteries / SD cards at position C, replacement of lost C-PODs and mooring gear at positions A and B
18.05.2014	NI-14-05	Reykjanes	Replacement of batteries / SD cards at positions A, B and C
02.07.2014	NI-14-06	Reykjanes	Replacement of lost C-POD and mooring gear at position A, no replacement of lost C-PODs B and C
27.07.2014	NI-14-06b	Arne Tiselius	Replacement of batteries / SD cards at position A, replacement of lost C-PODs and mooring gear at positions B and C
31.08.2014	NI-14-07	Reykjanes	Replacement of batteries / SD cards at positions A, B and C
11.10.2014	NI-14-08	Arne Tiselius	Dismantling of POD station Vesterhav Syd, recovery of C-PODs A and C with SD cards.

The C-POD losses at Vesterhav Syd were much greater than expected. The fact that no cardinal buoys were lost in periods with significant C-POD losses suggests that the latter were not caused by bad weather. Loss of C-PODs means loss of data. Unfortunately, all three C-PODs got lost after 18 May, causing a data gap from this day to 2 July at C-POD station Vesterhav Syd. However, one of these C-PODs was found washed ashore. The C-POD continuously registered clicks and the position sensor was active which registered the angle of the device relative to the surface. From this data it could be concluded that C-POD 1174 remained at its original position until 16 June and thereby reducing the data gap to two weeks (Figure 8). Usually such total data gaps can be avoided through the triple deployment of C-PODs.

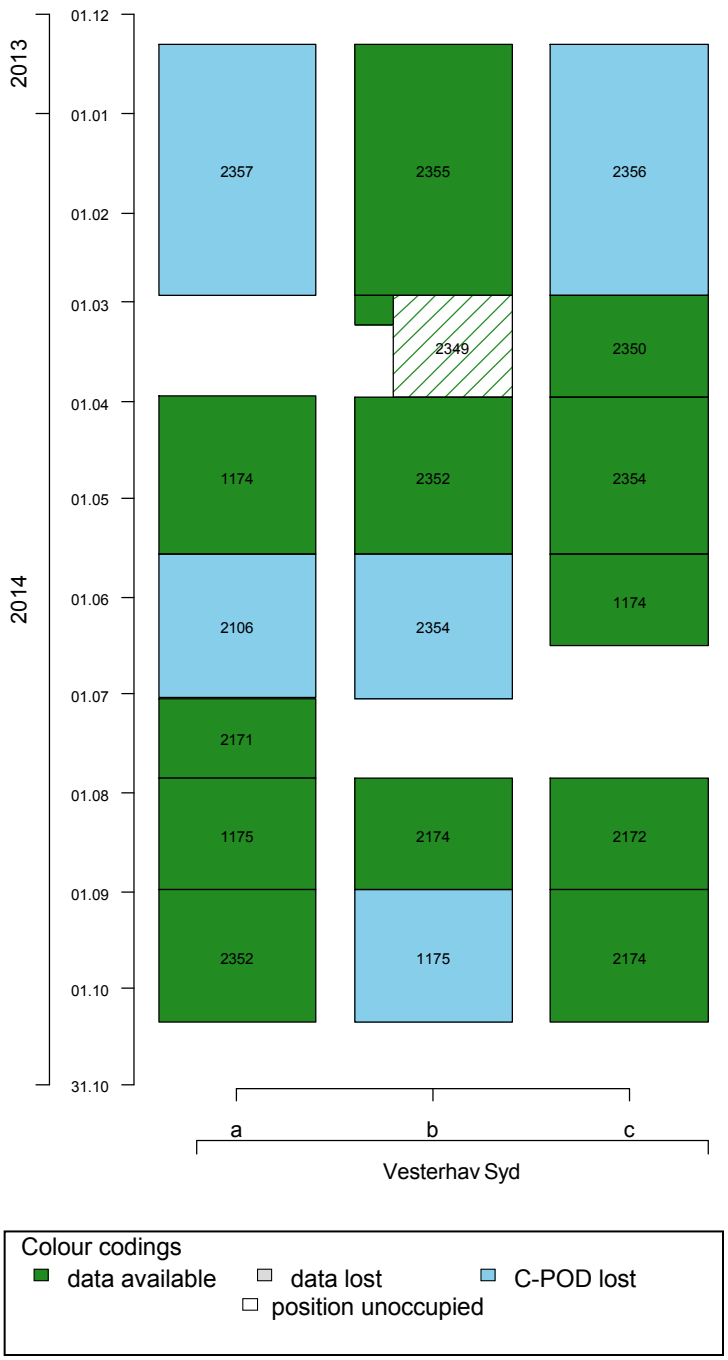


Figure 8: C-POD deployment times at the C-POD station Vesterhav Syd with its three substations (a, b, c) between 10 December 2013 and 11 October 2014.

4.2.2 *Data analyses*

For reading out the stored data on the CPOD SD card the software 'CPOD.exe' (v2.043, Tregenza 2013) is used. The software produces a raw data file (name extension .CP1) which contains all 'click' sounds within the C-POD's detection frequency range.

The same software is used for a basic analysis of the raw data. When processing the .CP1 files CPOD.exe identifies specific sequences of clicks by using an unpublished algorithm ('Kerno Classifier', Tregenza 2011). It creates .CP3 files which contain these filtered 'click trains'. Click trains are typical sounds emitted by porpoises and other toothed whales which can also be caused by ships sonar or by unidentified sources.

For the analysis of identified click trains the following 'species class' settings can be selected in the software: NBHF ('narrow band high frequency', i. e. porpoises), Other cet (other toothed whales) and Sonar (boat sonar). CPOD.exe also delivers probability values for the identified species class. The 'train classes' 'Hi' (high), 'Mod' (moderate), 'Lo' (low) and '?' (doubtful) can be selected.

For the statistical data analysis only the species class NBHF and the train classes Hi and Mod were selected. Misinterpreted click sources, so-called 'false positives' like crustaceans, waves or moving sediment, are largely filtered out this way. The export variables of CPOD.exe were stored as ASCII files and imported into the PODIS database (Klüver 2011) to be available for the script-based statistical analysis with R (version 3.0.0., R Development Core Team 2012).

The most appropriate approach to evaluating the C-POD data is to extract 'porpoise positive time units per superior time unit'. This parameter cannot yield an absolute abundance of harbour porpoises in the area but gives a dimension of relative abundance by the quantity of their acoustic activity.

The adequate time units for the evaluation are selected depending on the required temporal resolution and the general incidence of porpoises in the area. E.g., for a long-term study in a low density area the parameter 'porpoise positive days per month' would be a reasonable choice, and for investigating diurnal activity in a higher density area the parameter 'porpoise positive Minutes per hour' would be appropriate.

For evaluating the porpoise activity over a ten month period in the southwestern North Sea, an area with mainly average densities, the parameter 'porpoise positive 10 minutes per day' (pp10m/d) was selected. The calculation of the pp10m/d is affected by queries to the PODIS database. The variable pp10m/d indicates how many of the 144 10-minute sections of a 24-hour day contain at least one porpoise detection.

The area of Vesterhav Syd is a noisy environment for the C-PODs as noise from sand in suspension from tidal currents are recorded as clicks by the devices. C-PODs possess a click limit per minute. If this limit is reached no further signals are stored within that minute. This was often the case in Vesterhav Syd. The click limit setting could have been raised to a higher value but that would also have increased the risk of filling up the memory card long before the scheduled card change date. The risk of a certain data loss per day was though preferable to losing weeks.

Additionally, the data quality in a noisy environment is doubtful owing to the difficulty of distinguishing the click trains of the harbour porpoises from all the other noise (Tregenza 2014). On the one hand, it is possible that porpoises remain undetected as their clicks are drowned out. On the other hand, certain sounds from the environment could be wrongly interpreted as porpoises (resulting in "false positives"). Thus the risk of 'false positives' would also be much higher if all 'noise polluted' 10 minute periods were evaluated. Therefore, all 10-minutes intervals in which time losses occurred due to exceeding click limits

were excluded. As not all 10-minutes-intervals per day were analyzed, the pp10m/d are always given as a percentage rather than as absolute values.

From these criteria, 22 % of all 10-minutes-intervals from the entire data set of Vesterhav Syd had to be excluded. However, many datasets were redundant as different C-PODs detected porpoises parallel. Therefore, data rows were selected that the longest possible time bar was built. In this data set even 26 % of all 10-minutes periods had to be excluded. This greater proportion in this subset of data resulted from an unfavourable distribution of the lost time periods within the dataset. In cases where the redundant data set from another substation C-POD was available and did not exceed the click limit the data set could be completed. This reduced the total loss to 25 % of the10 minute periods per day. This yielded in eight days were all data had to be excluded. Nine further days had less than 10 complete 10-minute-intervals and were excluded completely from further analyses. Taking together, 18 days were removed from further analyses.

4.3 Assessment criteria

According to the EIA criteria the aim of an impact assessment is to estimate direct or indirect impacts at population level in relation to the number of individuals which are subject to different levels of impact (DEA 2013). An impact assessment at population level is often not possible since some factors which might have positive or negative effects on these animals are unknown. Accordingly, an overview of significant as well as assumed factors affecting marine mammals is given.

For the impact assessment, the methodology outlined by Energinet.dk and NIRAS (NIRAS 2013) was used. The chosen method is based on the criteria of the EIA directive. In the following the underlying assessment criteria are explained:

- Degree of disturbance / impact
- Importance
- Likelihood of occurrence
- Persistence

A combination of these criteria according to Table 29,

Table 30 and Table 31 in the Appendix section (chapter 20) leads to a given magnitude of impact within the categories “major, moderate, minor or negligible/neutral/no effect”. A description of these categories with examples of dominating effects is given in Table 6. The description of impact criteria follows in section 4.4. Besides these negative/neutral impacts positive impacts may also occur. They are mentioned separately in the text and do not follow the impact criteria described below.

Table 6: Category terminology for impact assessment (the terminology is used where legislation does not give quantifiable environmental goals or criteria).

Magnitude of impact	The following effects are dominant.
Negligible negative/ Neutral/ no impact	Small impacts, that are spacially restricted, uncomplicated, short-term persistent or without long-term effects and without any reversible effects.
Minor negative impacts	Impacts of some extent and complexity, a certain degree of persistence on top of the short-term effects, and with some likelihood to occur, but most probably without irreversible effects.
Moderate negative impact	Impacts with either a relatively large extent or long-term effects (e.g., lasting for the entire life span of the wind farm), occuring occasionally or with a relatively high probability, and which may cause local irreversible effects, e.g., loss of preservation worthy elements (nature, culture, etc.). Impacts that may necessitate mitigation measures. In this case, mitigation measures have to be integrated in the report and a new impact assessment including the recommended mitigation measures has to be applied.
Major negative impact	Impacts with a large extent and/or long-term effects, frequently occurring and with a high probability, and with the possibility of causing significant irreversible impacts. Impacts are classified as serious, thus changes in the project or the application of mitigation measures should be considered in order to minimize the impact amplitude. In this case, a new impact assessment is conducted, including the recommended mitigation measures.

4.4 Impact criteria

4.4.1 Degree of disturbance

The criteria used for the impact assessment in this report are described in the following. The evaluation follows either measurements according to the studies performed or is based on expert judgments with reference to the knowledge of previous studies on offshore wind farm projects or on relevant adjacent populations. The potential pressures on marine mammals due to the construction, operation and decommissioning of an offshore wind farm can be summarized as three main impacts: injury, behavioural response and habitat change. The same applies to offshore and near shore cable laying. The criteria determinating the degree of disturbance with regard to these impacts are described in Table 7.

Table 7: Definition of the parameter ‘degree of disturbance’ for different impacts.

Impact	Ranking of degree of disturbance	General remarks / Explanation of ranking
Injury	general remarks	Risk of a permanent or temporary hearing threshold shift (PTS/TTS)
	High	For the risk of injuries, the degree of disturbance is generally ranked as ‘high’
Behavioural response	general remarks	Dependent on the sensitivity of species, behavioural responses to project related pressures may vary widely ranging from small changes in activity level of the animal to total avoidance behaviour.
	High	High sensitivity of the species to anthropogenic disturbances, total avoidance of the relevant impact area.
	Medium	Moderate sensitivity to anthropogenic disturbances, partial avoidance of the relevant impact area.
	Low	Low sensitivity to anthropogenic disturbances, little or no avoidance of the relevant impact area.
Habitat change	general remarks	Habitat changes may result in direct loss of habitat or in changes in food availability. The impact level also depends on the flexibility of the species.
	High	Species is affected by severe loss of food resources and direct loss of habitat; species shows low flexibility in food choice and depends on the site.
	Medium	Species is fairly flexible in the choice of food; prey is not restricted to particular area.
	Low	Species is flexible, low numbers of individuals are affected.

4.4.2 Importance

The central aspects for assessing the importance of an impact for a species are the conservation status of the affected species, the importance of the affected area for the species (abundance, function) and the spatial extent of the affected area. The assessment is an expert judgement based on a mixture of the criteria laid out in Table 9, i.e. not all criteria attributed to a particular importance ranking need to be fulfilled.

Table 8: Definition of the parameter ‘importance’.

Ranking of importance	General remark / Explanation of ranking
General remarks	Range of impacts related to the project area. Conservation status: harbour porpoise (EU Habitats Directive Annex II, IV) ranked as superior to Harbour and grey seal (Annex II, V) Abundance and function: Density of species, presence of calves and breeding sites in relation to other areas inhabited by the biogeographical population
International	Impact area widely exceeding the project area; above-average densities of species that are protected by international legislation; important ecological function for the species (breeding, migration etc.)
National or regional	Impact area exceeding the project area; average densities of species that are protected by international legislation; average ecological function for the species
Local	Impact area limited to the project area and immediate surroundings; average or below-average densities of species that are protected by international legislation; average or below-average ecological function for the species
Not important	Impact area limited to the project area or a fraction of it; below-average densities of species protected by international legislation; below-average ecological function for the species

4.4.3 Likelihood of occurrence

This criterion mainly defines the likelihood that an impact will affect marine mammals at population level. For impacts that are little known it can also define the likelihood of actual occurrence (see Table 9).

An impact at population level can be judged in different ways. A rough estimate can be obtained by looking at the percentage of the population affected. A 1 % criterion is often applied to indicate a high level of impact (e.g. ASCOBANS 2000, 2002). Given that the relevant population consists of about 230,000 animals, which corresponds to the population estimate mentioned in Fredshavn et al. (2014) and Nehls et al. (2014), the 1 % criterion is reached if 2,300 animals are affected.

An alternative is to compare the affected numbers with the “potential biological removal” figure (PBR), which is 1,246 animals for the North Sea population according to ICES (2014). However, the PBR only refers to lethal effects. The expected effects of the wind farm project are mainly non-lethal and are therefore difficult to translate into a removal from population. This problem was recently addressed with the introduction of the “Interim Population Consequences of Disturbance” (PCoD) approach (see chapter 8.2.1).

Regarding the likelihood of occurrence, for precautionary reasons the conservative 1 % criterion is used for both non-lethal and potentially lethal effects (see Table 9).

Table 9: Definition of the parameter ‘likelihood of occurrence’.

Ranking of likelihood	General remark / Explanation of ranking
General remark	Considered as relevant biogeographical population estimates are 230,000 harbour porpoises in the North Sea and approx. 42,000 harbour seals in the Wadden Sea and Limfjord (see 6.4 and 6.5).
High	The occurrence of the impact is very likely; more than 1 % of the biogeographical reference population is affected
Medium	The occurrence of the impact is likely; more than 0,3 % of the biogeographical reference population is affected
Low	The occurrence of the impact is unlikely; less than 0,3 % of the biogeographical reference population is affected

4.4.4 Persistance

The persistence of the impact gives a temporal scale of how long the pressure is present. There are three categories defined: permanent, temporary and short-term (see Table 10).

Table 10: Definition of the parameter ‘persistence’.

Ranking of persistance	General remark / Explanation of ranking
General remarks	Impacts related to the operation of the wind farm are mainly permanent. During construction, most pressures are short-term. Impacts lasting the whole construction phase are considered as temporary.
Permanent	impact lasts for more than 5 years
Temporary	impact lasts for a period of 1 to 5 years
Short-term	impact lasts for a period of less than one year

4.5 Worst case assumptions

Since the turbine size and the layout of the Vesterhav Syd offshore wind farm depends on a number of factors e.g. environmental conditions such as ground texture and technical factors, e.g. wake loss and wind climates, the final layout has not yet been determined. Therefore, underwater noise levels considered in this report are based on a worst case assumption (see Table 11). Based on the worst case assumption a noise propagation model was prepared for installation of a single monopile foundation (NIRAS 2015) (see also Table 16 and Table 18). Since the preparation of the noise modelling report

Energinet.dk on behalf of the Danish Energy Agency and the Danish Nature Agency, established a working group for marine mammals and underwater noise. This working group has given recommendations on how to regulate underwater noise associated with the construction of Horns Rev 3 Offshore Wind Farm (Working Group, 2015). These recommendations have been related to the conditions at six Danish offshore wind farms including Vesterhav Syd offshore wind farm. The work includes an update of the worst case scenario so that it complies with the new recommendations (NIRAS, Rambøll, DHI, 2015)

Noise exposure within the construction-phase of either fewer monopile foundations with a greater amount of noise (10 MW turbines), or more monopile foundations with a smaller amount of noise during a single piling operation but with a longer construction phase, might lead to differences in the behavioural responses of marine mammals in the area.

Here the worst case assumption for underwater noise is considered to be a construction with 10 MW turbines. A scenario for a wind farm construction with about 66 3 MW turbines has not been modeled (see Layout, Figure 2), but will be discussed in context with the impact on marine mammals due to habitat changes.

Table 11: Listed parameters for the worst case assumption and noise modeling parameters. The foundation type is presumed to be a monopile.

Input parameters	Value
Turbine size	10 MW
Number of turbines	20
Monopile diameter	10 m
Hammer force	3,000 kJ
Source level ($SPL_{zero\text{-}peak}$ at 1 m)	244.7 dB re 1 µPa
Source level (SEL at 1m)	221.6 dB re 1 µPa s
Strike interval	1 strike pr. 2 sec. (30 strikes per minute)
Total number of strikes for cumulative modelling	1,800 strikes (per hour) = 32.6 dB increase
Number of foundations installed at any one time	1

4.6 0-alternative

In order to apply an impact assessment a common base for comparison is necessary. The impact assessment has to be compared with the 0-alternative, which is defined as the case whereby the wind farm is not established.

If the project is not realised, there will be no environmental impacts either offshore or onshore. The offshore area will remain unaffected, and the existing stations on land will operate with the present environmental impact.

5 CONSERVATION

5.1 Conservation status of marine mammals

Since marine mammals are one of the most important top-predators in the marine environment they are listed in different conventions aiming to protect populations and their living environment (see Table 12). Three action plans have been prepared by the Danish Ministry of Environment in order to implement the international regulations for the protection of harbour porpoises (e.g. Miljøministeriet Skov og Naturstyrelsen 2005). The main focus of these plans is on regulations on bycatch in fisheries, health status research, abundance and habitat use.

Table 12: Conservation status of marine mammal species occurring in the Vesterhav Syd area (specific status of the Baltic Sea is excluded). Status according to the different agreements is listed (IUCN 2014).

Species protected by	**Harbour porpoise** (*Phocoena phocoena*)	**Harbour seal** (*Phoca vitulina*)	**Grey seal** (*Halichoerus grypus*)
IUCN red list*	Least concern (LC)	Least concern (LC)	Least concern (LC)
CITES	Annex II, IV	_	
EU-Habitat-Directive (92/43/EEC)	Annex II, IV	Annex II, V	Annex II, V
Bern Convention	Annex II	Annex III	Annex III
Bonn Convention	Annex II	Annex II	Annex II (Baltic Sea Populations)
ASCOBANS	included	included	
OSPAR	included (Region II, III)		
TWSC		included	included

5.2 Natura 2000 sites

One Natura 2000 “Site of Community Interest” (SCI) is situated in the north of the planned wind farm site Vesterhav Syd within the potential impact area of cumulative noise: “Sandbanker ud for Thorsminde” (DK00VA341) (Eunis 2014) (a) (Figure 9). Although the SCI has listed the harbour porpoise in the standard data form as “Species referred to in Article 4 of Directive 2009/147/EC and listed in Annex II, V of Directive 92/43/EEC” (European Economic Community 2007), it is not a conservation objectives of the area (site assessment category D).

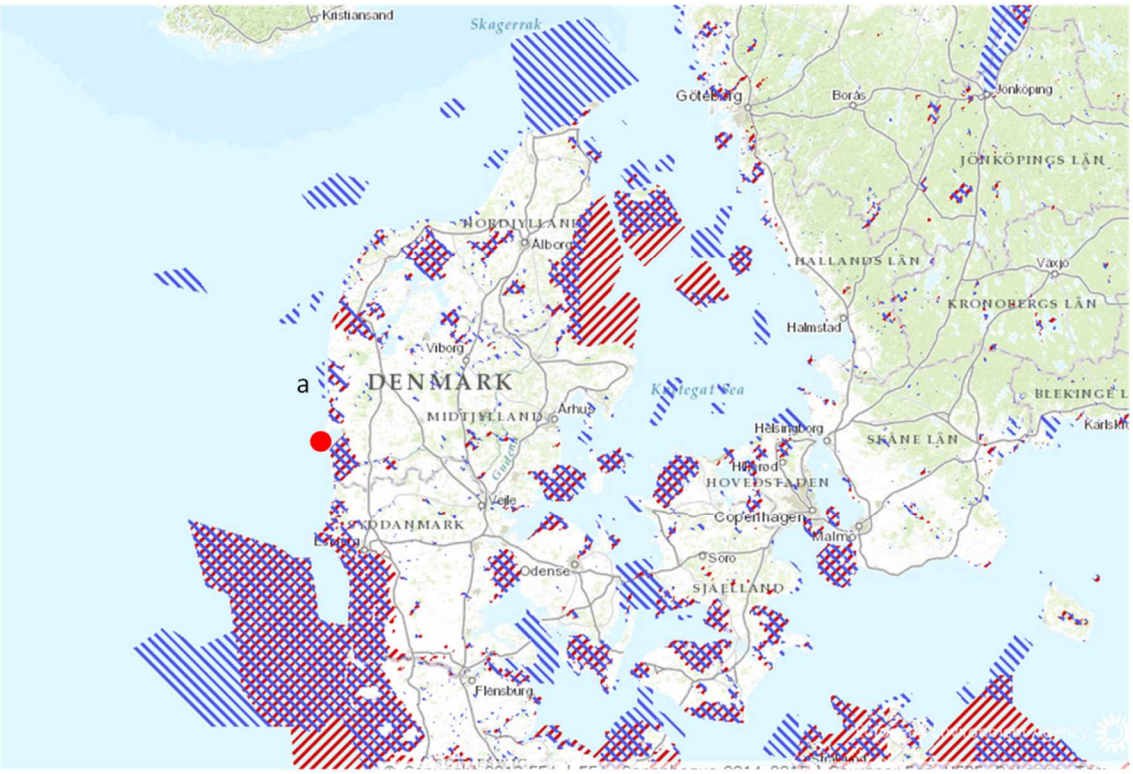


Figure 9: All Natura 2000 sites. Habitat Directive Sites (SCI) are marked in blue, Birds Directive Sites (SPA) are marked in red. The area of Vesterhav Syd is marked with a red spot (Source: http://natura2000.eea.europa.eu/).

The closest Natura 2000 areas to Vesterhav Syd where marine mammals defined as conservation objectives are the SCI's DK00VA347 "Southern North Sea" (A) and DK00AY176 "Wadden Sea" (B) (Eunis 2014) which are situated about 60 km south of the wind farm site (Figure 10). Seals as well as porpoises are specified as conservation targets in both Natura 2000 areas. The conservation of harbour seals and their haul-out sites is a protective target of the SCI DK00EY133 "Agger Tange, Nissum Bredning, Skibsted Fjord & Agerø" (C) which is located in the western Limfjord about 60 km north of Vesterhav Syd.

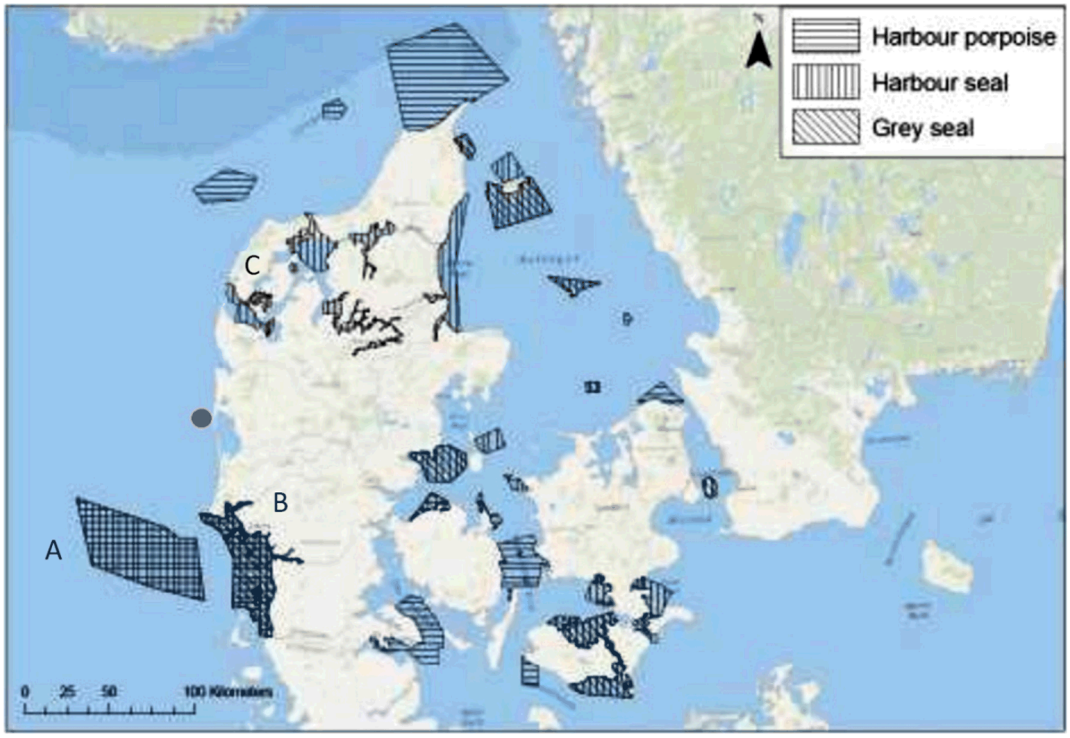


Figure 10: Natura 2000 sites where marine mammals are part of the conservation objective. The area of Vesterhav Syd is marked with a red spot (Source: DEA 2013).

5.3 Species protection

The North Sea population is also listed, together with the populations of the Baltic Sea, western North Atlantic, Black Sea and North West Africa, in Appendix II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS). Furthermore, the harbour porpoise is listed in Annex IV of the Habitats Directive and is thus subject to an assessment of strictly protected species in relation to Article 12 of the Directive.

For the Vesterhav Syd project the prohibitions expressed in Article 12 (1) of the Council Directive 92/43/EEC on the protection of species are relevant. Article 12 (1) states that Member States shall take the requisite measures to establish a system of strict protection for the animal species listed in Annex IV 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) deliberate destruction or taking of eggs from the wild;

(d) deterioration or destruction of breeding sites or resting places.

As harbour porpoises do not have definable breeding and resting sites the obligations under (c) and (d) are not applicable for the species.

6 EXISTING CONDITIONS

This chapter contains background information on the three resident marine mammal species, harbour seal, grey seal and harbour porpoise. Furthermore, it presents the results of our study as well as additional knowledge relevant to marine mammals impact assessment in the Vesterhav Syd area.

6.1 Biology of harbour porpoises

Harbour porpoises (*Phocoena phocoena*) are Europe's smallest toothed whales. At an average weight of 60 kg females reaches a length of about 160 cm. Males are smaller than females with an average length of 145 cm and weighing about 50 kg (Bjørge & Tolley 2009). With an average lifetime of 8-10 years and a maximum of 20 years (Benke et al. 1998, Bjørge & Tolley 2009), their lifespan is short compared to other toothed whales.

Harbour porpoises reach their sexual maturity at an age of 3-4 years. At the age of 5 (males) and 7 years (females) the animals are fully grown. After a 10.5 months pregnancy they can give birth to one calf per year. The breeding season varies regionally, but in most areas calving takes place from late May to August (Bjørge & Tolley 2009). In Denmark calving mostly occur in July (Sørensen & Kinze 1994). Species specific breeding grounds in Danish waters are unknown. Some breeding "hotspots" in the Baltic Sea are assumed on the basis of calf sightings (Loos et al. 2010). In the neighbouring German North Sea, foraging hotspots are known in the area of Borkum Reef Ground and Sylt Outer Reef (Gilles et al. 2009). Harbour porpoises predominantly occur singly or in small groups of 1-2 individuals, e.g. mother-calf pairs, but larger groups of 6-8 animals are not unusual (Bjørge & Tolley 2009). The average group size in German waters was determined to be between 1.17 and 1.8 (Scheidat et al. 2004, Siebert et al. 2006, Robinson et al. 2011, Teilmann & Carstensen 2012).

6.1.1 Feeding ecology and foraging behavior

Harbour porpoises are known to feed on a relatively broad spectrum of prey. They mainly feed on small and medium sized pelagic fish as well as on demersal and benthic fish species (Santos & Pierce 2003, Benke et al. 1998). Major prey species such as sandeel, gobies, cod and herring have been shown to be important prey in the North Sea and in the Baltic Sea (Gilles et al. 2008, Sveegaard et al. 2011a). Prey composition can vary regionally and seasonally and interannual differences have also been demonstrated (Gilles et al. 2008). Recent studies show that abundance and distribution of harbour porpoises can be closely linked to migration and abundance of their prey (Sveegaard et al. 2011a, 2012).

6.1.2 Echolocation and hearing

The harbour porpoise relies heavily on its acute sense of hearing underwater (Andersen 1970, Kastelein et al. 2002) and the ability to use ultrasonic sounds (echolocation) for both spatial orientation and navigation underwater (Verfuß et al. 2005) as well as for finding prey (DeRuiter et al. 2009, Miller & Wahlberg 2013). The hearing abilities of the harbour porpoise were first investigated by Andersen (1970) and since then have been (re-)evaluated through a number of studies using either behavioural response paradigms (Kastelein et al. 2002, 2010) or auditory evoked potentials (Lucke et al. 2008, 2009). The results indicate that the audiogram of the harbour porpoise has one of the widest bandwidths of any animal (Miller & Wahlberg 2013). However, the audiograms show large differences in frequency range and hearing thresholds of harbour porpoises which may not be caused by methodological differences

alone but also by individual differences in hearing ability, motivation, sensitivity and tolerance towards sound (Figure 11). In more detail, the behavioural audiograms showed that harbour porpoises have their best hearing ability (defined as the range up to 10 dB above the highest sensitivity) between 16 and 140 kHz with a hearing threshold of approximately 40 – 60 dB re 1µPa (Kastelein et al. 2002) at frequencies between 100 - 140 kHz. This coincides with the frequency range in which harbour porpoises produce ultrasound signals for echolocation (Kastelein et al. 1999). However, porpoises can also hear frequencies below 10 kHz (tested down to 250 Hz) with a gradual drop off in sensitivity of approximately 10 dB per octave (Kastelein et al. 2002), albeit newer data suggest better hearing capabilities between 2 and 10 kHz (Kastelein et al. 2010). Above 140 kHz sensitivity has a very sharp drop off of approximately 260 dB per octave (Kastelein et al. 2002). Humans have a hearing sensitivity in water of around 67 dB re 1µPa and the highest sensitivity of around 0.4 to 1 kHz (Nedwell et al. 2007b). Our normal hearing activity at air which is best at 3.4 to 4 kHz and the hearing threshold here is -5 dB re 20µPa. However, underwater acoustics and normal acoustic at air are difficult to compare as both media differ considerable which is already visible in the reference system to measure dB (1µPa vs 10µPa).

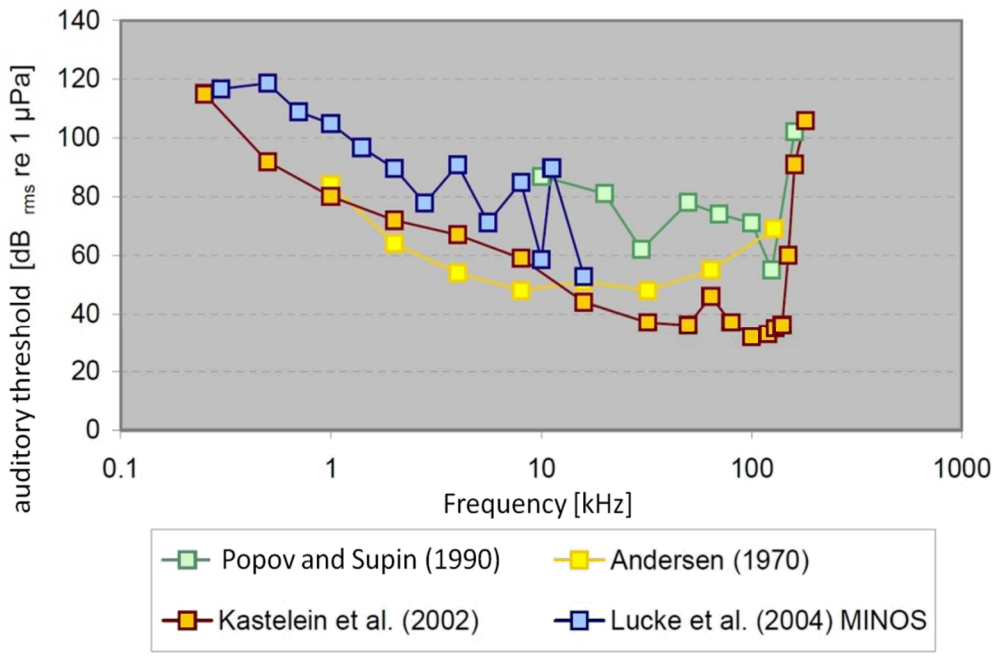


Figure 11: Audiograms of harbour porpoises according to various studies (Source: Lucke et al. 2004)

6.2 Biology of harbour seals

Harbour seals (*Phoca vitulina*) are distributed from the east Atlantic to the north Pacific (King 1983).They are the most widely distributed seal in the world. Size and weight varies among populations. Total length and body mass of full grown animals of the Dutch North Sea has been reviewed by Reijnders (1992). According to Reijnders, harbour seal males grow up to a size between 150 and 175 cm with a body mass of approximately 100 kg. Females reach a size between 130 and 155 cm at approx. 80 kg. Within a maximum life span of 35 years females reach their physical fecundity at an age of 6-7 years. Fecundity of males occurs a little later at an age between 7-9 years. Depending on popula-

tion and region moulting takes place within 2-3 months from mid summer to early autumn (Burns 2009). The main breeding season in Denmark is from the end of May to the end of June (Olsen et al. 2010). After a period of 10.5 months from fertilization to birth, including a 2.5 month of embryonic diapause, females give birth to a single pup (rarely twins) (Burns 2009). Unlike grey seal pups, they lose their embryonic fur (lanugo) during parturition. This allows the newborn pups to swim almost immediately after birth. Breeding, moulting and weaning take place on haul-out areas on sandbanks and inshore coastal areas. During these periods, therefore, harbour seals spend more time resting on land than during the rest of the year. Because of this, harbour seals are more sensitive to disturbances in the period from June to September.

6.2.1 Feeding ecology and foraging behavior

Harbour seals are opportunistic in prey selection. As shown in different studies, prey varies depending on season and location. It has been shown that foraging strategies and prey preference can be linked to prey abundance (Tollit et al. 1998). As haul-out areas are important for resting, moulting, mating and birthing, harbour seals predominantly forage close to haul-out and near shore areas (e.g. Liebsch 2006, Herr et al. 2009c, McConnell et al. 2012). Despite that, individual seals travel over long distances (e.g. Dietz 2003, Adelung et al. 2004, Reijnders et al. 2005, Liebsch 2006, Cunningham et al. 2009). As shown in many different studies the prey spectrum is broad, but often a few fish species are dominant in the diet. In the Wadden Sea harbour seals predominantly feed on demersal, i.e. on various flatfish species (e.g. Gilles et al. 2008). Depending on location and season other species such as cod (*Gadus morhua*), whiting (*Merlangius merlangus*) and sandeel (*Ammodytes* sp.) are preferred as well (Brown & Pierce 1998, Brown et al. 2001, Thomsen 2009). There are no studies directly related to the Vesterhav Syd area, but harbour seals' diet in the area of the Limfjord has been analysed by Andersen et al. (2007). In the Limfjord area two haul-out sites have been studied, one on the west side with direct access to the North Sea (Nissum Bredning) and one more easterly in the more brackish area (Løgstør Bredning). In the period from June to July seal prey in Nissum Bredning consists mainly of eelpout (*Zoarthes viviparus*), sprat (*Sprattus sprattus*), black goby (*Gobius niger*) and lesser sandeel (*Ammodytes tobianus*). In Nissum Bredning plaice (*Pleuronectes platessa*), greater sandeel (*Hyperoplus lanceolatus*) and flounder (*Platichthys flesus*) were the dominant prey species. These facts strongly suggest that foraging behaviour and prey preferences is closely related to fish abundance in the vicinity of the seals haul-out site.

6.2.2 Senses

Unlike harbour porpoises, harbour seals' foraging and navigation is predominantly based on their tactile sense. Basically seals gain hydrodynamic information through specific sensory cells in their whiskers. With these whiskers the smallest movements in the water column can be detected accurately by seals (Dehnhardt 1998, 2001, Hanke et al. 2010). Despite that, pinnipeds have evolved an accurate sense of hearing underwater as well as in air. The ear is well adapted to amphibious living. A cavernous tissue in the middle ear enables the seal to cope with higher pressure while they are diving. In-air hearing of pinnipeds is assumed to work as well as in terrestrial mammals. The function of pinnipeds' hearing under water is still not completely understood. Because the outer ear canal is closed during diving, hearing through bone conduction is assumed (Hemilä et al. 2006, Kastelein et al. 2008).

The hearing ability of harbour seals has been investigated in different studies. Summarizing the results of these studies, harbour seals have an in-air hearing ability in a range between 1 and (30)50 kHz with

hearing thresholds of about 58 to 60 dB re 1 µPa (Møhl 1968, Terhune & Turnbull 1995, Kastak & Schusterman 1998, Kastelein et al. 2009b). Under water harbour seals can detect noise in a range between 0,075 kHz and 128 kHz (thresholds of 101.9 dB re 1 µPa to 125 dB re 1µPa). If the signal is loud enough, very high frequencies of about 180 kHz can be detected as well (Richardson et al. 1995). As important as the sensitivity of the whiskers is for a seal's foraging effort, its hearing and vocalization are just as important for mating and maternal bonding.

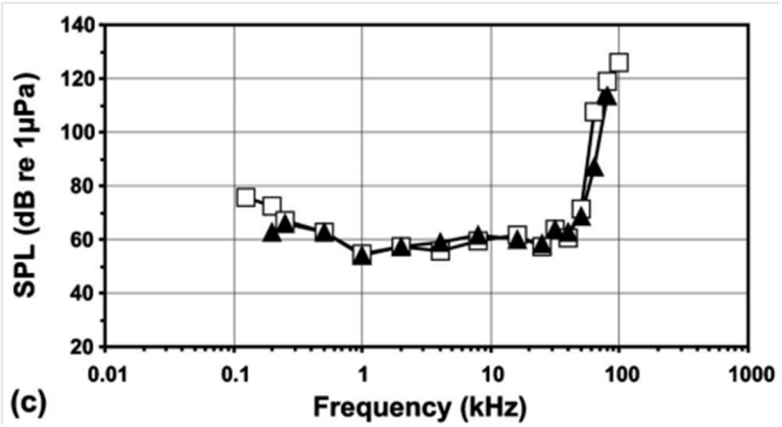


Figure 12: Audiograms of harbour seals, mean underwater hearing threshold for two animals for 1/3-octave noise bands (▲) and for tonal signals (□) (Source: Kastelein et al. 2009a, 2009b)

6.3 Biology of grey seals

The grey seal (*Halichoerus grypus*) is found along the eastern and western coasts of the North Atlantic Ocean. An isolated population exists in the Baltic Sea forming the *H. grypus macrorynchus* subspecies. It is a large seal of the family Phocidae ('true seals'). Adult males of the Eastern Atlantic population generally measure up to 2,5 m in length and weigh 170-310 kg, adult females measuring up to 2,1 m in length and weighing 100-190 kg (Hall & Thompson 2009). It is essentially distinguished from the harbour seal by its straight head profile, its less spotted coat and its size.

Females normally live up to 35 years of age, males up to 25 years. Females reach sexual maturity at 3-5 years, males around 6 years, attaining a 'socially mature' status some years later (Hall & Thompson 2009). The breeding season varies between populations. For North Sea grey seals it is usually autumn and winter while the Baltic population gives birth in February and March (Härkönen et al. 2007, Southall et al. 2007). Neither lactating females nor mature males feed during the breeding season. The breeding rookeries are usually on remote beaches and uninhabited islands.

Pups are born with a dense, creamy white fur which they moult after 2-4 weeks for a shorter adult-like coat. The pup is nursed for an average of 18 days, rapidly gaining weight. Towards the end of the nursing period the mother mates again. After the pup is weaned it stays some weeks at the rookery until it has fully moulted, living off its blubber reserves, and eventually goes to sea to feed on its own (Hall & Thompson 2009).

6.3.1 *Feeding ecology and foraging behavior*

Like harbour seals, grey seals are opportunistic feeders. They feed on a wide variety of fish, crustaceans and cephalopods. They feed primarily on demersal or benthic fish species. Seabirds and even harbour porpoises are also eaten occasionally (Haelters et al. 2012). Depending on season and location, differences in prey selection have been shown for grey seals as well (e.g. Bowen et al. 1993, Haelters et al. 2012). In most studies a broad spectrum of about 20-40 prey taxa consumed by grey seals have been revealed. But in almost all studies a small number of fish species dominate the samples. (Bowen & Harrison 1994, Hauksson & Bogason 1997, Hammond & Grellier 2006). Depending on season and location, sandeels (*Ammodytes* sp.), atlantic cod (*Gadus morhua*), saithe (*Pollachius virens*), flatfish including dab (*Limanda limanda*), flounder (*Platichthys flesus*) and plaice (*Pleuronectes platessa*), or herring (*Clupea harengus*) and capelin (*Mellotus villosus*) are important prey species (Bowen et al. 1993, Hall & Thompson 2009). Typically, grey seals hunt at the sea bed in relatively shallow waters, though dives of more than 300 m depth and diving times of up to 20 minutes have been recorded (Hall & Thompson 2009).

Grey seals can travel long distances between haul-out and feeding sites and the foraging trips can last up to 5 days. However, most animals range within a 40 km radius of the haul-out site, focused on discrete areas they prefer (Hall & Thompson 2009). The average daily food requirement is estimated to be 5 kg, though the seal does not feed every day and it fasts during the breeding season.

6.3.2 *Senses*

The most important sensory system for pinnipeds is their whiskers. Seals are able to detect fine underwater movements by highly sensitive sensory cells in their whiskers (Dehnhardt 1998, 2001, Schusterman et al. 2004, Hanke et al. 2010, Miersch et al. 2011).

Although touch by use of the whiskers is the most important sense in the context of foraging, hearing is likely to be important for communication. Under water grey seals use a complex repertoire of vocal sounds at frequencies of about 40 kHz (Schevill et al. 1963, Oliver 1978). These sounds produced by seals are used for intraspecific communication and avoidance of predators (Schusterman et al. 1970). In-air vocalization rarely takes place, except with pups and males uttering guttural sounds during fights (McCulloch et al. 1999). Therefore, it is likely that grey seals have evolved good hearing abilities underwater and on land. Only a few studies on the hearing sensitivities of grey seals are known (Ridgway & Joyce 1975, Sundermeyer 2006, Ruser et al. 2014) (Figure 13). The underwater hearing ability of grey seals has been described to be in a range of 1,4 kHz to 150 kHz (at 83 dB re 1 µPa to 148 dB re 1 µPa) with the highest sensitivity at 25 kHz (61 dB re 1 µPa) (Ridgway & Joyce 1975).

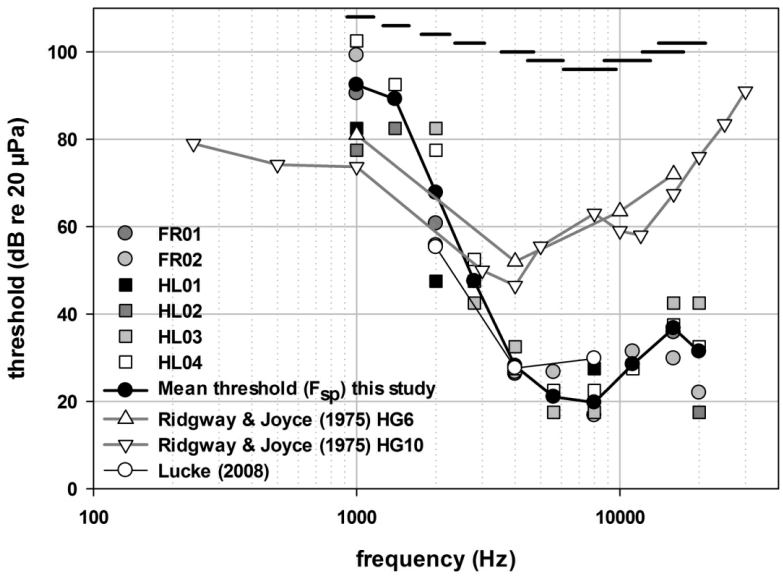


Figure 13: Audiograms of grey seals, measured in air (Source: Ruser et al. 2014).

6.4 Abundance and distribution of harbour porpoises

Harbour porpoises are distributed throughout coastal waters in the northern hemisphere (Reid et al. 2003). In Danish waters these small whales can be found throughout the year (e.g. Sveegaard et al. 2011b, Teilmann et al. 2013). In the North Sea they are the most abundant marine mammal and the only cetacean which is known to be breeding.

The first survey of the entire North Sea and adjacent waters was conducted in 1994. It was estimated that in total 341,366 (95 % confidence interval (CI) = 260,000–449,000) animals were present in the study area (Hammond et al. 2002). These surveys were repeated in 2005 whereby additional, previously not monitored, areas in the north western part of Ireland and Great Britain and coastal areas in southern France, Spain and Portugal were included. The total estimates yielded by this survey were 375,358 harbour porpoises, of which 323,968 (95 % CI = 256,300–549,700) individuals were within the area of previous surveys. However, the distribution has since changed. In 1994, animals congregated in the coastal waters of Scotland and Denmark while maintaining high concentrations in the central part of the North Sea (see Figure 14 left). In the more recent survey in 2005, animals congregated at the east coast of Great Britain and west of Cornwall and densities dropped around Denmark (see Figure 14 right).

In each report the west coast of Denmark represented a counting cluster. In 1994 it was estimated that 11,575 harbour porpoises were present in the area yielding a density of 0.555 ind./km². In 2005 11,870 individuals were thought to be at the west coast of Denmark resulting in a density of 0.635 ind./km².

Representing a distinct population in the Baltic, the population of harbour porpoise in inner Danish waters was estimated at approx. 18,500 animals in July 2012 (Hansen 2013).

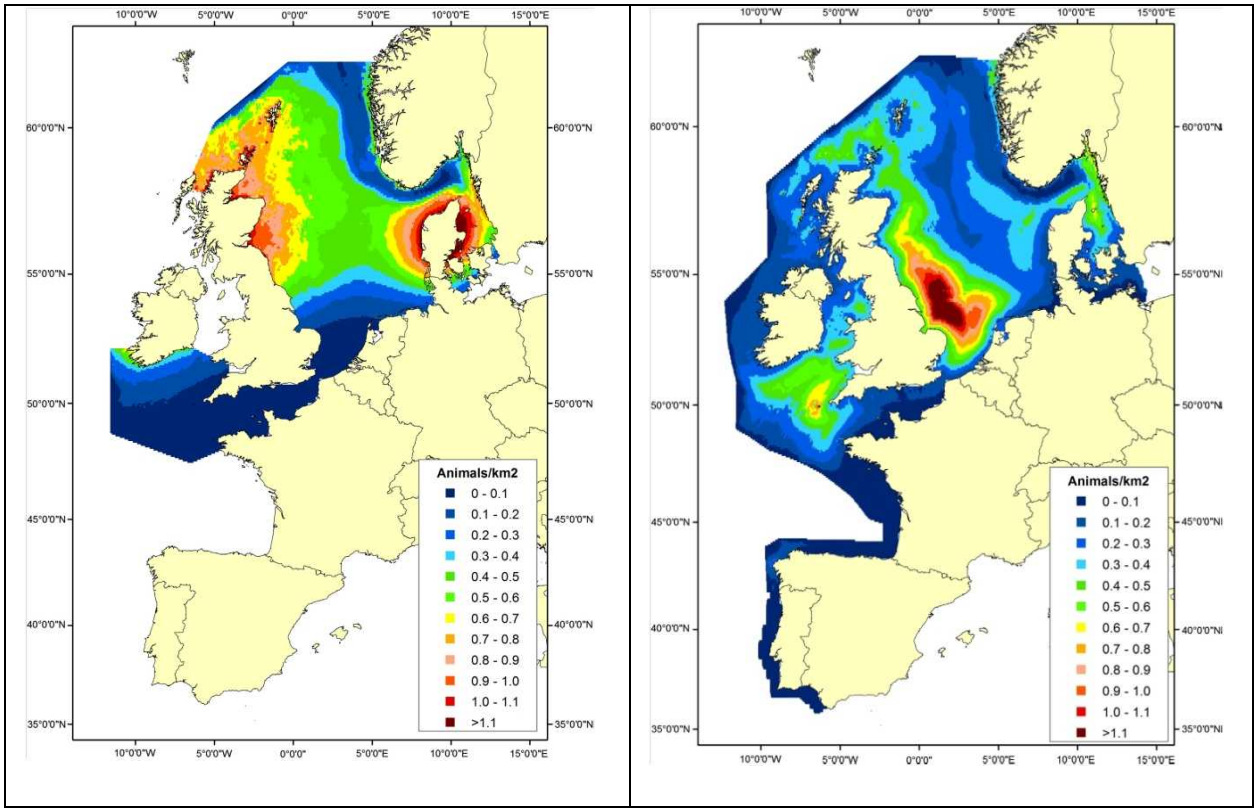


Figure 14: Distribution of harbour porpoises in the North Sea and adjacent areas according to SCAN-Survey 1994 (left) and 2005 (right) (Source: Hammond et al. 2013).

Teilmann et al. (2008) named 16 high density areas of harbour porpoises in Danish Waters. The Vesterhav Syd area is not part of one of them. Skagerrak in the north and Horns Rev / German Bight in the south are the closest high density areas to Vesterhav Syd. The southern area also stretch further south into German waters (Gilles et al. 2009) forming a larger high density area (see Figure 15) (Gilles et al. 2011). This area is also important for calving (Sonntag et al. 1999). Densities here are highest in spring / summer, especially in May / June during calving (Gilles et al. 2009). These findings are similar to those of surveys in the southern North Sea of Denmark (Teilmann et al. 2008).

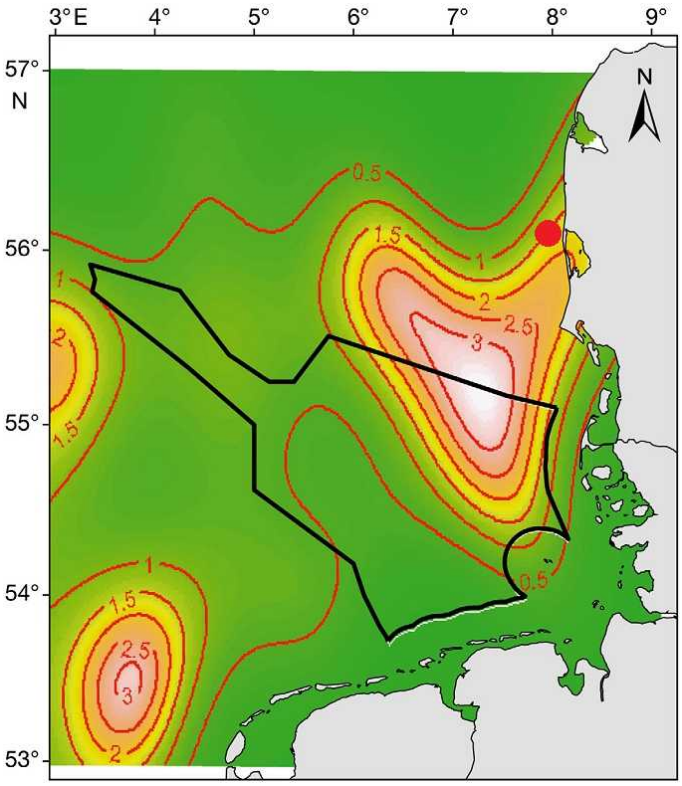


Figure 15: Modelled distribution of harbour porpoises in the German Bright and the Danish southern North Sea. The area of Vesterhav Syd is marked with a red spot. (Source: Gilles et al. (2011)).

Within the Danish North Sea EEZ, harbour porpoises are regularly surveyed in and around the Natura 2000 areas in the Skagerrak and south of Blåvands Huk (NOVANA programme, Figure 16). Both areas are highly frequented by porpoises. The results of the flight survey in July 2012 confirm the importance of the Danish southern North Sea as a calving ground and high density area, at least in summer (Figure 16 B)., (Hansen 2013).

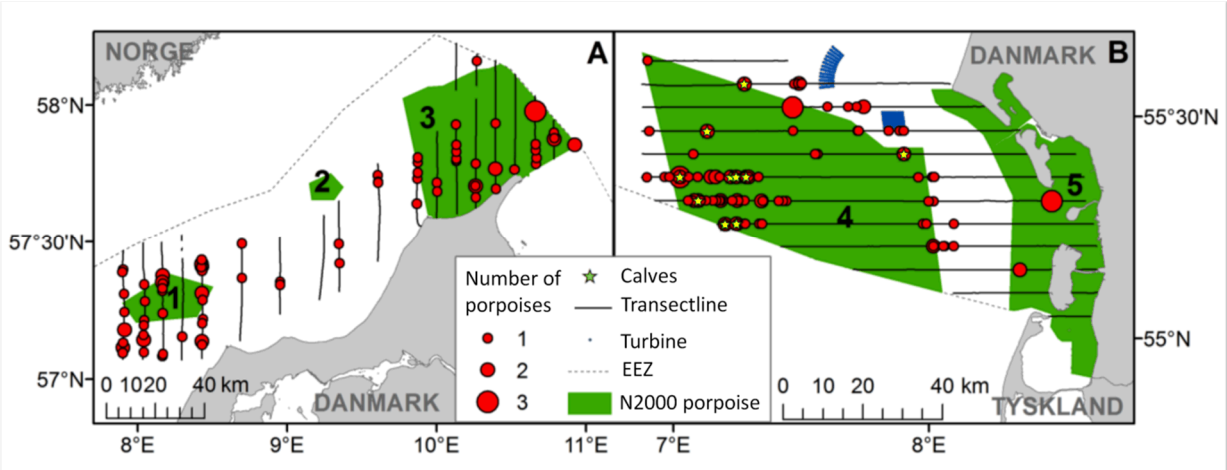


Figure 16: Aerial survey in the Skagerrak (A) and North Sea (B). Both flights conducted on 25. July 2012. Numbers indicate N2000 - areas: 1) Gule Rev, 2) Store Rev, 3) Skagens Gren and Skagerrak, 4) southern North Sea and 5) the Wadden Sea with Ribe Å, Tved Å and Varde Å west of Varde (Source: Hansen 2013).

Very recently (2013), surveys were conducted for the Horns Rev 3 wind farm. There, numbers peaked in August yielding a density of more than 6 porpoises per km² (Nehls et al. 2014). Densities were generally high with more than 2 individuals per km² from May to September and low during the winter months. Calves were seen most often in July. Up to 13 Calves were seen there during one flight, which represents 18 % of the animals present at this day.

6.4.1 Harbour porpoises in the Vesterhav Syd area

Aerial surveys

Overall, 221 harbour porpoises were sighted during the nine survey flights between November 2013 and July 2014. The determined densities ranged between 0.06 harbour porpoises per km² (25.11.2013) and 1.96 animals / km² (18.05.2014). The average density in the Vesterhav Syd investigation area was about 0.67 porpoises / km² during the nine month period. Above-average densities were found in February and May (Table 13).

Table 13: Density of harbour porpoises for each of the nine surveys (lower 95% confidence interval (LCI) and higher 95 % confidence interval (HCI) are given).

Date	Valid effort (km)	ESW	g(0)	Valid porpoise sightings	Mean group size	Density (ind./km²)	Density LCI	Density HCI	Population estimate
25.11.2013	958	0.130	0.26	2	1.00	0.06	0.05	0.07	58
03.02.2014	873	0.130	0.23	5	1.00	0.19	0.17	0.22	184
11.02.2014	985	0.130	0.23	37	1.14	1.44	1.27	1.63	1,371
11.03.2014	992	0.130	0.28	19	1.05	0.56	0.50	0.64	536
25.03.2014	732	0.130	0.28	6	1.00	0.23	0.20	0.26	218
16.04.2014	981	0.130	0.34	12	1.00	0.28	0.24	0.31	262
18.05.2014	957	0.175	0.28	81	1.15	1.96	1.72	2.25	1,865
11.06.2014	857	0.175	0.27	10	1.10	0.27	0.24	0.31	256
07.07.2014	973	0.175	0.27	26	1.12	0.63	0.55	0.71	594
total	**8,309**	**-**	**-**	**198**	**1.11**	**0.67**	0.59	0.76	**638**

Overall, the seasonal phenology at Vesterhav Syd fluctuates greatly and doesn't show a clear trend (Figure 17). After two clear peaks in February and May with high densities above 1.4 porpoises / km² average densities around 0.6 ind. / km² were found in early March and in July. The lowest densities were determined for the first two surveys in late November and early February. However, low densities below 0.3 porpoises / km² were also found in late March, in April and in June.

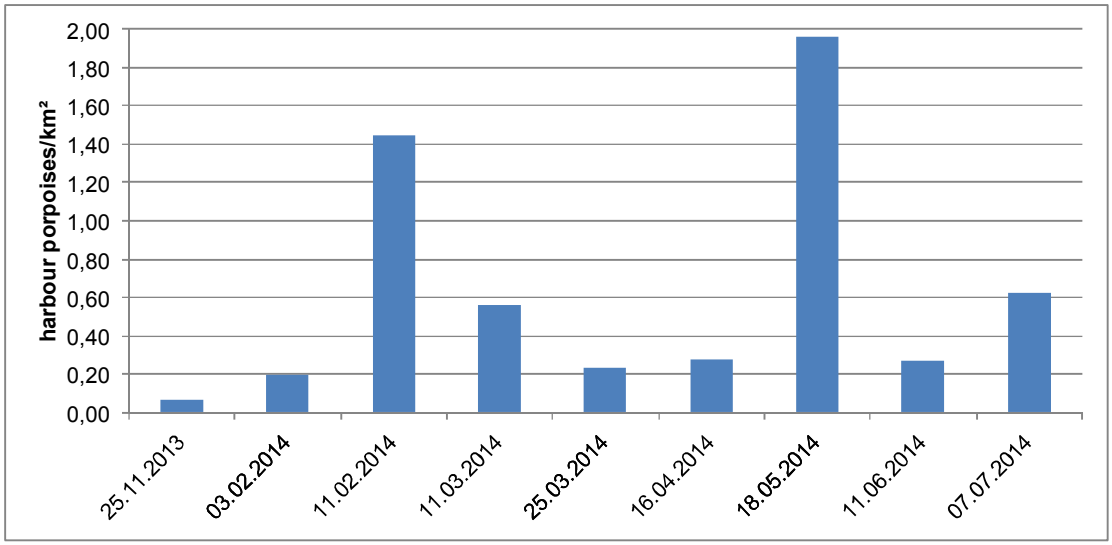


Figure 17: Density of harbour porpoises in the Vesterhav Syd investigation area during nine survey flights between November 2013 and July 2014.

Based on the determined densities, the estimated harbour porpoise population in the investigation area (950 km²) varies seasonally from 58 to 1,865, with an average of 638 animals (560 – 725 animals, 95 %-confidence interval).

Based on the whole investigation period the mean group size was small, comprising 1.11 porpoises per sighting. The strongest trend to swim in groups was observed in February and May when densities also were highest. Among the groups five mother-calf pairs were detected during the May and July surveys. The highest calf rate during a survey flight was about 9 % on 7 July. Including another three sightings of subadults in February and April, the calf rate for the whole investigation period was 3.6 %.

The distribution map combining all nine surveys shows a scattered pattern of porpoise presence over the whole investigation area (Figure 18). The overall impression is a tendency towards higher densities in the central eastern part of the area. The intended wind farm site partially belongs to this area (Figure 18). In the southeast and the northwest the investigation area shows a tendency towards lower densities. Coastal waters up to 5 km from land were generally seldom frequented by porpoises.

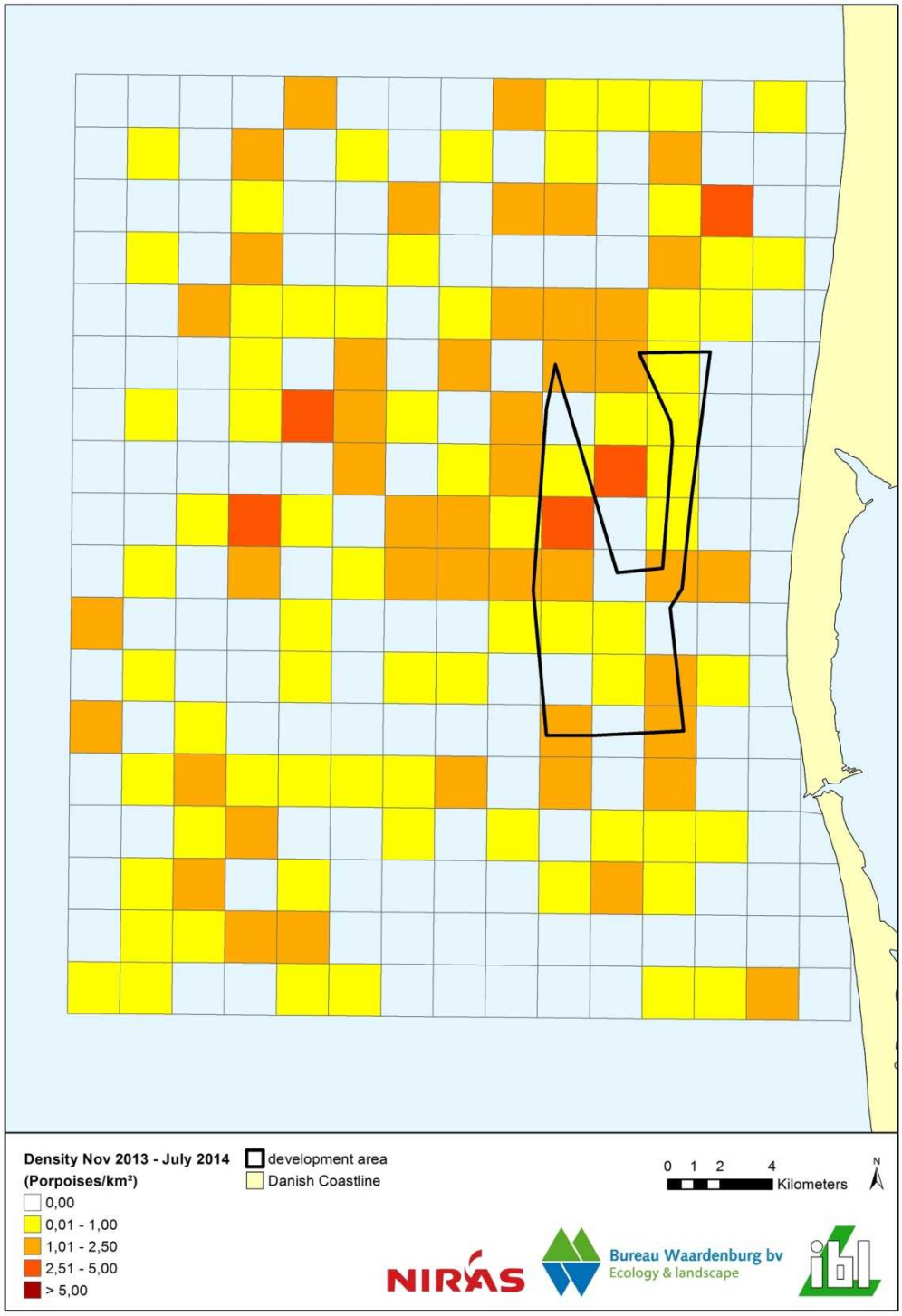


Figure 18: Density of harbour porpoises (n/km²) based on nine survey flights from November 2013 to July 2014 (2 x 2 km square grid).

Figure 19 shows the summarized distribution for three specific periods with three survey flights respectively. (In view of the lower number of sightings underlying the data, the grid size was doubled with respect to Figure 18 in order to 'smooth' the picture.) The combined survey results for the periods November to February, March / April and May to July do not reveal any substantial seasonal variation of

the porpoise distribution in the area. Harbour porpoises showed up in the vicinity of the intended wind farm during all seasons.

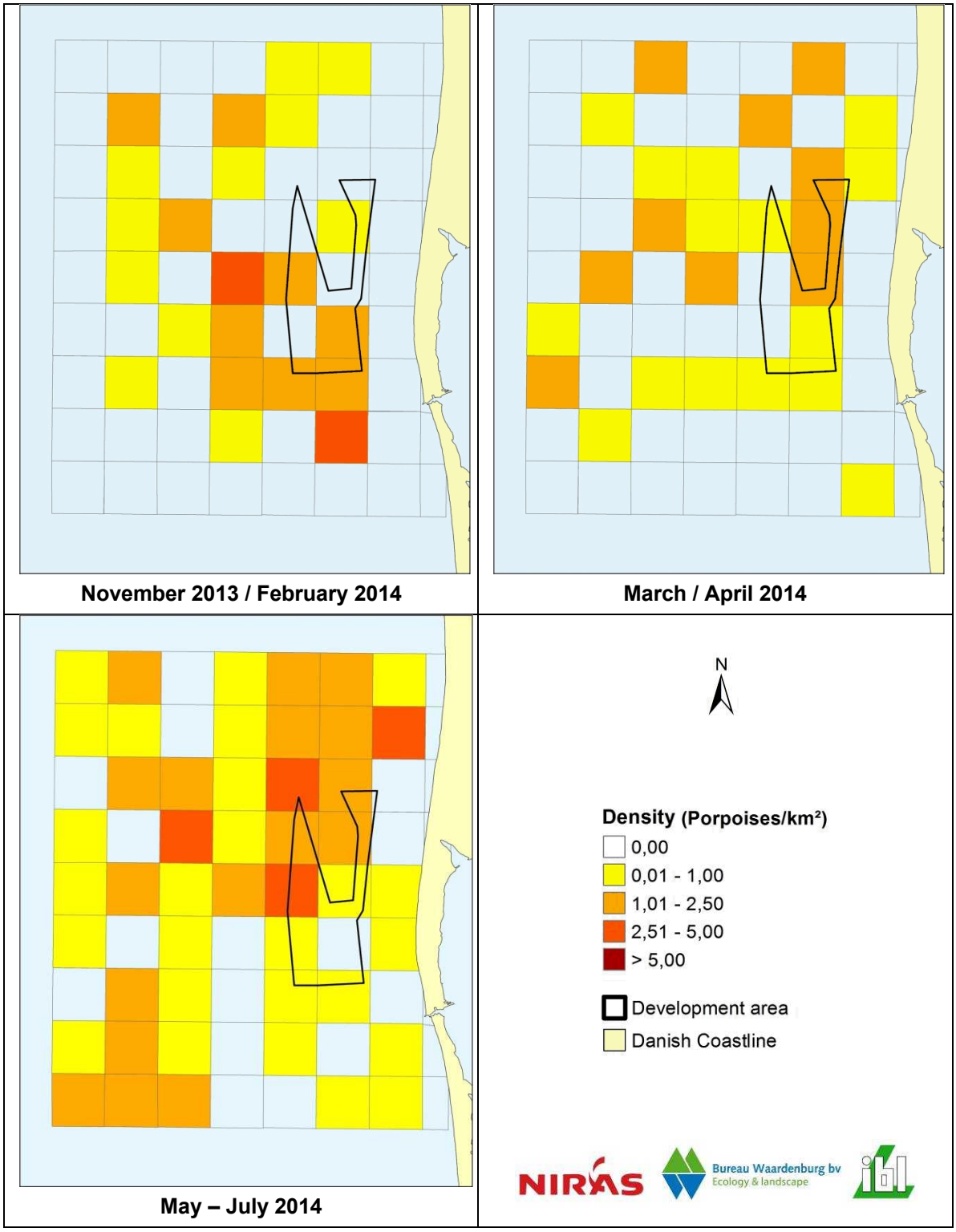


Figure 19: Density of harbour porpoises (n/km²) during the periods November - February, March/April and May – July, based on three survey flights in each case (4 x 4 km square grid).

In the coastal area the water depth increases up to more than 10 m within the first kilometers from the coastline. The distribution of the harbour porpoises reveals a tendency to prefer the 15-25 m depth range as shown by the calculation of densities in relation to depth categories (Figure 20). Average densities were found in the 25-30 m category and under-average densities in the <15 m and >30 m categories.

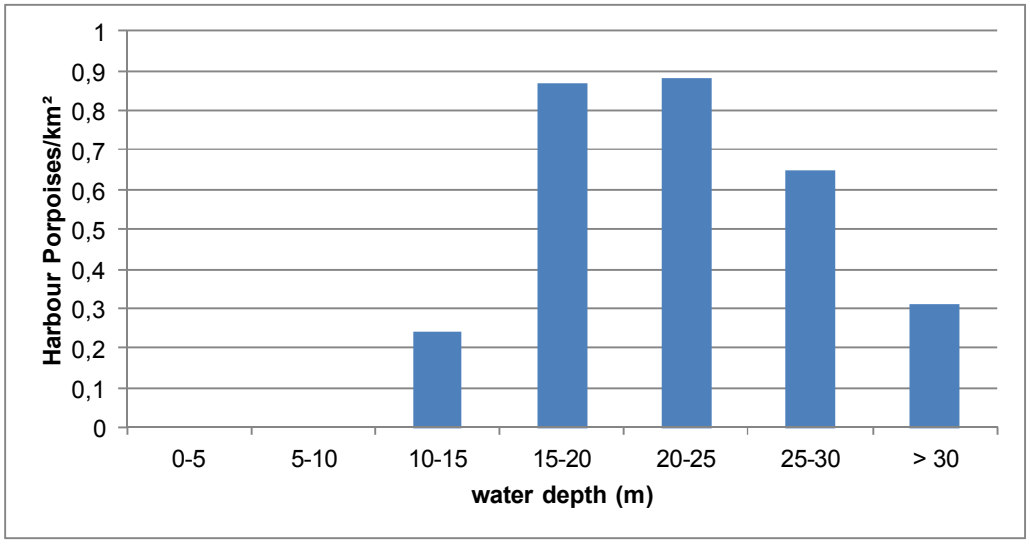


Figure 20: Density of harbour porpoises in relation to water depth (minimum water depth 1 m, maximum 32 m).

The lower porpoise density in the northwest and the southeast of the investigation area with larger and lower water depths respectively may also be related with the more intense ship traffic in these areas (Figure 21). In the German Bight below-average densities of harbour porpoises have been found along highly frequented ship traffic routes (Herr et al. 2009a).

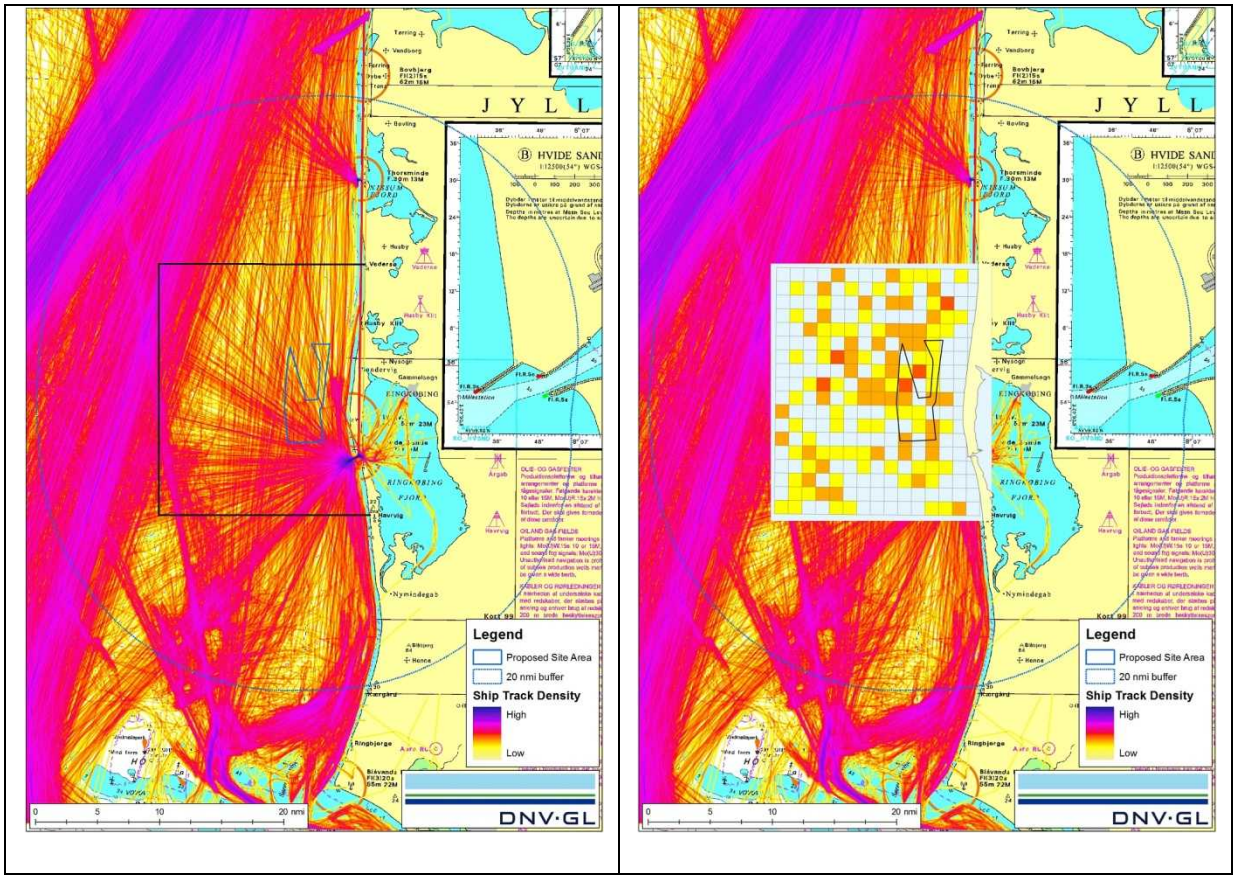


Figure 21: Density of harbour porpoises and density of ship traffic in the Vesterhav Syd investigation area (Source: Det Norske Veritas & KEMA Nederland B.V. 2015).

Passive acoustic monitoring

Data from passive acoustic monitoring is available between 10 December 2013 and 11 Ocotober 2014 for analysis (see chapter 4.2.1). Figure 22 illustrates the level of porpoise activity. Time intervals with too much background noise were excluded beforehand according to the above criteria (see chapter 4.2.2). Porpoises were continuously present at the POD-station throughout the entire study period, although single days without any porpoise detection occurred throughout the survey period.

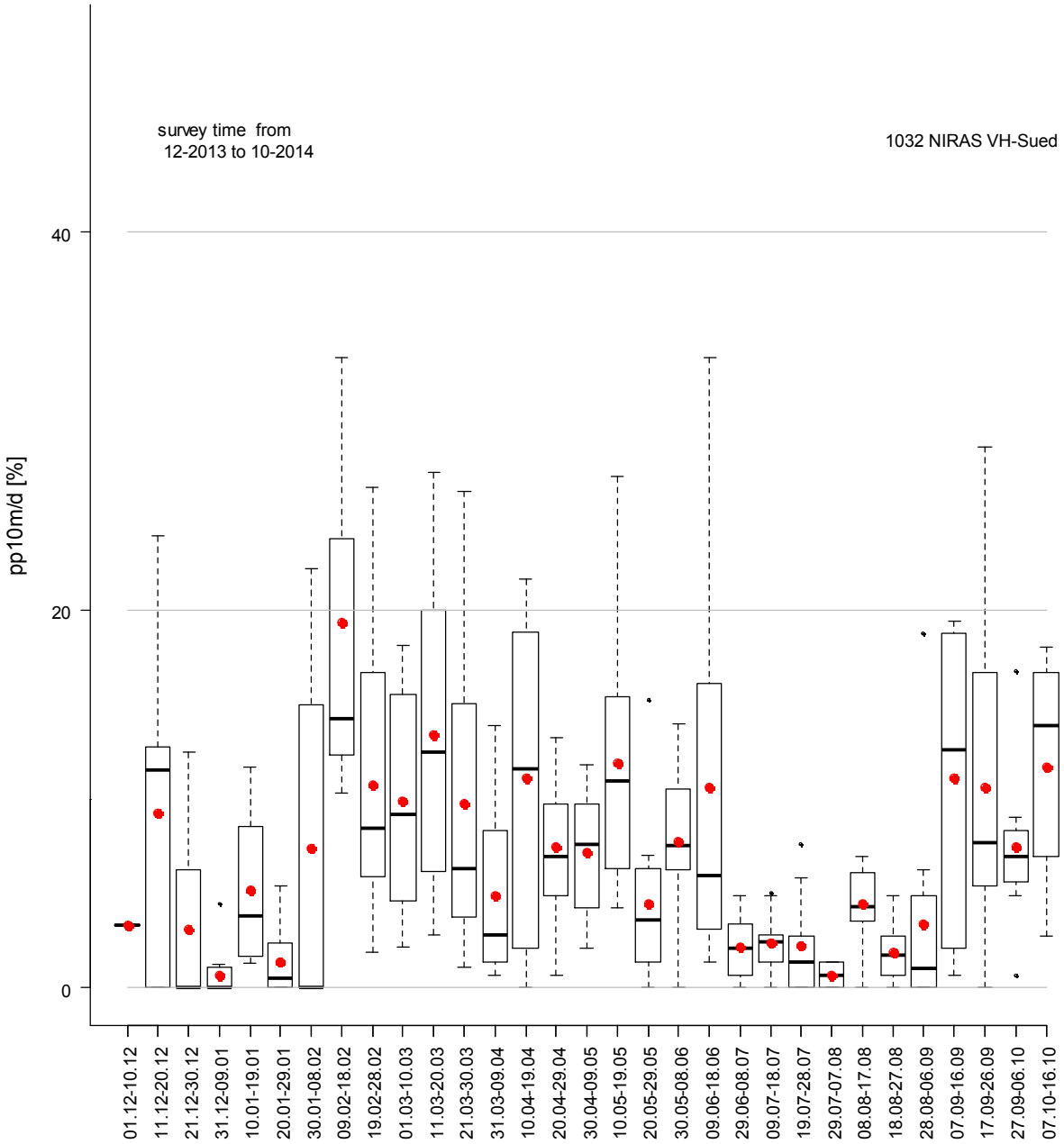


Figure 22: Averaged presence rate of harbour porpoises at the C-POD-station at Vesterhav Syd in the time between 10 December 2013 and 11 October 2014. No data available between 16 June and 2 July due to C-POD losses. (Presentation as box-whisker box: black line = median, the box contains the upper and lower first quartile of data, whisker contain data of up to 1.5 times the size of the first quartile, crosses represent outliers, red dot = mean, pp10m/d = porpoise positive 10 minutes/day (number of 10-minute-blocks with porpoise detection per day).

As an average over the entire study period 6.74 % of all analyzed 10-minutes-intervals contained detection of porpoises. A maximum of 33.3 % porpoise positive 10-minutes-intervals was recorded on 18 February 2014.

The phenology in the analyzed time span does not reveal a clear annual pattern, however, some fluctuation arises. Generally, around 10 % of all analyzed 10-minutes-intervals contained porpoise detections. Two time spans occurred where the porpoise activity was much lower. Those are from late December 2013 to early February 2014 and again more pronounced with less fluctuatin between early July and early September. During this time less than 5 % of all analyzed 10-minutes-intervals contained porpoise detections. During the rest of the time porpoise activity was considerably higher. Porpoise activity of more than 20 % of all analyzed 10-minutes-intervals occurred regularly but not often.

The porpoise densities detected during flight surveys were compared with concurrent C-POD recordings. Initially only data from the same date were used. No significant effect was detected (linear regression, $p = 0.422$, adjusted $r^2 = -0.038$) (see Figure 23 left). This demonstrates that the techniques are not directly comparable. The C-PODs only record porpoises within a distance of maximally 300 m. In contrast, the flight survey covers an area of 950 km². The average porpoise activity of 5 days (day of flight ± 2 days) was then calculated as it was suspected that this value could be a better approximation of the general porpoise activity during the entire time span. Results then are very similar (linear regression, $p = 0.325$, adjusted $r^2 = -0.021$) (see Figure 23 right). As mentioned, the spatial scale monitored by the two techniques is very different. Furthermore, both techniques have limitations which can lead to different results. During survey flights only porpoises at the surface or in water depths up to 2 m can be recorded. If for example during that time more animals than usual are hunting below 2 m, they cannot be seen and the availability factor is overestimated, but porpoises show more acoustic activity and are more likely to be detected at the POD-station. The reverse could be true if porpoises are resting on the surface. Then they are very likely to be seen and could show low acoustic activity.

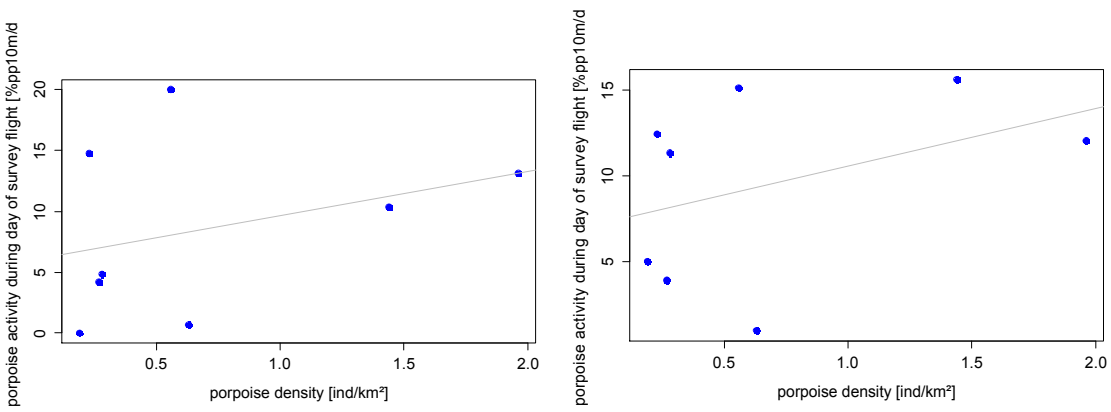


Figure 23: Correlation between porpoise density recorded during the survey flights and recorded acoustic porpoise activity during the same day (left) and during a five day period around the flight date (right).

Porpoises were recorded during the night as well as during the day. The activity levels varied greatly between days. Normally the porpoise positive minutes / day (in percentage) was analyzed. But here data were analyzed not over the day but for each of the 144 10-minutes time intervals of a day (see Figure 24). The analysis refers to local winter time as then 12 o' clock fits roughly with the highest position of the sun during the day. When fitting a smoothing curve it is evident that activity on average is lowest between 11 PM and 3 AM. It then increases relatively rapidly until 6 AM and stays on an elevat-

ed level until it decreases slowly in the afternoon. Analyzing data with increasing interval to midnight, the activity increases significantly (linear regression, $p < 0.001$, adjusted $r^2 = 0.211$).

This is in contrast to Brandt et al. (2014) or Todd et al. (2009). Both authors studied diel rhythm of porpoises at artificial structures such as bridges or platforms and in both cases the activity during the night was more intensive than the activity during the day. They linked this to better foraging opportunities during the night at artificial reef like structures. This indicates that porpoises use different prey here which of course could change after the erection of wind turbines and the installation of structures resembling artificial reefs. Nehls et al. (2014) found different diel rhythms within the Horns Rev area. In the eastern part, they found a slight tendency to increased activity during the day in line with our results. In the western area, porpoises showed an intense night activity during one part of the year, which could be connected to high numbers of sandeels present only in this area.

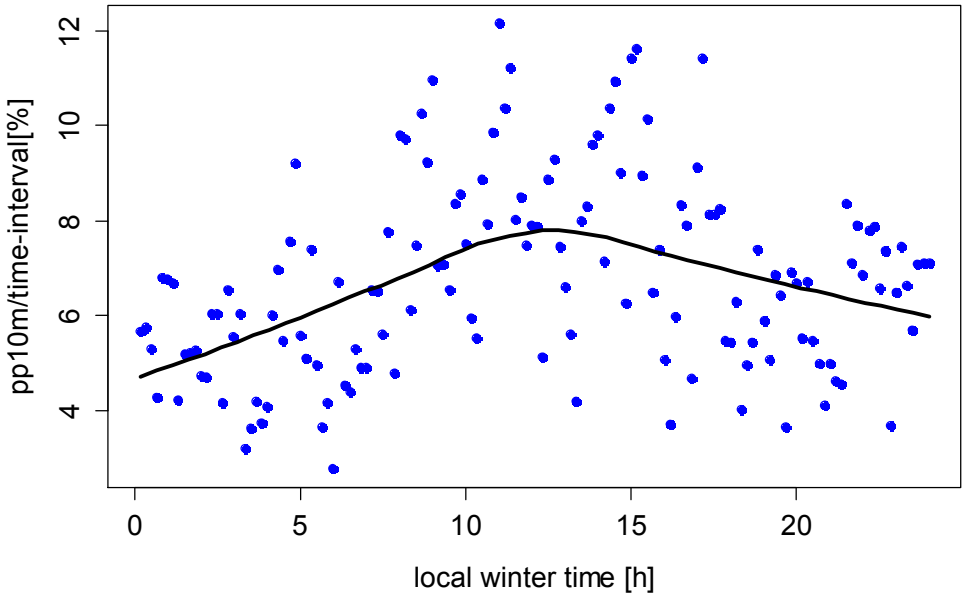


Figure 24: Porpoise activity during the day. Each blue dot represents the average porpoise activity at one single 10-minute-interval from all 144 10-minutes intervals of a day. A smoothed curve was fitted (black line).

6.4.2 *Abundance and distribution in the Vesterhav Syd area according to other studies*

For the Vesterhav Syd offshore wind farm site and its closer vicinity hardly any information on abundance and distribution of marine mammals is available from other studies. Referring to the wider surroundings, Teilmann et al. (2008) published the distribution in the Danish North Sea and found accumulations mainly in the area of Horns Rev (Figure 26, Figure 27) and north of Jutland (between Hanstholm and Skagen; Figure 28).

Especially for the Horns Rev area the occurrence of marine mammals is well known due to wind farm related survey programs. Very recently such investigations have been performed in 2013 and 2014 for

the planned wind farm Horns Rev 3. The wind farm site is located west of Blåvands Huk, around 45 km south of Vesterhav Syd. Compared to the Horns Rev 3 results from 10 survey flights between January and November 2013 (Nehls et al. 2014), the Vesterhav Syd porpoise densities are relatively low, especially in summer. However, at Vesterhav Syd no survey flights have been conducted in August and September when densities at Horns Rev 3 were highest.

Figure 25 shows the mean density for each flight in the Horns Rev 3 investigation area. The abundance exceeded 2 animals / km² during four of five flights between May and September. The maximum of 6.4 porpoises / km² reached in August is more than three times higher than the maximum density found at Vesterhav Syd.

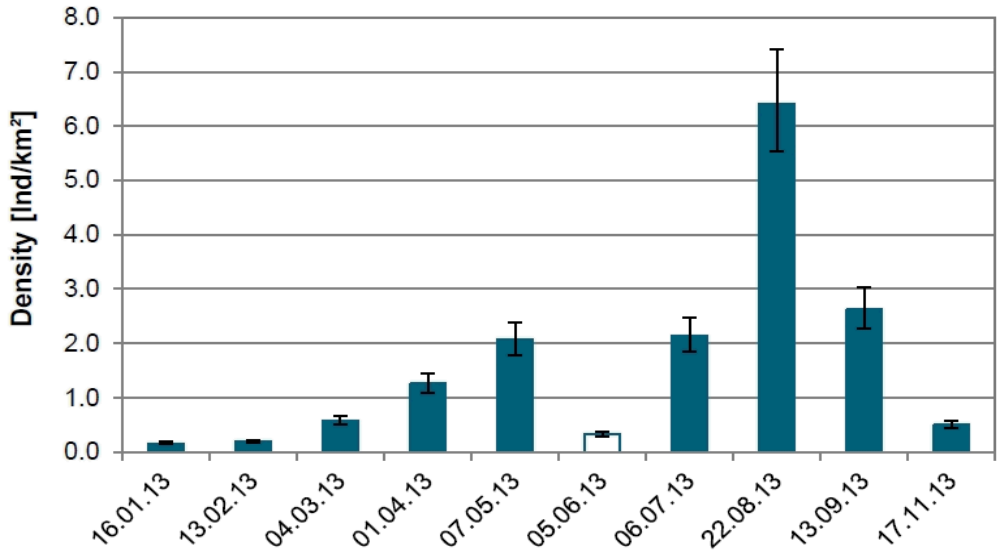


Figure 25: Harbour porpoise density in the Horns Rev 3 investigation area during 10 flight surveys in 2013 (Source: (Nehls et al. 2014).

Teilmann et al. (2008) also reported high densities at Horns Rev (Figure 26). This area obviously stretches along the German EEZ border and until a distance of around 100 km in front of the coast (Figure 27). The Danish southern North Sea probably forms a high density area together with areas west of northern Frisia. This corresponds to the modelled distribution prepared by Gilles et al. (2011) (see Figure 15).

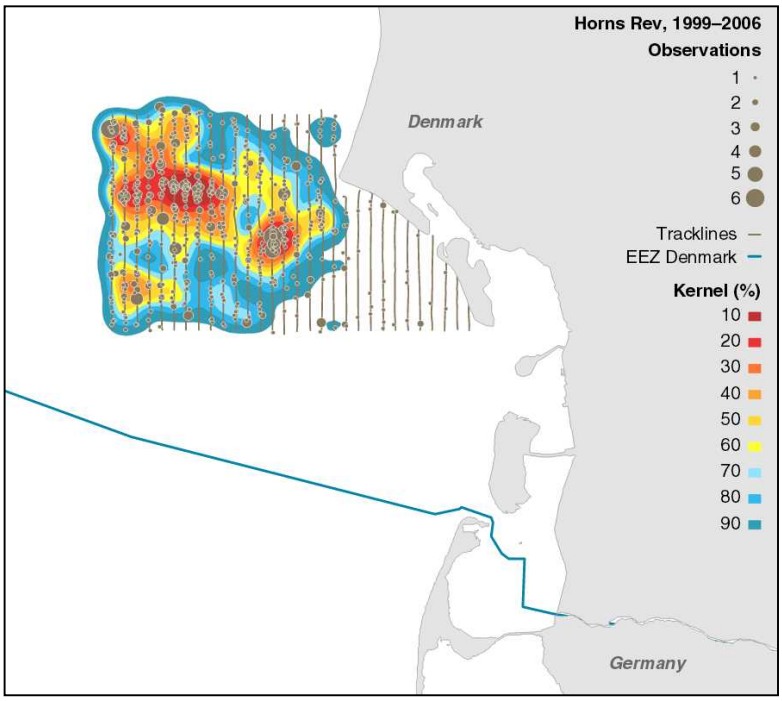


Figure 26: Distribution of harbour porpoises in the Horns Rev area during 33 aerial surveys from 1999 to 2005 (all months are covered). (Source: Teilmann et al. (2008)).

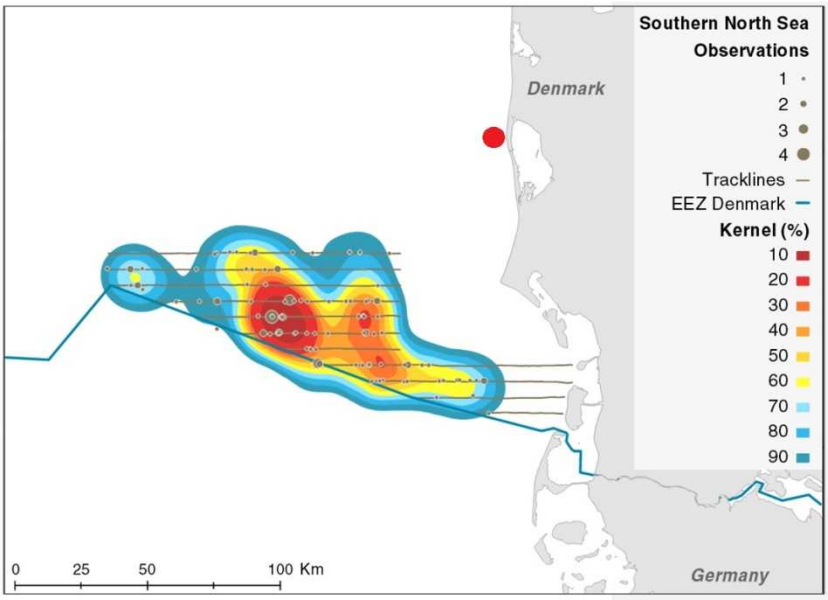


Figure 27: Distribution of harbour porpoises in the Southern North Sea (corresponding the Natura 2000 site "Sydlige Nordsø") close to the German border during three aerial surveys between February and May 2003. The area of Vesterhav Syd is marked with a red spot. (Source: Teilmann et al. (2008)).

Other areas where harbour porpoises accumulate are located north of Jutland. Survey flights there were performed only occasionally. Results here suggest that the high density area does not stretch further south along the west coast of Denmark (Figure 28).

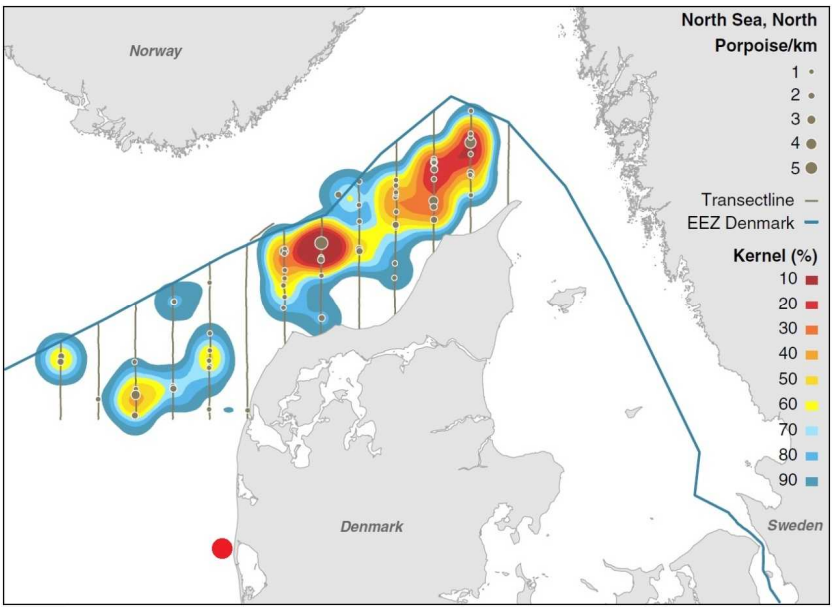


Figure 28: Distribution of harbour porpoises in the Skagerrak area and the Northern North Sea during three aerial surveys in autumn 2006 and 2007 (August to October). High density areas correspond more or less the Natura 2000 site “Skagens Gren og Skagerak”. The area of Vesterhav Syd is marked with a red spot. (Source: Teilmann et al. (2008)).

Additionally to the data from survey flights, information on the more northerly areas is available from a logger study. Sveegaard et al. (2011b) tagged 64 harbour porpoises in inner Danish waters and in the Skagerrak area. This sample comprised members of two subpopulations from the Danish North Sea and from the inner Danish Waters (Andersen et al. 2001). The animals marked in the inner Danish Waters only rarely reached the North Sea (see Figure 29). In contrast, animals tagged in the Skagerrak area were found regularly in the North Sea. They were found predominantly in the northern North Sea and hardly ever south of Horns Rev, although this is an important area for porpoises (see above). Those animals also seldomly reached the area of Vesterhav Syd. Porpoises here are probably connected to the Horns Rev high density area but the home range of porpoises in that region was not yet investigated in a tagging study.

Tagged animals from the study of Sveegaard et al. (2011a) revealed a high density area that is located north of Jutland (which is in line with results from Teilmann et al. 2008), stretching further offshore along the Norwegian coast. Sveegaard et al. (2011a) showed that recorded positions of tagged animals are a reliable source to determine high density areas for porpoises. However, animals from other sites have to be tagged as well in order to determine important areas for harbour porpoises in the North Sea.

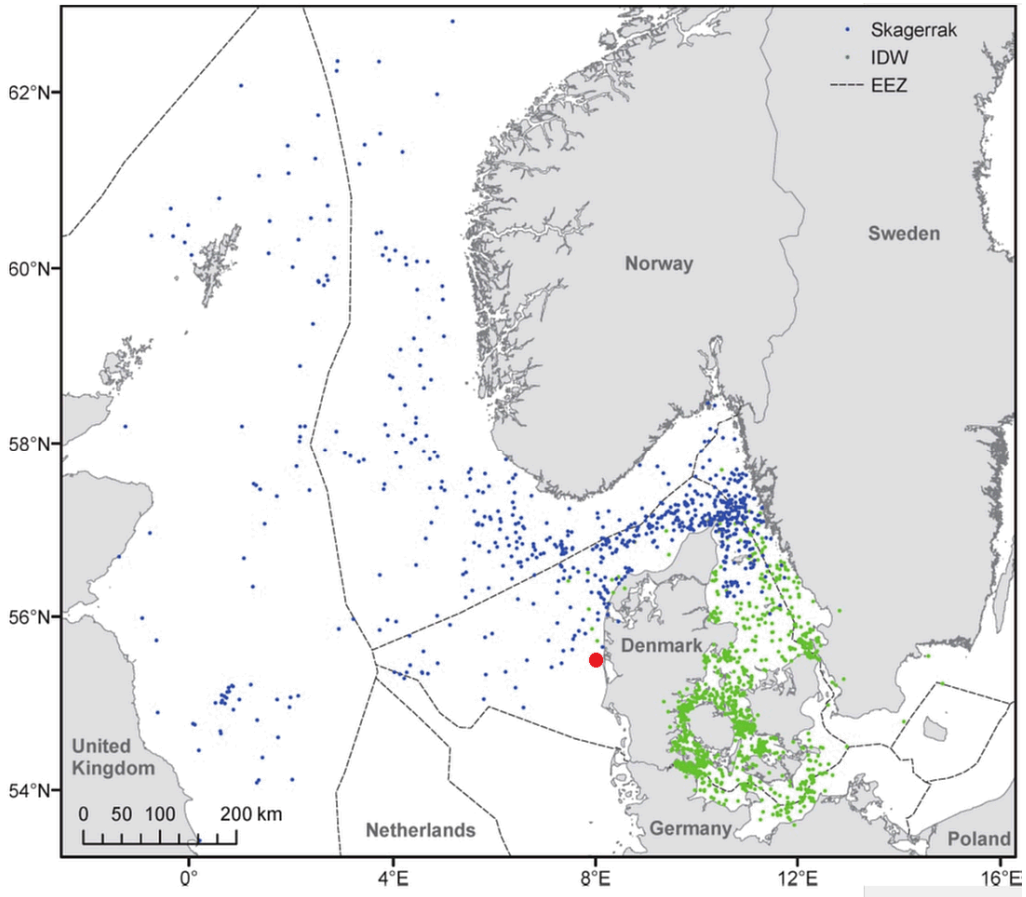


Figure 29: Distribution of 64 tagged harbour porpoises between 1997 and 2007 (Green dots represent positions of mammals tagged in Inner Danish Waters, blue dots represent position of porpoises tagged in the Skagerrak area. The area of Vesterhav Syd is marked with a red spot. (Source: Sveegaard et al. 2011b).

About 45 km north of Vesterhav Syd, the parallel marine mammal monitoring for the planned wind farm Vesterhav Nord revealed considerably lower porpoise densities than at Vesterhav Syd. In the Vesterhav Nord area less than 1 animal / km² was found during each flight (Figure 30). The annual pattern seems to be clearer in Vesterhav Nord where higher densities are mainly found from spring to early summer. In Vesterhav Syd the presence of harbour porpoises seems to fluctuate and high densities with more than 1 animal / km² were occasionally found (February and May). Overall, the porpoise density at Vesterhav Nord was around one third less than at Vesterhav Syd (0.45 vs. 0.67 animals / km²).

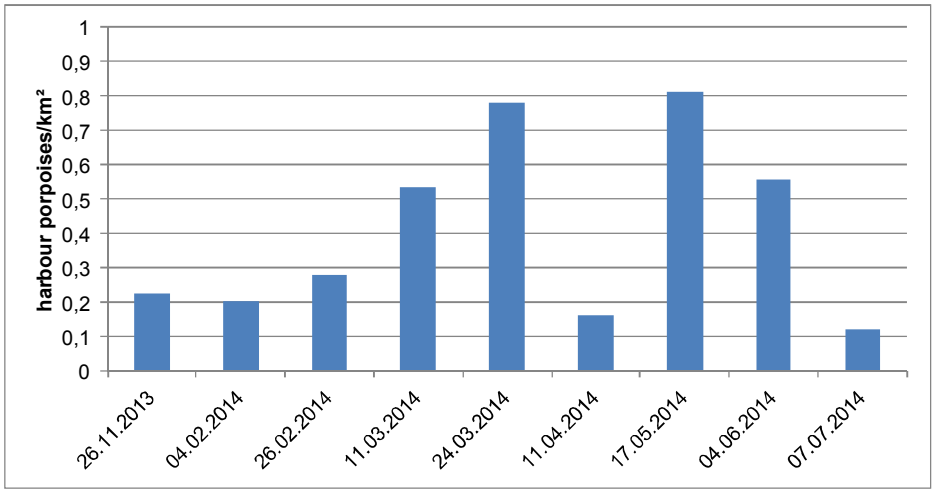


Figure 30: Density of harbour porpoises in the Vesterhav Nord investigation area during nine flight surveys between November 2013 and July 2014.

Subsequent to the NOVANA survey flight in July 2012 across the Danish southern North Sea and the Skagerrak (see Figure 16) a relative abundance of 0.13 harbour porpoises per kilometer transect effort was calculated for both areas (Hansen 2013). In 2011 very similar values were obtained. In the Vesterhav Syd study area much lower concentrations were found during most flights. However, a maximum of 0.19 porpoises per km transect effort was reached here on 18 May 2014.

The level of porpoise activity at the Vesterhav Syd POD station was considerably lower than the activity recorded in the Horns Rev 3 area (Nehls et al. 2014). At Horns Rev 3, even C-POD stations with generally little porpoise activity had an average of more than 10 % porpoise positive 10-minutes-intervals per day. Interestingly, the stations there could be divided roughly into two types. One type in the west had generally higher activity levels. The annual pattern was well pronounced and highest monthly mean was over 60 % pp10m/d. Stations in the east had generally lower activity levels and annual differences were not noticeable. The habitat differs between the two groups of C-PODs. The habitat in the west was attractive to sandeels. Accumulations of harbour porpoises during summer could be linked to prey availability. So far our data has more similarity with the eastern stations: a generally low level of porpoise activity and so far no clear annual pattern emerges. However, the annual cycle is not completed and additional data from the forthcoming months will help in the interpretation of the results.

As at Vesterhav Syd, the harbour porpoise activity at the Vesterhav Nord offshore wind farm site was also evaluated with C-PODs at a C-POD station. The Vesterhav Nord station is located at a comparable distance from the coast (6.3 km), at position 56°36.595’ N / 8°02.510’ E. The phenology is surprisingly similar for both stations with low values in December/January and again in July/August. Overall, the porpoise presence at Vesterhav Nord was lower than at Vesterhav Syd (see Figure 31 and Figure 22 for comparison). The difference can be traced back to lower presence rates mainly until June at Vesterhav Nord. However, the increase in September and October is more pronounced at Vesterhav Nord which thereby diminishes the overall difference.

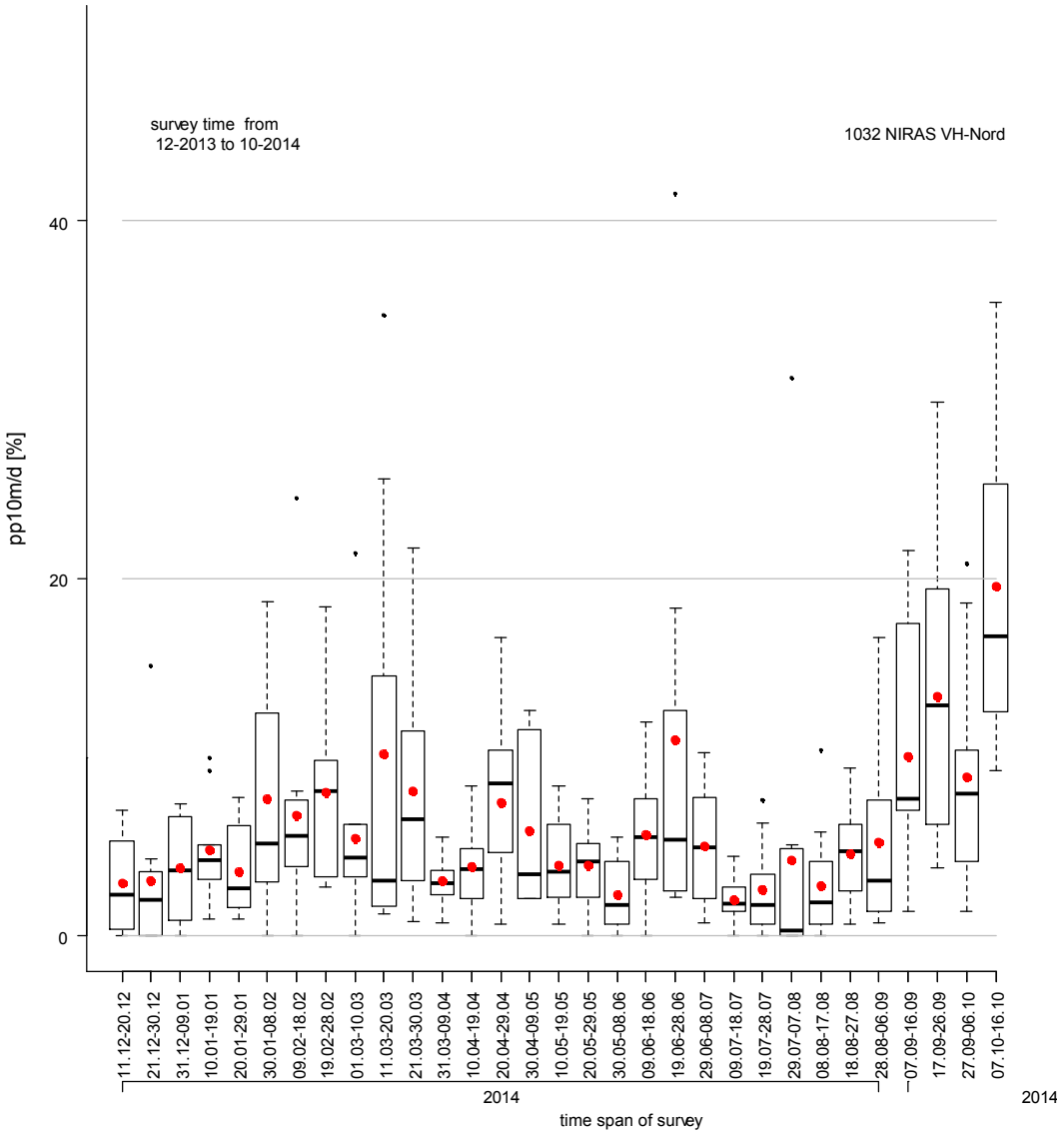


Figure 31: Averaged presence rate of harbour porpoises per 10 day period at the C-POD station at Vesterhav Nord between December 2013 and October 2014.

6.4.3 *Importance of the Vesterhav Syd area for harbour porpoises*

According to the results of the aerial survey and the passive acoustic monitoring, Vesterhav Syd is an area of moderate densities of harbour porpoises. It is located relatively close to high density areas at Horns Rev and to the Natura 2000 site “Sydlige Nordsø” which are both further south. However, densities at Vesterhav Syd are much lower than in the Horns Rev area. Nevertheless, densities are still higher in the Vesterhav Syd area than in other areas along the Danish west coast, e.g. Vesterhav Nord. Five sightings of calves do not speak for a special importance as calving ground. Overall, the importance of the Vesterhav Syd area for harbour porpoises can be assumed to be minor to average.

6.5 Abundance and distribution of harbour seals

The harbour seal has the widest distribution of any pinniped. It occurs in a great variety of habitats along the shores of the northern hemisphere (Burns 2009). It is also the most common seal in the North Sea and in Denmark. The North Sea population is estimated at more than 45,000 individuals (ICES 2007).

The Danish harbour seal population comprised around 16,000 animals in 2012 (Hansen 2013) (Figure 32). The population has been growing almost steadily since the late 1970s, when only 2,000 animals were present in Denmark. The phocine distemper epidemics in 1988 and 2002 caused severe short-term decreases but the population fully recovered in the following years.

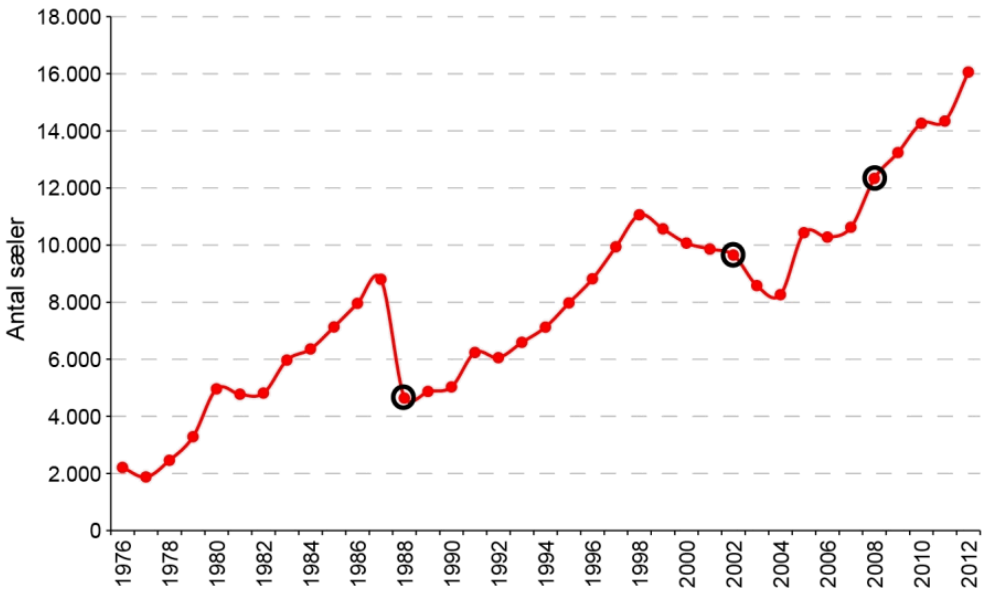


Figure 32: Total number of harbour seals in Denmark from 1976-2012. Numbers calculated from counts at haul-out sites and the average proportion of seals in the water (25% in the Wadden Sea, 43% in other waters (Härkönen et al. 1999). For 1976-1978, the numbers are estimated from various types of counts that are not standardized. The three epidemics 1988, 2002 and 2007 are indicated by circles). (Source: Hansen 2013).

In Denmark, the harbour seal's distribution shows some core areas (Figure 33). These can roughly be distinguished as the Wadden Sea (A), the Limfjord area (B-E), the Kattegat (F, G, L) and the western Baltic. On the basis of aerial counts, the highest numbers of harbour seals are found on Hesselø (L) and Anholt (G) in the Kattegat and at Knudedyb (A) in the Wadden Sea (Andersen 2011).

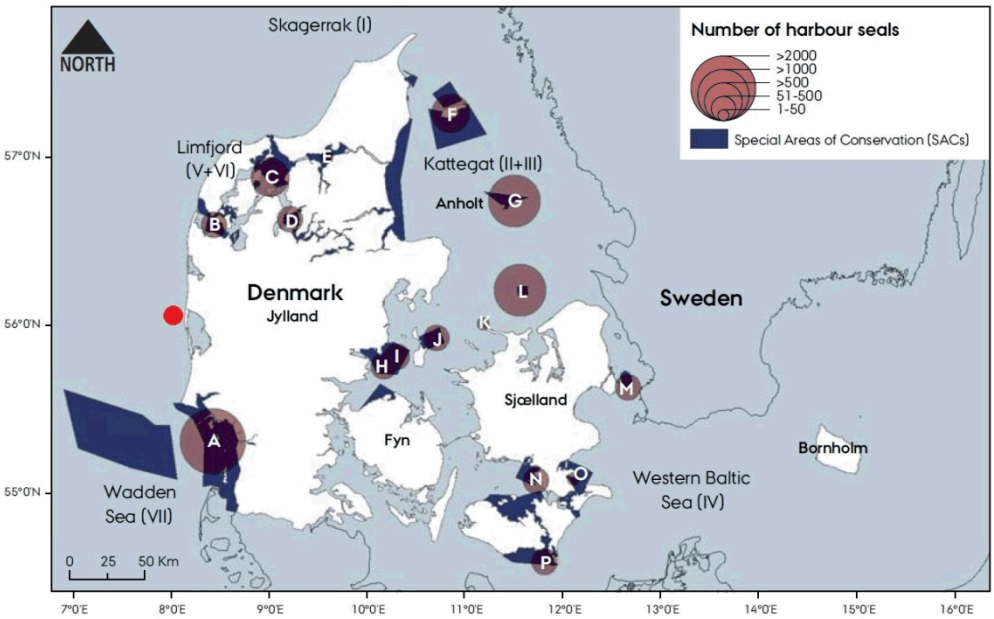


Figure 33: Regional populations of harbour seals in Denmark. The area of Vesterhav Syd is marked with a red spot. (Source: Andersen 2011).

Satellite telemetry studies with tagged animals have shown that harbour seals can reach areas far away from coast during foraging trips (Tougaard et al. 2008) (see Figure 36). However, most animals are found in coastal waters adjacent to their haul-out areas. On the basis of numerous seal sightings during aerial and ship surveys in the German Bight, Herr et al. (2009a) created a seal density map for the German Exclusive Economic Zone (EEZ) of the North Sea (Figure 34). Very few animals were seen beyond the 30 m depth contour, which lies inside the 0.01 – 0.02 seals/km² density area. The pictured abundance pattern probably continues northwards to the Danish southern North Sea and Wadden Sea, but a decrease of coastal densities can be expected north of Blåvands Huk as haul-out sites are absent.

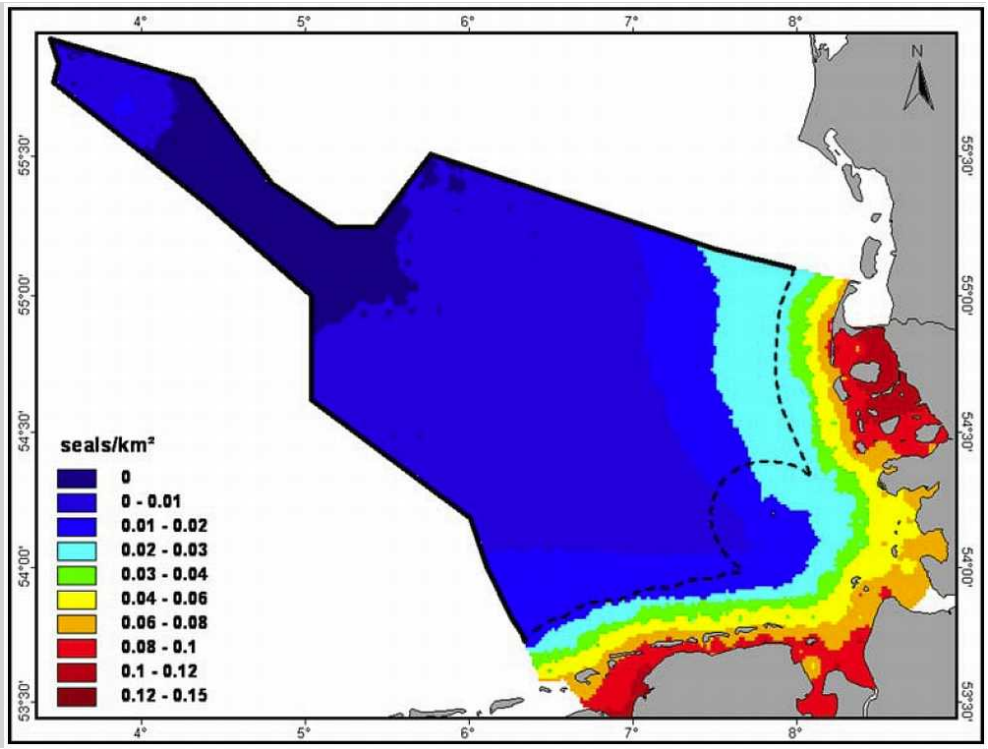


Figure 34: Seal density map of the German North Sea EEZ (Source: Herr et al. 2009b).

6.5.1 *Harbour seals in the Vesterhav Syd area*

During the nine survey flights between November 2013 and July 2014, 25 harbour seals, 6 grey seals and two unidentified pinnipeds were observed (Figure 35). The latter belong most likely to one of the other two species. Identifying the species from a plane is difficult in most cases, so all seal sightings are considered together here. It is not possible yet to calculate seal densities from raw sighting numbers because correction factors are not available.

The distribution of the recorded seals show a accumulation within a 10 km strip along the coast, with 29 of 33 individuals being inside this area (Figure 35). This roughly corresponds with the depth zone below 25 m. In contrast, the north to south distribution of the sightings doesn't show any gradient.

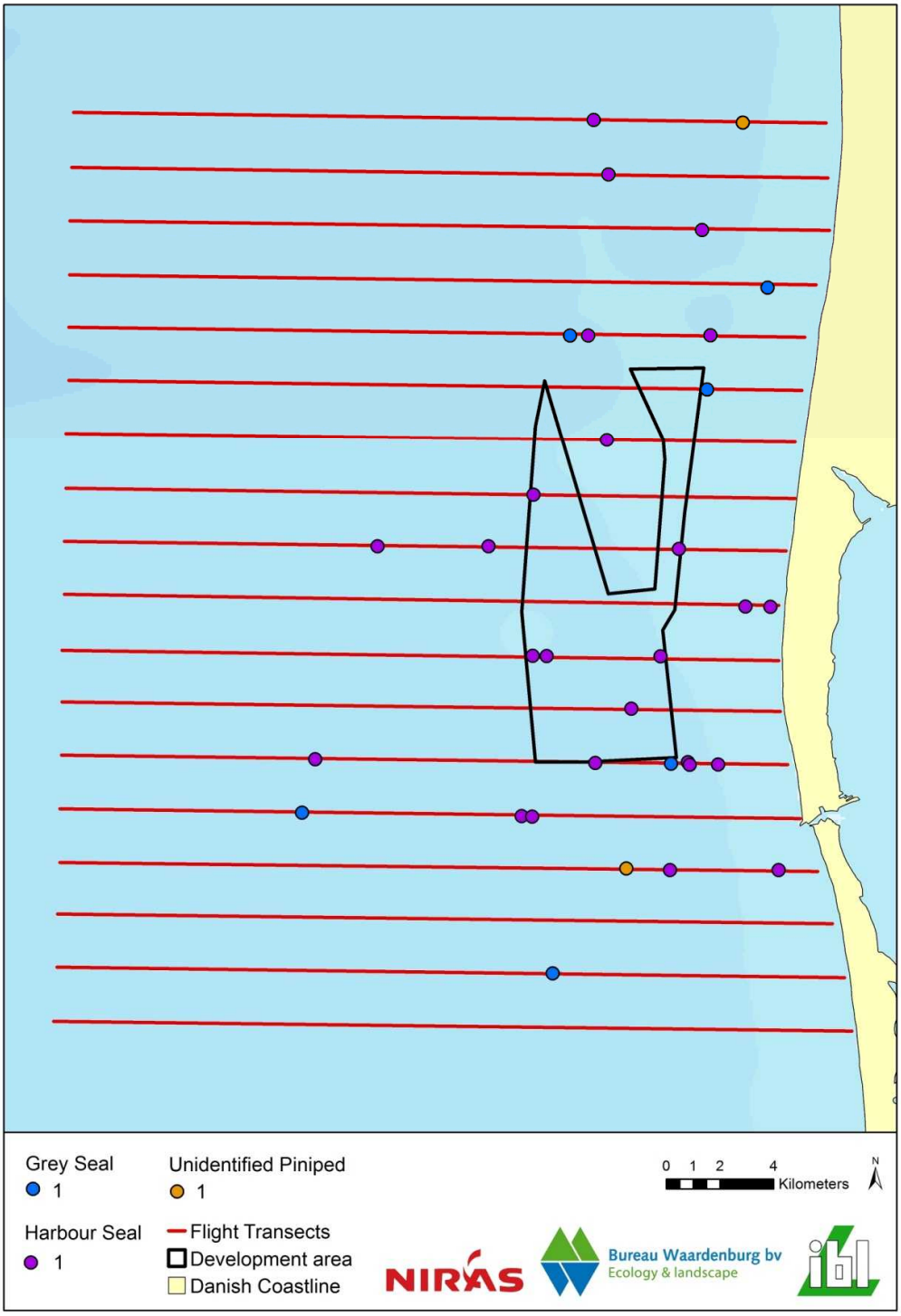


Figure 35: Sightings of seals in the Vesterhav Syd investigation area during 9 flight surveys between November 2013 and July 2014.

6.5.2 *Abundance and distribution in the Vesterhav Syd area according to other studies*

For the Vesterhav Syd area hardly any seal data from other studies is available. The North Sea coast section from Blåvands Huk in the south to Thyborøn in the north does not possess any important seal

haul-out sites. However, as the results of the aerial surveys show, seals do utilise the Vesterhav Nord area as a foraging ground (Figure 35). Most of them probably belong to the 'haul-out population' in the Wadden Sea as indicated by movement profiles of tagged animals (Figure 36) (Tougaard et al. 2008).

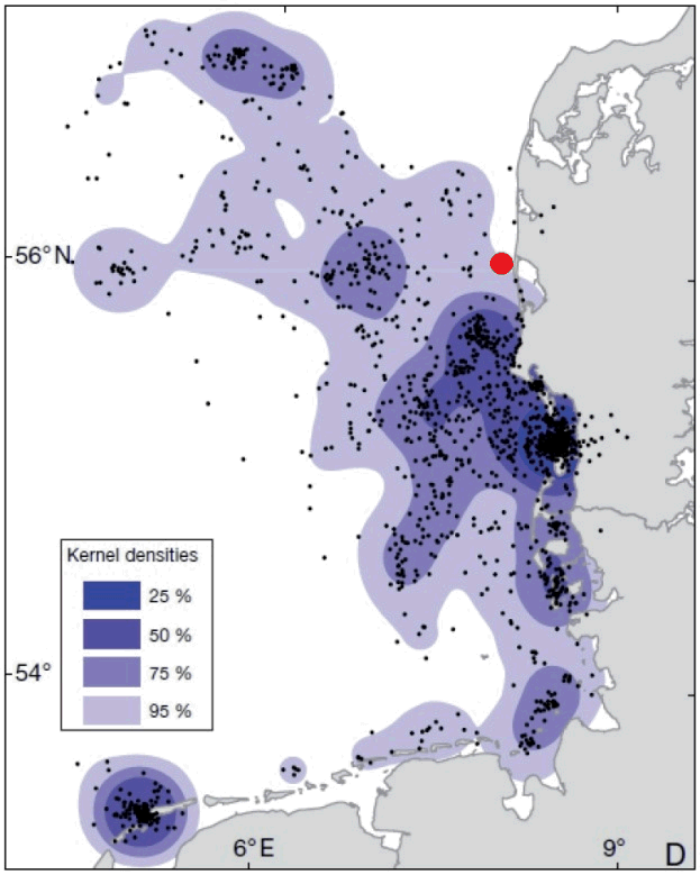


Figure 36: Kernel densities of satellite telemetry tagged harbour seals from Rømø. Kernel densitiy is a statistical non-parametric approach to model the likelihood of the range in which individuals occur in the area. The smaller the kernel density category is (e.g. 25 %), the more frequently it is used by the animal. The area of Vesterhav Syd is marked with a red dot. (Source: Tougaard et al. 2008, in Nehls et al. 2014).

In the Danish Wadden Sea harbour seals are counted annually within the framework of a trilateral survey programme. During the 2013 survey 2,759 harbour seals were counted at their haul-out sites in this area as part of a total of 26,788 animals in the entire Wadden Sea from Texel in the west to Fanø in the north (TSEG 2013) (Figure 37).

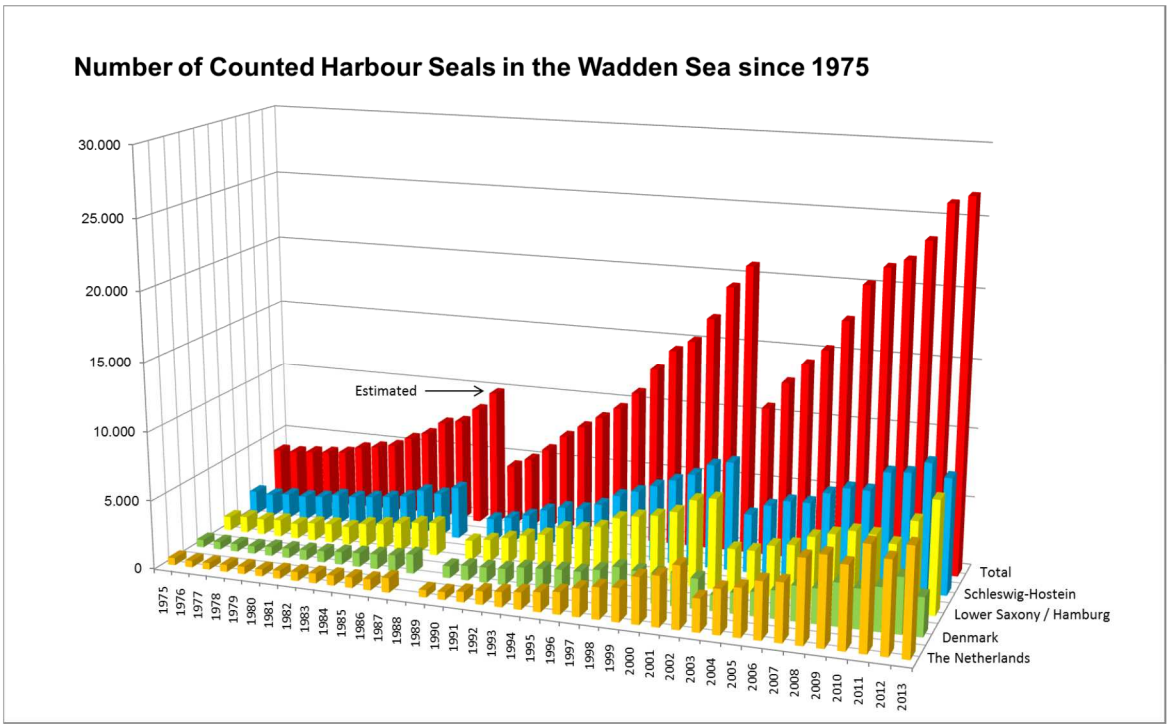


Figure 37: Population size of harbour seals in the Wadden Sea from 1975-2013 (Source: Annual Report 2013, TSEG (Trilateral Seal Expert Group) TSEG 2013).

Including seals in the water during the survey, the total population size of harbour seals in the Wadden Sea in 2013 was about 39,400 (TSEG 2013). The total size of the Danish Wadden Sea population was estimated to be around 4,500 animals including seals in the water in 2012 (Figure 38) (Hansen 2013).

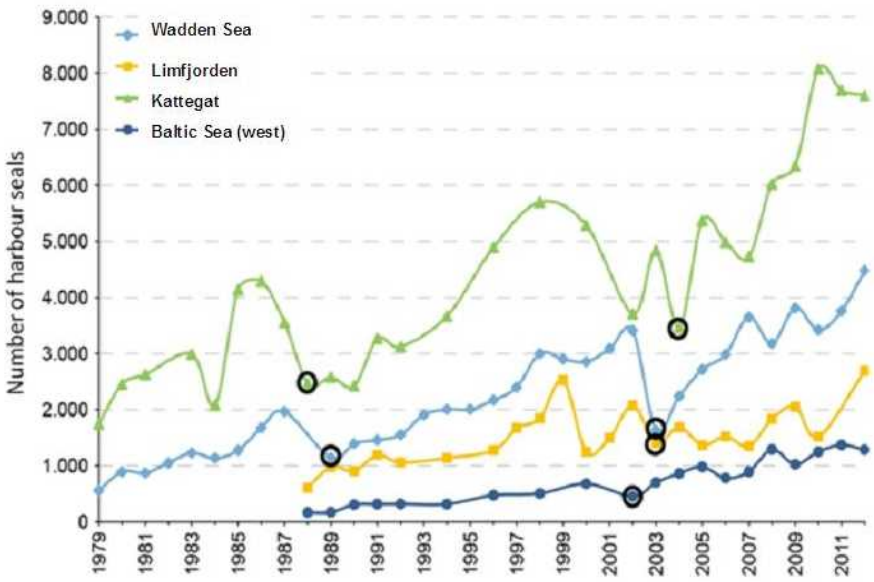


Figure 38: Regional numbers of harbour seals in Denmark in the Wadden Sea area, the Limfjord area, the Kattegat and the western Baltic Sea in the period 1979-2012 (Numbers calculated from counts at haul-out sites and the average proportion of seals in the water (25% in the Wadden Sea, 43% in other waters (Härkönen et al. 1999). The first census after epidemics in 1988 and 2002 marked with circles). (Source: Hansen 2013).

Besides harbour seals from the Wadden Sea some animals from the Limfjord area may also roam the Vesterhav Syd area. Whereas in the last ten years harbour seal numbers in the Kattegat and Wadden Sea have been increasing, the Limfjord population has rather stagnated (Figure 38). Because the Limfjord system is not as open as the coastal habitats, food limitations may be responsible for the relative stagnation (Andersen 2011). During the parallel survey in the Vesterhav Nord study area which is close to the Limfjord, only half as many seals were observed as at Vesterhav Syd. Seen from Vesterhav Nord, Vesterhav Syd is located half-way to the Horns Rev area, which marks the northern border of the Wadden Sea area. Within the Horns Rev 3 study area, overall 112 seals were observed during ten survey flights in 2013 (Nehls et al. 2014). Considering the different flight effort, the number is twice as high as at Vesterhav Syd and about five times higher than at Vesterhav Nord, indicating a north to south abundance gradient similar to the kernel model shown in Figure 36.

6.5.3 *Importance of the Vesterhav Syd area for harbour seals*

Considering the relatively small number of observed harbour seals, it can be assumed that the coastal section and open sea around Vesterhav Syd is an area of minor to average importance for the species. It is utilised as an occasional foraging habitat, probably mainly for harbour seals of the Wadden Sea population.

6.6 Abundance and distribution of grey seals

As part of the world-wide population of around 300,000, there are currently estimated to be about 130,000 grey seals in the eastern Atlantic region - mainly at the UK coasts - and about 7,500 in the Baltic Sea (Hall & Thompson 2009).

In Danish waters the grey seal was once a common and widespread species that breed at Danish coasts until around 1900. Having been almost eradicated in Denmark for roughly 100 years, the grey seal has re-colonized some sites in the Kattegat, the Baltic Sea and the Wadden Sea during the past decade. It now regularly breeds near Gedser on 'Rødsand' where up to five annual births have been observed since 2003 (Edrén et al. 2010, Hansen 2013). Along the west coast, grey seals are regularly present in the Wadden Sea area. In 2012 about 160 grey seals were counted in the Danish western Baltic and 76 individuals in the Danish Wadden Sea (TSEG 2012, Hansen 2013). Taking into account the proportion of animals in the water, the Danish grey seal population probably comprised around 350 individuals in 2012. Figure 39 shows the population dynamics of grey seals in the Danish Baltic since 2002, calculated from aerial surveys at haul-out sites during the moulting season.

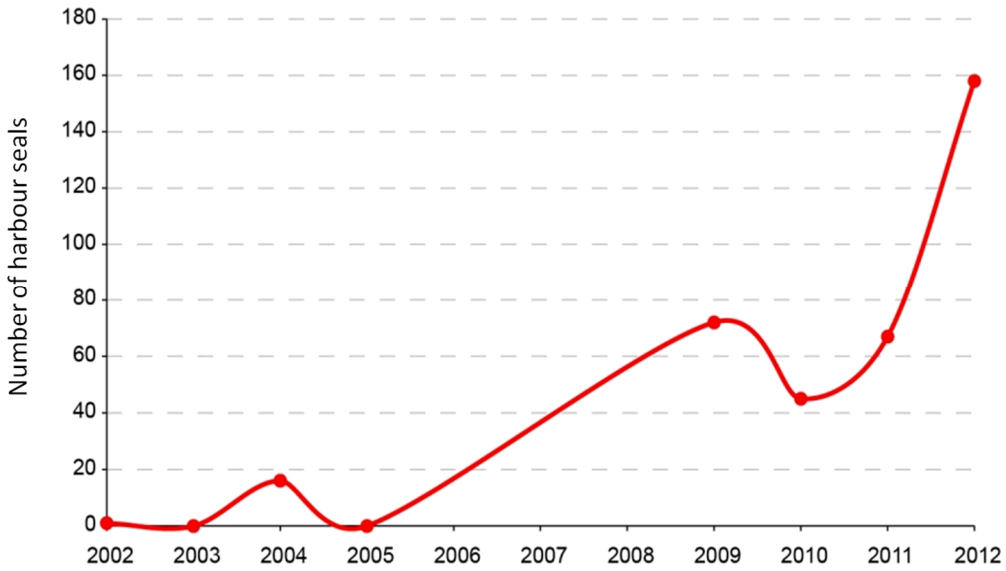


Figure 39: Number of grey seals in the Danish western Baltic Sea in the period 2002-2012. Numbers indicate actual counts, as they are not adjusted for any seals in the water. (Source: Hansen 2013).

6.6.1 *Grey seals in the Vesterhav Syd area*

During the survey flights 6 grey seals were observed between November 2013 and July 2014 (see Figure 35). In general the occurrence of grey seals in the Vesterhav Syd area is widely unknown. During the recent investigations at Vesterhav Nord and Horns Rev 3 comparably low numbers of grey seals were observed there as at Vesterhav Syd (Nehls et al. 2014).

6.6.2 *Importance of the Vesterhav Syd area for grey seals*

The results of the Vesterhav Syd survey and also of the Horns Rev 3 and Vesterhav Nord investigations indicate that the Danish northern North Sea and the Danish west coast north of Blåvands Huk is not an

important area for grey seals. However, the animals seem to pass through the Vesterhav Syd area regularly when migrating between the more important habitats in the Wadden Sea and the western Baltic.

6.7 Other marine mammal species

Besides the three native species some other marine mammals may occur vagrantly in Danish waters. Minke whales (*Balaenoptera acutorostrata*) and white-beaked dolphins (*Lagenorhynchus albirostris*) are observed quite frequently in central parts of the southern North Sea (Hammond et al. 2013). During the aerial survey in the Vesterhav Syd investigation area an unidentified whale was recorded which might belong to one of these species.

It would also be possible to detect dolphins acoustically at the C-POD station Vesterhav Syd. Dolphins emit click sounds in a lower frequency range than porpoises. However, the risk of ‘false positives’ would be very high due to the considerable amount of background noise clicks within the same frequency range, especially from moving sediment. Therefore, it was decided to exclude evaluation of possible dolphin presence from the C-POD data.

7 POTENTIAL IMPACTS ON MARINE MAMMALS

Turbine sizes as well as the wind farm layout are important factors according to the description of the impact assessment on marine mammals. There might be differences in the influence on seals and harbour porpoises which are related to turbine size, number and position. As the final layout may be modified by the approved developer, environmental needs should be taken into account. To give an overview, a description of activities which are considered to have an effect on marine mammals in the wind farm area is given in Figure 40. Positive as well as negative effects which might be related to the construction and operation of wind farms are represented. In this report the effects which are assumed to be most likely and the most substantial are discussed. A short description of effects on marine mammals in response to disturbance due to noise and habitat changes, are presented in the following.

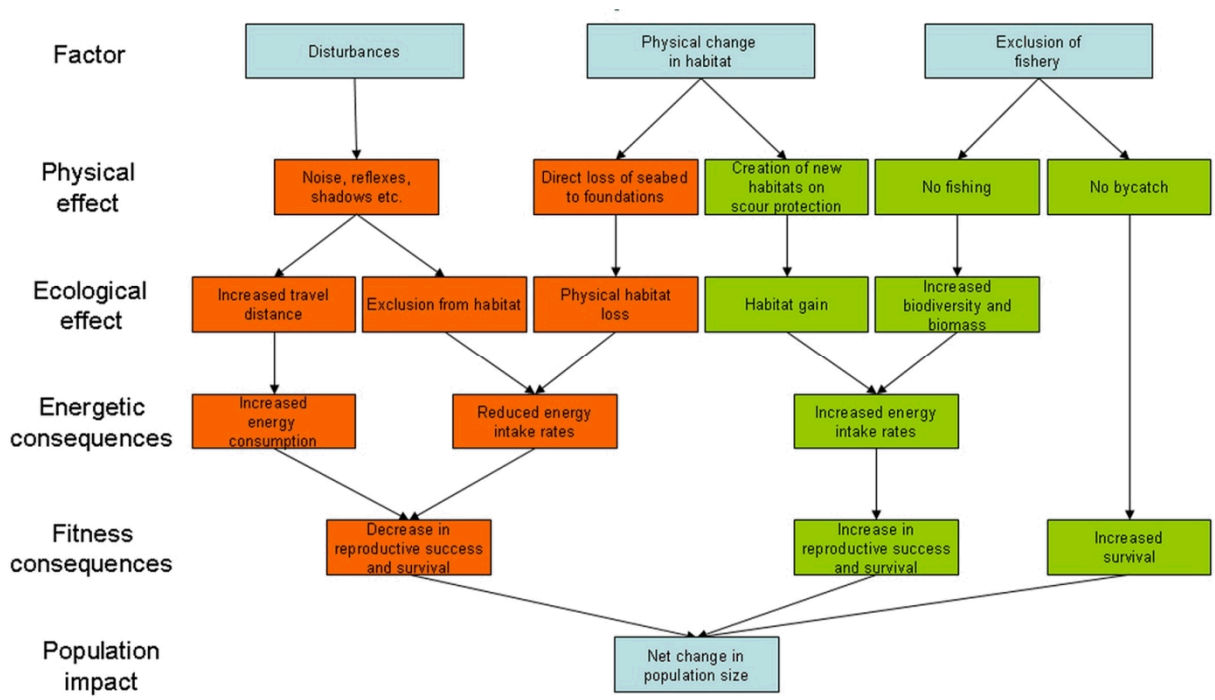


Figure 40: Potential effects of offshore wind farms on marine mammals in the surrounding waters. Factors with negative effects are shown in red; factors with positive effects are shown in green. Disturbance is the dominant factor during construction, whereas all three factors could play a role during operation of the wind farm. (Source: Tougaard & Teilmann 2007, after Fox et al. 2004).

7.1.1 Potential impacts due to preliminary measures

Prior to construction, pre-investigation surveys are conducted to evaluate the foundation ground and minimize potential risks (e.g. detection of military remains). Such pre-investigation surveys might include, for instance, site scans and UXO (Unexploded Ordnance) surveys, both making use of ultrasonic sounds that have the potential to affect marine mammals (ICES 2005). The source level of the ultrasonic sound emissions of e.g. side scans and UXO surveys exceeds 180-230 dB re 1µPa-m (root mean square pressures) at frequencies between 12-500 kHz (Richardson et al. 1995). Depending on the method and sound level marine mammals are exposed to, these surveys might lead to physical damage and behavioural responses, such as variation in activity patterns (Pirotta et al. 2014).

Following the pre-investigation survey, it is often obligatory to deploy underwater explosives (e.g. for the clearing of shipping lanes and/or cable routes, ammunition removal). Underwater explosions constitute the most intense anthropogenic point source noise in the oceans and have the potential to lead to severe injuries in marine mammals (Richardson et al. 1995, Lewis 1996). Owing to the extremely high detonation velocity, the pattern of sound propagation is unique: After an initial shock wave, characterized by an extremely short signal rise time and a high overpressure, this primary pulse can be followed by a negative phase and a number of oscillating bubble pulses. Depending on the intensity of the detonation, injuries directly caused by the shock wave are often lethal at very close ranges (Landsberg 2000). Even at greater distances underwater detonations can still lead to a temporary or permanent threshold shift (Lewis 1996, Koschinski 2011). Therefore, it is strongly recommended to make use of mitigation measures, such as the application of a bubble curtain (Nützel 2008, Schmidtke 2010, Koschinski 2011), whenever underwater detonations cannot be avoided. Alternative methods to the conventional ammunition removal by blasting are described in Koschinski and Kock (2009). Dual noise-exposure criteria as defined by Southall et al. (2007) for pulsed sounds such as seismic airguns, sonar or pile driving, cannot be applied to underwater explosions due to their distinct sound propagation with a much shorter rise time (Koschinski & Kock 2009).

7.1.2 Potential impacts during construction phase

The most important effect on marine mammals caused by offshore wind farm construction is noise from building activities (e.g. pile driving) and shipping traffic (Carstensen et al. 2006). As project related shipping traffic also occurs during operation and decommissioning of the wind farm, it is considered separately in chapter 7.1.5. The same holds true for sedimentation and turbidity (chapter 7.1.6), which could affect marine mammals during construction, decommissioning and cable laying.

Impacts of underwater noise

The effects of noise are usually assigned to one of four ’zones of noise influences’: ’zone of audibility’, ’zone of masking’, ’zone of responsiveness’ and ’zone of hearing loss, discomfort or injury’ (Richardson et al. 1995, Thomsen et al. 2006) (Figure 41). The extent of these zones is relative to the marine mammals perception of noise whereby physical constitution and distance to the source have roles to play (Southall et al. 2007). The main sound type during offshore wind farm construction is a pulsed sound, induced by pile-driving. As pile driving sounds are assumed not to cause significant masking effects (Madsen et al. 2006) and no guidance levels for masking effects are established, the focus here is on the acute effects which might lead to behavioural responses, avoidance or hearing loss.

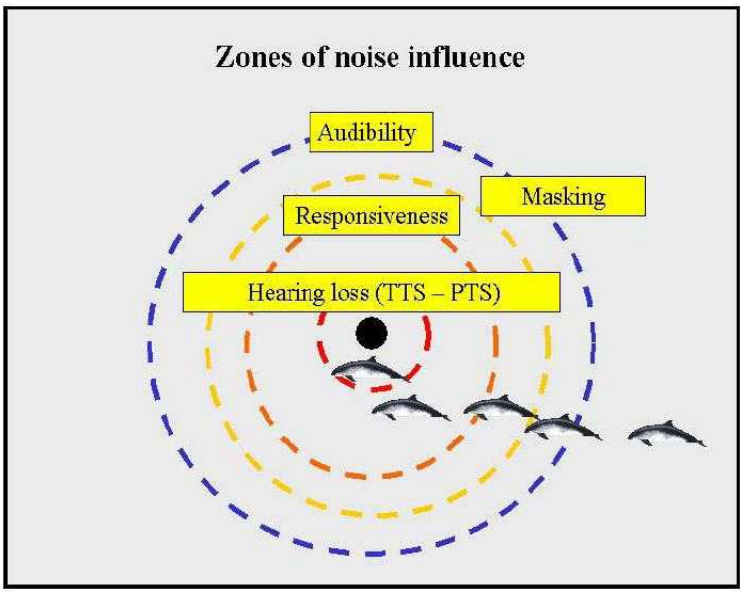


Figure 41: Zones of underwater noise influence on marine mammals (Source: Thomsen et al. 2006, after Richardson et al. 1995)

Physical effects such as hearing loss can be permanent (PTS = Permanent Threshold Shift) due to injury of of the hearing apparatus, or temporary (TTS = Temporary-Threshold Shift). Behaviour responses like fleeing or avoidance are hard to detect. It is difficult to define behaviour responses, and changes in behaviour due to noise exposure might differ greatly among individuals (Richardson et al. 1995). Different studies have shown that behaviour reactions can differ among individuals and species according to age, sex, experience or physical condition (Buck & Tyack 2000, Clark et al. 2009, Kastelein et al. 2013). Reactions are not only different; but avoidance behaviour also differs. For instance, avoidance behaviour can be directed away or towards the disturbance (Richardson et al. 1995). Despite the fact that behaviour response is difficult to detect, Southall et al. (2007) established an index for assessing behavioural responses of free ranging marine mammals. Based on the work of Southall et al. and recent findings regarding the effects of noise on marine mammals a working group established by Energinet.dk has provided exposure limit values for behavioural responses of pinnipeds and harbour porpoises (Working Group, 2015). In the present report the impact assessment is based on these thresholds, which are listed in Table 14.

A recent study of Kastelein et al. (2015) indicates that TTS and PTS values might be considerably higher (TTS at 180 dB re 1 µPa2s SEL_{cum} across 1 hour and PTS at 195 dB re 1 µPa2s SEL_{cum} across 1 hour). These values are considerably higher than the ones used in this report. These new results could have substantial consequences on the evaluation of cumulative piling noise on harbour porpoises.

Table 14: Limit values for underwater noise for seals and porpoise. PTS = Permanent hearing loss. TTS = Temporary hearing loss. SEL = Sound Exposure Level, the total noise energy produced from a single noise event (cumulative SEL). From (Working Group, 2015). Underwater noise is measured in dB re. 1 µPa. This means that levels of underwater noise cannot be compared to noise above water, which is measured in dB re. 20 µPa.

	Effect	SEL (dB re 1µPa^{2}s)
Seals	PTS	200
	TTS	176
Porpoise	PTS	183
	TTS	164
	Behavioural change	140 (single strike)

Pile-driving

Pile driving sounds are pulsed sounds which are audible to harbour porpoises over tens of kilometers (Madsen et al. 2006, Kastelein et al. 2013). Pile driving is assumed to have the most disturbing effect on marine mammals during the installation of offshore wind farms (Madsen et al. 2006). At short distance pile driving noise may even have fatal consequences for porpoises. As porpoises are dependent on their sense of hearing for foraging and orientation, any permanent hearing damage may potentially result in starvation or stranding (Sundermeyer 2006). However, the examination of stranded animals in the vicinity of the wind farm 'Egmond aan Zee' did not demonstrate such a case (Leopold & Camphuysen 2008). Even presumably much smaller values at greater distances from the sound source or those resulting from mitigation measures (e.g. bubble curtains or pingers), can still be high enough to cause displacement effects. Such effects have been observed at a distance of approximately 20 km (Tougaard et al. 2009a, Brandt et al. 2011, Dähne et al. 2013a). Furthermore wind farm construction might have temporary or long term effects on abundance and distribution of marine mammals (e.g. Nysted (pile driving by vibration) Carstensen et al. 2006, Teilmann & Carstensen 2012) Horns Rev 1 (Tougaard et al. 2006)).

7.1.3 Potential impacts during operation phase

During the operation phase of the wind farm, habitat changes and noise emissions could affect harbour porpoises and seals. Disturbance due to underwater noise during offshore wind farm operation is known to affect marine mammals much less than during installation (Madsen et al. 2006). Underwater noise produced by ships during the operation phase will mainly be linked to maintenance and service. Since this includes crew transfer and transport of equipment, normally small vessels or motorboats will be used. Shipping activity will be less frequent compared to the activity during the construction phase. The potential impacts of ship traffic and habitat changes are discussed in chapter 7.1.5 and chapter 7.1.7 respectively.

Operational noise

Noise emissions which are associated with the operation of wind turbines can be aerodynamic noise and mechanical noise. The aerodynamic noise coming from the spinning rotor is broad-band and rela-

tively unobtrusive. Moreover, the transmission of airborne sound into the water body is limited as the major part is reflected from the sea surface (Richardson et al. 1995). Therefore the aerodynamic noise of the wind turbines is not considered as relevant for marine mammals. Nevertheless, seals are able to hear the aerodynamic noise as they regularly raise their head and ears into the air when breathing or resting at the surface.

The mechanical noise of the turbine is transferred into the water body primarily through the submerged part of the tower and the foundation. According to various studies on offshore wind turbines in Denmark and Sweden, the emissions occur predominantly in the low frequency range up to 500 Hz (Madsen et al. 2006, Elmer et al. 2007). The highest underwater source level reported for the tonal noise component during operation of a wind turbine is 151 dB re 1 µPa at 1 m, for a wind speed of 13 m/s and at a frequency of 180 Hz (Wahlberg & Westerberg 2005). Nedwell et al. (2007a) examined the operating noise as part of the background noise in an offshore wind farm. They measured an average background sound level increase of 6.3 dB inside the wind farm compared to areas outside.

In a study on three wind farms (Middelgrunden, Vindeby and Bockstigen-Valar) the total sound pressure level was found to be in a range of 109–127 dB re 1 µPa at a distance of 14-20 m from the foundations (Tougaard et al. 2009b). Elmer et al. (2007) measured the operating noise at the Danish offshore wind farms Horns Rev (North Sea) and Nysted (Baltic Sea). The nominal power of the examined wind turbines was 2 to 2.3 MW, located at water depths of 8 - 12 m. When working at nominal power (full load), the underwater noise emissions at 100 m distance reached 120 dB re 1 µPa in the low frequency range around 125 Hz, suggesting a source level around 140 dB. The value at 100 m distance corresponds roughly with the hearing threshold of the harbour porpoise in this frequency range. When the nominal power is not reached, which is the case at wind speeds below 12 m/s, the measured values are significantly lower. Koschinski & Culik (2001) found porpoises and seals to keep a minimum distance of 60 m from the source of simulated operational noise of a 2 MW wind turbine.

The studies cited above refer to wind turbines with much lower nominal power than the 10 MW ‘worst case turbine’ of Vesterhav Syd. Turbines with 2-3 MW were common a few years ago. Currently for the most part systems with 4-8 MW are used. For a 10 MW wind turbine it can be hypothesised that under full load it is audible for harbour porpoises at more than 100 m distance and can be heard by seals several hundred meters from a turbine. However, audible does not mean disturbing. Presumably, potential behavioral effects of harbour porpoises are limited to a range less than 100 m from the pile. Harbour seals have better hearing capabilities within the frequency range of the operating sounds but seem to be more tolerant to underwater noise (Southall et al. 2007, Kastelein 2011). This finding is supported by a recent study on seals at the German offshore wind farm ‘alpha ventus’ (Russell et al. 2014). A tagged harbour seal foraged at the foundations of all 12 operating wind turbines and it clearly preferred the foundation structures over other areas inside the wind farm (see Figure 43).

Some mechanical noise may be generated by equipment on the transformer platform (transformers, diesel generators etc.). These noise contributions are not deemed significant for the overall noise emissions from the offshore wind farm.

7.1.4 Potential impacts during decommissioning

During decommissioning of the offshore wind farm, impacts on marine mammals similar to those during construction are to be expected. These include underwater noise emissions due to the decommission-

ing work and the increasing ship traffic as well as increasing sedimentation and turbidity. Ship traffic is likely to be as frequent as during the construction phase. The removal of the wind turbine foundations leads to habitat changes by reversing the changes described in chapter 7.1.7. The potential impacts of ship traffic and sedimentation are discussed in chapter 7.1.5 and chapter 7.1.6.

In general, the decommissioning of the wind turbines is expected to be less noisy than the pile driving during construction. However, this does not apply to gravity foundations as on the one hand they do not require pile driving during construction and on the other the removal of ballast during decommissioning would be noisy. Another exception would be the use of explosives during decommissioning. Explosions would have far reaching effects as described in chapter 7.1.1.

7.1.5 Potential impacts due to ship traffic

About 75 % of anthropogenic induced underwater noise is caused by ships (ICES 2005). Ship noise is suspected to have caused an increase in the ambient ocean noise level of about 12 dB (Hildebrand 2009). During construction an increase of ship traffic is expected. Small and fast vessels as well as large boats or barges will be used. In general, the effect of noise produced by ship-traffic has not been studied very well. However, underwater noise produced by small and fast motorboats is known to be more disturbing than the noise produced by large ships. Larger vessels seem to cause less disturbances, although the absolute sound pressure level is higher. The bigger and slower rotating propellers of their diesel engines produce noise at considerably lower frequencies. (Richardson et al. 1995) (Table 15). Porpoises are less sensitive in this frequency range (see Figure 11). Sound pressure levels increase with speed (Erbe 2002). Temporary threshold shifts caused by boats have been reported by Popov et al. (2011) for a Yangtze finless porpoise at frequencies between 32 -128 kHz and sound pressure levels of 140 dB re 1µPa. Kastelein et al. (2012) demonstrated a TTS of 6 dB in harbour porpoises. This resulted from an exposure to a low level of octave band noise around 4 kHz and an exposure of 120 dB re 1µPa for 120 minutes. These findings lead to the insight that the effect of shipping noise is heavily dependent on the kind of vessels and on the number of trips.

Table 15: Sound pressure levels of different vessels (source: Hildebrand 2009)

Sound source	**Source level [dB re 1 µPa at 1 m]**	**Frequency range [Hz]**
Small boat outboard engine (20 knots)	150-180	1,000 – 5,000
Cargo vessel (173 m length, 16 knots)	192	40–100
Super tanker	195	10- 50

Besides the noise from vessels related to the wind farm construction and operation, a high level of noise from the shipping lanes north and west of the Vesterhav Syd area has to be taken into account (see Figure 21). In the German Bight below-average densities of harbour porpoises have been found along highly frequented shipping routes (Herr et al. 2009a). However, in the Danish western Baltic some areas with intense ship traffic show high abundance of harbour porpoise (Sveegaard et al. 2012).

7.1.6 Potential impacts due to sedimentation and turbidity

Harbour porpoise

Sediment gets suspended in the water during construction. This happens mainly during piling and cable laying. The suspended sediment increases the turbidity of the water. This impairs visual orientation e.g. during hunting. However, harbour porpoises also inhabit turbid waters. Harbour porpoises live mainly in shallow waters including the North Sea where high turbidity occurs regularly in estuaries, after storms or around special currents and the animals are adapted to this habitat. In studies performed near Sylt, sand was extracted for island protection, which also results in an increased turbidity at the extraction site. Effects here were only found on a small scale (up to 600 m) in relation to the vessel. On a larger spatial scale no decrease in harbour porpoises' numbers were found and if the vessel was absent, occurrence of harbour porpoises normalized again. This suggests that the small effect that was found is most likely directly related to the vessel and noise emission from this vessel (Diederichs et al. 2010b).

Apart from their visual orientation harbour porpoises are greatly dependent on their echolocation system. They use it even in familiar waters with high clarity during the day. Verfuß et al. (2009) tested how harbour porpoises orient blindly with eyes covered. Harbour porpoises still oriented successfully and found food offered to them. The echolocation activity per time unit did not increase, but they reduced swim velocity. Thereby, the echolocation activity per distance covered did increase. Harbour porpoises also hunt during the night, possibly benefiting from the lack of light because with their echolocating system they are possibly less affected by it than their prey, which relies more heavily on its visual system (Brandt et al. 2014). It is therefore not assumed that harbour porpoises are directly affected by sediment spill. However, fish could react to the increased turbidity and therefore prey density could decrease. The suspended sediment will settle on the sea floor and this could affect benthos communities, which possibly could lead to further decrease in fish density.

Seals

Harbour seals live in the Wadden Sea and are therefore well accustomed to turbid waters. In the Wadden Sea a large amount of fine sediment is in the water column as the tidal currents continue to suspend the sediment. Seals do not possess an echolocation system like porpoises but have vibrissae. These are tactile sensory organs with which they can not only detect prey in direct contact but also register water turbulences caused by fish at a distance of 40 m (Dehnhardt et al. 2001). This together with hearing and smell can guide harbour seals efficiently. Summarizing, orientation and foraging are based on multi sensory input. If one sensory organ fails or gets insufficient input, the animals can rely on other sensory systems which are sufficient for the task of orientation or even hunting. The visual system, however, is affected by even medium scales of turbidity (Weiffen et al. 2006). Grey seals probably have similar abilities. They also inhabit turbid waters and--as close relatives--have similar sensory prerequisites. As mentioned above, the total density of fish could decrease due to increased turbidity and later

settlement of suspended sediments could affect the benthos community. Both factors would decrease prey densities.

7.1.7 Potential impacts due to habitat changes and habitat loss

Harbour porpoise

During the operation phase, scour protection and the piles from wind turbines will consist of hard substrate. After decommissioning the hard material of the scour protection will remain in the water. Additionally, hard material used to protect the cables will remain in the project area. One important prey item for all three considered mammal species is demersal fish such as flatfishes or sandeels (see chapter 6.1.1, 6.2.1 and 6.3.1). For these species groups the available habitat area could be reduced as a lot of hard substrate will be introduced. Additionally, the remaining habitat could become less attractive for some species that rely on larger homogenous sandy habitats. On the other hand, fishery is excluded, so the status of the remaining habitat could also be improved. No fish are removed and no beam trawling activity takes place, which could benefit the benthic community as a whole and could allow long-lived animals to establish themseves. However, for 'alpha ventus', the diversity of epifauna and infauna was slightly reduced inside the wind farm between turbines compared to a reference area outside. The abundance (numbers) of individuals was similar in both areas (Gutow et al. 2014). Additionally, the turbines themselves and the scour protection could constitute structures resembling an artificial reef structure. Hard substrate could facilitate the settlement of sessile benthos organisms. These together with the hard substrate itself and the exclusion or regulation and limitation of fisheries could lead to an enhancement of the densities of young fish (Gutow et al. 2014). This in turn could attract harbour porpoises, harbour seals and grey seals as all three are opportunistic feeders. Summarizing, there is the possibility that the group of fish relying on sandy habitats could be reduced. However, we assume that it is highly likely that this will be offset by the creation of a species community that relies on hard substrate (artificial reef).

For harbour porpoises reported effects in existing wind farms are heterogeneous. During construction there is generally a reduction in porpoise presence mainly due to noises caused by pile driving. After construction, the numbers of harbour porpoises in and around the wind farm increase again. However, on the question of whether wind farms are preferred or avoided results are different and possibly site specific. In Nysted offshore wind farm the porpoise activity is still below the level that was recorded during baseline surveys (Teilmann & Carstensen 2012). Explanations offered for the avoidance are speculative. It may be that porpoises simply remain in the foraging areas they exploited during the construction phase even after the wind farm becomes accessible to them during the operation phase. They could also be still displaced as wind turbines constitute unknown obstacles in the water and emit noise. In contrast, porpoise activity was higher in the wind farm Egmond aan Zee in the Dutch North Sea (Figure 42). The activity level increased in the whole study area because of a general increase of porpoises in Dutch waters. However, the porpoise activity increased disproportionally showing a clear preference for the wind farm (Scheidat et al. 2011). The reasons for the preference are unclear and it could be attributed to a foraging area favoured due to artificial reef effects, or it could also be caused by an absence of ship traffic in the wind farm (shelter effect), or a combination of both factors. Porpoises are also found at offshore platforms other than wind farms (Todd et al. 2009) that are possibly comparable to some extent as they also form structures resembling artificial reefs.

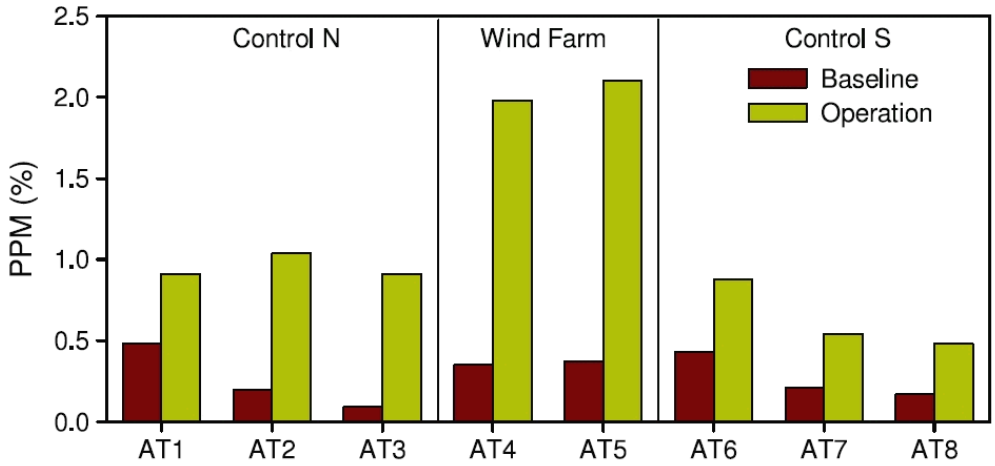


Figure 42: Activity of harbour porpoises within the OWF 'Egmond aan Zee' and two reference areas during baseline monitoring and operation of the wind farm (Source: Scheidat et al. 2011).

Seals

Like the harbour porpoise, seals too could be affected by wind farms. Scenarios of both avoidance and preference are imaginable. From Horns Rev it is known from observational data that harbour seals enter the wind farm and use the area and its surroundings with intensities similar to other areas (Tougaard et al. 2006). Animals were also tracked with GPS tags and undoubtedly entered the wind farm, albeit spatial precision of the method was low. In a recent study harbour seals were tagged with high resolution GPS tags in the Netherlands and in Great Britain. Dutch seals entered the offshore wind farm alpha ventus and British animals entered Sheringham Shoal. Whereas some animals moved and foraged apparently at random inside the wind farm, some other animals showed a special foraging strategy. They visited one turbine and stayed around the pile for a while and then went directly to another wind turbine (Figure 43). This results in a grid based movement pattern that demonstrates that piles were searched systematically for food (Russell et al. 2014).

As with the harbour seal, grey seals were also reported to follow anthropogenic structures such as underwater cables (Russell et al. 2014). Therefore, it is expected that grey seals will react to wind farms in the same way as harbour seals.

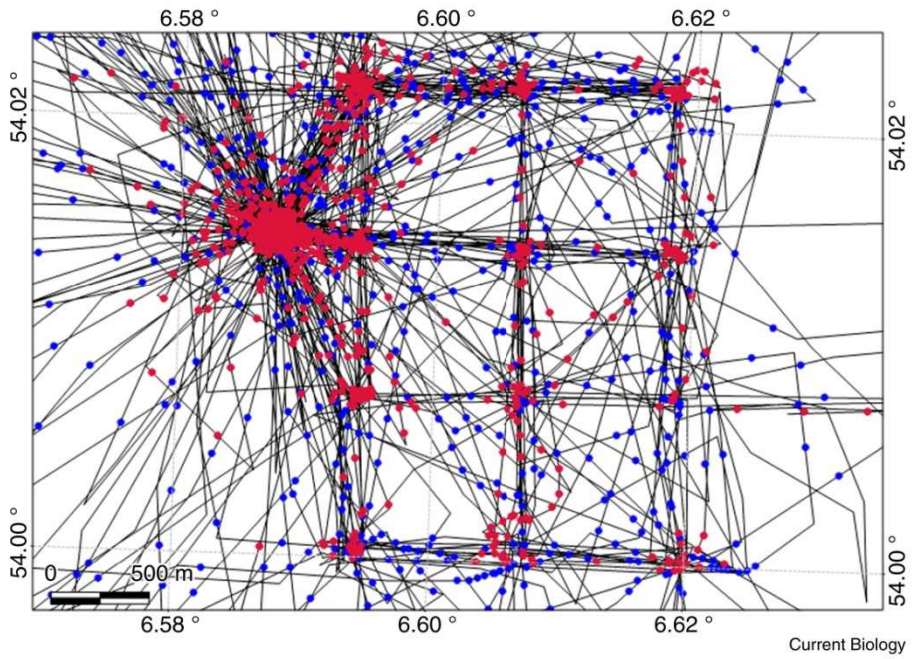


Figure 43: Tracks of a tagged harbour seal around the wind farm 'alpha ventus' (12 turbines) and the research platform FINO 1 (left of alpha ventus). Points show locations at 30 minute intervals; red indicates greater foraging potential (Source: Russell et al. 2014).

7.1.8 Potential impacts due to electromagnetic fields from high voltage cable

Strong electromagnetic fields are only expected in close proximity to cables as the strength of an electromagnetic field decreases with the inverse square of the distance to the cable. Additionally, underwater cables are normally isolated and grounded. The impact on the environment is therefore assumed to be small. However, whales like some other vertebrates seem to possess the ability to orientate with the help of magnetic fields. Magnetic anomalies might increase the likelihood of strandings (e.g. Kirschvink 1990). But how might electromagnetic fields contribute to that? Magnetic orientation is still not completely understood, and the underlying sensory systems are still being widely discussed. If the magnetic senses in whales are similar to those in birds, whales could possibly possess a magnetic map and a magnetic compass. The magnetic map could help the whale to determine its position and the compass to determine its direction. Even just a few meters away from the cable the magnetic field is so reduced that it constitutes only a small part of the overall magnetic field, resulting in no more than a marginal magnetic anomaly (Tricas & Gill 2011). Therefore, disorientation would only be a problem close to cables and reorientation would be possible as soon as whales leave these areas. However, oscillating magnetic fields can disrupt the compass sense, even though their strength is much smaller than the stationary magnetic field. Recently, it has been shown that even weak electromagnetic fields can disrupt orientation in birds. However, the critical frequencies for birds were between 50 kHz and 5 MHz. Electromagnetic fields from high voltage cable have a frequency of around 50 Hz. This left orientation abilities unaffected (Engels et al. 2014). Further, orientation is normally based on several senses (hearing, smelling, and vision). If one sense fails to deliver reasonable data, animals can normally rely on other orientation systems. However, orientation mechanisms and the integration of different orientation cues in marine mammals have not been studied very well.

8 IMPACT ASSESSMENT OF THE CONSTRUCTION PHASE

This chapter describes the impact of different factors which are assumed to affect marine mammals during the wind farm construction. The impact assessment is listed in Table 20. Arguments with respect to the evaluation of the degree of disturbance are discussed in separate subchapters referring to the source impact.

8.1 Preliminary measures

Prior to construction, pre-investigation surveys are conducted to appraise the foundation ground and minimize potential risks (for description of potential risks see 7.1.1).

The impact is assumed to be limited to a radius below 1 km around the survey vessel of prior investigations. The surveys would cover the intended wind farm site, the immediate vicinity and the intended cable route.

As a result of the pre-investigation survey, it might be required to deploy underwater explosives for the clearing of cable routes, ammunition removal etc. Explosions are considered as special cases not directly related to the wind farm. The impact assessment refers solely to the usual pre-investigation measures.

The degree of disturbance due to bottom profiling and other preliminary measures is ranked in a worst case scenario as medium as only a small proportion of marine mammals would avoid the area. The importance of the effect is considered local as impacts are limited to the vicinity of the survey route and the density of marine mammals is relatively low. The likelihood of occurrence is ranked as low because only a small proportion of the mammal population would be affected. The persistence is short-term at any survey location.

The overall magnitude of impacts on marine mammals due to preliminary measures is assessed as negligible (Table 20).

8.2 Impact of underwater noise

The main source of underwater noise during the construction of the wind farm will be the sounds emitted by pile driving. Noise originating from the increasing construction-related ship traffic and from sea bed preparation will be much weaker but may also affect marine mammals during periods without pile driving.

8.2.1 *Pile driving*

Worst case scenario

In general, pile driving noise emissions increase with the diameter of the pile (Koschinski & Lüdemann 2013). Since the size of the designated wind turbines has not yet been determined, the following impact assessment is based on the worst case scenario (see chapter 4.5 for worst case assumptions).

Assuming the largest possible turbine type (10 MW) with the largest monopile diameter (10 m), a noise propagation model has been prepared as part of the EIA wind farm (NIRAS 2015), and this work has been updated so that it complies with the newest recommendations (NIRAS, Rambøll, DHI, 2015). The propagation model provides the impact radiuses where the relevant thresholds for health problems (hearing damage as PTS/TTS) and for disturbance effects on marine mammals would be exceeded. The sound exposure level (SEL) thresholds given by the working group established by Energinet.dk (Working Group, 2015) were selected for the assessment. The noise propagation model considers cumulating noise regarding PTS and TTS and a single pile strike regarding behavioural effects.

Harbour porpoise

Table 16 gives an overview of the worst case impact ranges and impact areas based on the unweighted SEL thresholds for harbour porpoises.

Table 16: Potential impact ranges (PTS = Permanent Threshold Shift; TTS =Temporary Threshold Shift; SEL = sound exposure level; unw = unweighted SEL). Landmass is subtracted from the impact area.

Species (group)	Impact	Threshold	Distance to thresholds		Worst case impact area (km²)
			R mean (m)	R max (m)	
Harbour porpoise	PTS	183 dB re. 1 µPa ^{2} • s cumulative SEL(unw)	6,300	8,150	**209**
	TTS	164 dB re. 1 µPa ^{2} • s cumulative SEL(unw)	23,600	26,500	**1,655**
	Behavioural response	140 dB re. 1 µPa ^{2} • s single strike SEL(unw)	24,100	26,700	**1,680**

Regarding the harbour porpoise, the worst case impact radius would be 8.15 km with the risk of a permanent hearing threshold shift (PTS), 26.5 km with the risk of a temporary threshold shift (TTS) and 26.7 km with disturbance effects or behavioural responses (Table 16). The size of the corresponding impact areas is 209 km² with potential PTS, 1,655 km² with TTS and 1,680 km² with behavioural responses. These values represent the ‘worst case of the worst case’ because they are based on the maximum impact and not the mean impact radiuses. They are also based on a piling event as far from shore as possible. This means that the proportion of affected area that is at sea is maximized.

Figure 44 shows the maximum distribution of noise that can cause PTS, TTS and behavioural effects in porpoise.

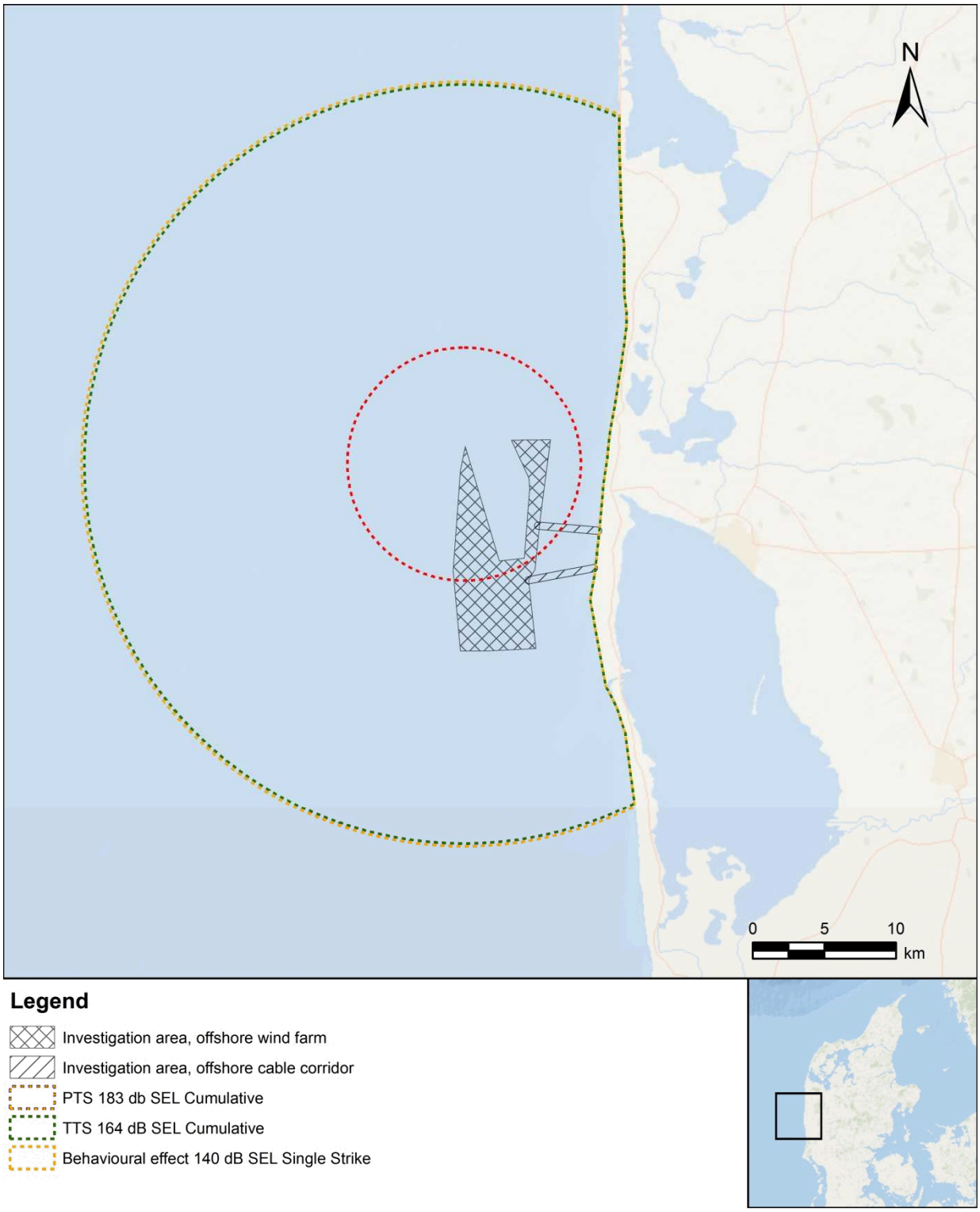


Figure 44: Areas where there is a risk of PTS (183 dB SEL), TTS (164 dB SEL) and behavioural effects in porpoise (140 dB SEL). The figure shows the maximum distribution of noise during piling of one foundation (10 MW).

To judge by the results of the aerial surveys, Vesterhav Syd is an area with low densities in autumn and fluctuating, mainly average densities in the other seasons. It shows a relatively homogeneous porpoise

distribution without explicit hot spots. Hence, no further modeling of distribution was applied for calculating the number of affected animals. The mean density of 0.67 animals/km² has been used to evaluate the effects on porpoise. As mentioned in Section 4.4.3 the population estimate for harbour porpoises in the North Sea is approximately 230,000 animals. The total number of about 230,000 porpoises within the North Sea is considered as the relevant reference population. Defining a 'local population' below that level would be dubious as the North Sea is an open system and little is known about the home range of porpoises ocurring in the Vesterhav Syd area.

Table 17: The number of porpoise affected by piling of one foundation (NIRAS, Rambøll, DHI, 2015).

Scenario	Worst case		2 km deterrence and 9.7 dB reduction of source level	
Effect	% of population	Number of porpoise	% of population	Number of porpoise
PTS (183 dB) (cumulative SEL)	0.061	140	0	0
TTS (164 dB) (cumulative SEL)	0.481	1,106	0.213	489
Behavioural effect (140 dB) (single strike)	0.487	1,121	0.230	530

The number of affected animals in Table 17 is found using a model developed by a working group established by the Danish Energy Agency and Energinet.dk (Working Group, 2015). This model has been adapted to the conditions at Vesterhav Syd offshore wind farm (NIRAS, Rambøll, DHI, 2015). As the exact effect of pingers and seal scarers is uncertain the model has been used to calculate the number of animals affected and the necessary reduction of the noise source level using deterrence to both 1 and 2 km.

In Table 17 it is assumed that the animals are deterred to a distance of 2 km. If it is only possible to deter the animals to a distance of 1 km the necessary reduction of the noise source level will be 12.5 dB and the number of porpoise affected by TTS and behaviourally will be 371 and 412 animals respectively (NIRAS, Rambøll, DHI, 2015). The use of 2 km as a deterrence distance inTable 17 is based on guidelines issued in association with the construction permit of Horns Rev 3 Offshore Wind Farm.

The Danish Energy Agency and Energinet.dk have initiated studies on the effect of deterrence on porpoise and seals using pingers and seal scarers. The result of these studies is expected to be available before the tender to construct Vesterhav Nord offshore wind farm is issued.

The number of animals in Table 17 is the result of modelling for piling of one foundation. However it is not possible to multiply by the number of foundations that is installed. The piling of different foundations will probably take place on consecutive days or a few days apart. Some of the animals affected are likely to be the same, meaning animals that stay in the area around Vesterhav Syd offshore wind farm and migrate in and out of the area during piling activity and breaks in piling activity. However, attention must be drawn to the fact that the total number of piling events might affect more animals than indicated

in Table 17. It is also important to note that piling of foundations closer to land will affect a smaller area than the foundation that is the basis of the results of Table 17.

The duration of the avoidance reaction is limited to the actual pile driving period plus a subsequent 'waiting time'. The latter is dependent on the duration of the pile driving and the distance to the construction site, i.e. the received noise level. In the vicinity of pile driving sites in the BARD Offshore 1 wind farm a longer lasting below average presence was detected at distances up to 8 km (PGU 2013). According to Brandt et al. (2011) the disturbance effect would last 1-3 days where noise levels exceed 160 dB SEL and less than one day at lower noise levels. As the above 160 dB noise level in the worst case would cover a large proportion of the wind farm area and that piling of different foundations will probably take place on consecutive days or a few days apart, it is to be expected that harbour porpoise densities will consistantly be reduced at the wind farm site during the whole construction period.

Based on the recommendations of the working group established by Energinet.dk it is necessary to include a scenario where no porpoise experience PTS (Working Group, 2015). As it can be seen in Table 17 it is likely that 140 porpoise will experience PTS in the worst case scenario. Therefore a scenario including deterrence of porpoise to 2 km from the piling site and a reduction of noise source level by 9.7 dB is included in Table 17. In addition to this the scenario assume that the animals flee with a speed of 1.5 m/s. 9.7 dB is the reduction necessary to reduce the number of porpoise that experience PTS to zero.

Regarding behavioural effects attention must be drawn to the fact that cumulative effects are not modelled. It is possible that there will be behavioural effects at larger distances (>30 km) than the maximum of approximately 27 km modelled for a single strike. As actual behavioural response ranges, distances of roughly 20 km to various OWF pile driving activities have been found (Brandt et al. 2011, PGU 2013). (However, the worst case assumption for Vesterhav Syd is based on higher noise emissions.) Behavioural responses do not necessarily lead to total avoidance. The effect on the porpoise activity decreases with increasing distance to the pile driving site. The investigations of Pehlke et al. (2013) (cited in Nehls et al. (2014)) and (PGU 2013) at the construction sites of the wind farms Trianel Borkum and BARD Offshore 1 revealed that total avoidance only occurs at noise levels above 160 dB SEL. As regards the 140 dB SEL 'behavioural response radius', a proportion of about 60 % of the harbour porpoises would actually leave the area (Pehlke et al. 2013).

Seals

Table 18 gives an overview of the worst case impact ranges and impact areas based on the unweighted SEL thresholds for seals.

Table 18: Potential impact ranges (PTS = Permanent Threshold Shift; TTS =Temporary Threshold Shift; SEL = sound exposure level; unw = unweighted SEL). Landmass is subtracted from the impact area.

Species (group)	Impact	Threshold	Distance to thresholds		Worst case impact area (km²)
			R mean (m)	R max (m)	
Seals	PTS	200 dB re. 1 µPa ^{2} • s cumulative SEL(unw)	115	220	**0.15**
	TTS	176 dB re. 1 µPa ^{2} • s cumulative SEL(unw)	12,000	14,300	**585**

In the case of cumulating pile driving noise, the risk of PTS and TTS for seals would be present within the worst case threshold radiuses of 220 m and 14.3 km respectively (Table 18). The size of the corresponding impact areas is 0.15 km² with potential PTS and 585 km² with TTS.

As correction factors are not known, it is not possible to calculate densities for seals. From the number of sightings it can be assumed that the densities of these species are quite low in the Vesterhav Syd area. A maximum density estimation of 0.08 animals per km² (both species summarized) in the wind farm area seems to be justifiable, based on the seven times higher detection rate of porpoises and the coastal density gradient shown in the map of Herr et al. (2009b) (see Figure 34). There are approximately 130,000 grey seals in the eastern Atlantic region (Section 6.6). It is assumed that the relevant biogeographical population of harbour seal consists of the populations of the Wadden Sea and the Limfjord area, making a total number of more than 42,000 individuals (Hansen 2012, TSEG 2013). These numbers are used as the relevant biogeographical populations in Table 19.

Figure 45 shows the maximum distribution of noise that can cause PTS and TTS and in seals.

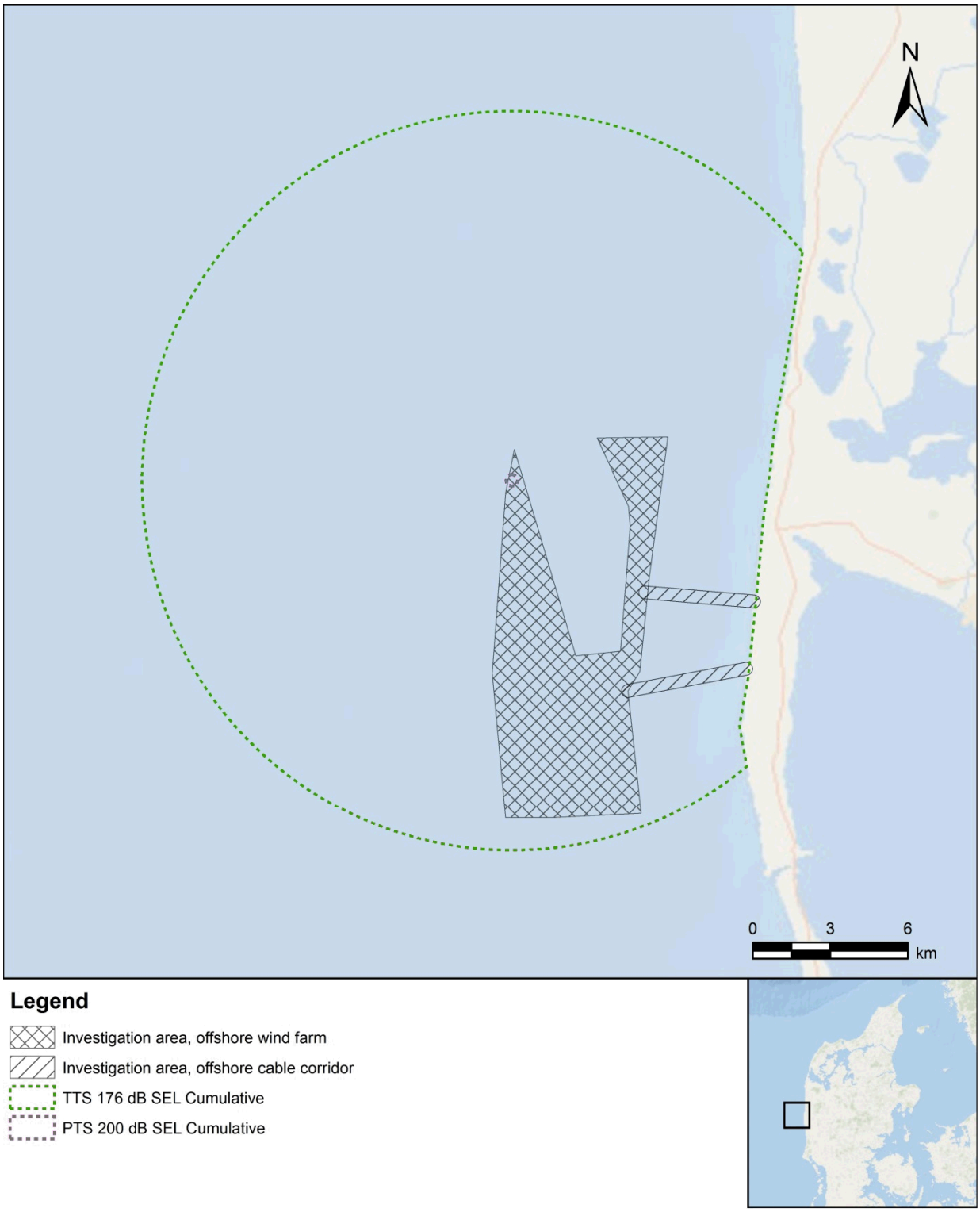


Figure 45: Areas where there is a risk of PTS (200 dB SEL) and TTS (176 dB SEL) in seals. The figure shows the maximum distribution of noise during piling of one foundation (10 MW).

Table 19: The number of seals affected by piling of one foundation (NIRAS, Rambøll, DHI, 2015).

Scenario	Worst case		2 km deterrence and 9.7 dB reduction of source level	
Effect	% of population (grey seal/harbour seal)	Number of seals	% of population grey seal/harbour seal)	Number of seals
PTS (200 dB) (cumulative SEL)	0/0	0	0/0	0
TTS (176 dB) (cumulative SEL)	0.036/0.112	47	0.007/0.021	9

In Table 19 it is assumed that the animals are deterred to a distance of 2 km. If it is only possible to deter the animals to a distance of 1 km the necessary reduction of the noise source level to prevent porpoises from experiencing PTS will be 12.5 dB. This will reduce the number of seals experiencing TTS from 9 to 5 (NIRAS, Rambøll, DHI, 2015).

The number of animals in Table 19 is the result of modelling piling of one foundation. However it is not possible to multiply by the number of foundations that is installed. The piling of different foundations will probably take place on consecutive days or a few days apart. Some of the animals affected are likely to be the same, meaning animals that stay in the area around Vesterhav Syd offshore wind farm and migrate in and out of the area during piling activity and breaks in piling activity. However, attention must be drawn to the fact that the total number of piling events might affect more animals than indicated in Table 19. It is also important to note that piling of foundations closer to land will affect a smaller area than the foundation that is the basis of the results of Table 19.

The percentage of populations affected in Table 19 is based on the unlikely worst case assumption that all seals in the area are either grey seal or harbour seal.

The recommendations of the working group (Working Group, 2015) suggest that it will be necessary to deter porpoise and reduce the noise source level when piling at Vesterhav Syd to prevent porpoise from experiencing PTS. As the PTS noise criteria for seals is higher than for porpoise this is not necessary to ensure that the project will not cause permanent hearing damage in seals. However, deterrence and mitigation will also to some extent be beneficial to seals.

Deterrence and a reduction of source level will to some degree prevent that seals in the area will experience TTS. However, it will not necessarily completely prevent TTS.

PBR and PCoD approaches

According to ICES (2014) the PBR of the North Sea population is 1,246 harbour porpoises, based on a minimum population estimate of 216,400. The PBR is the number of animals that could die as a result of human activities without depletion or impeding recovery of the population. In this number all anthropogenic effects of e.g. fishing, ship traffic and wind farm construction have to be considered. This calculation is relevant mainly for lethal effects, as applied for the biological relevance of fisheries (Read 2013).

The mentioned PBR value is lower than the 1 % criterion which is often used to assess the impact at population level (ASCOBANS 2000, 2002). However, in contrast to PBR the 1 % criterion refers to the

mean population estimate and includes non-lethal disturbance effects. The PBR approach only refers to human-caused mortality. It does not include non-lethal reversible effects such as TTS, displacement and behavioural reactions. Additionally, the PBR concept includes all human-created mortality and therefore the question that has to be answered is whether the wind farm effect will increase the human-created mortality beyond the threshold of PBR.

As the designation “Interim Population Consequences of Disturbance” indicates, the PCoD approach refers also (and mainly) to the non-lethal effects of pile driving on the harbour porpoise population (Harwood et al. 2014). The PCoD model describes the short-term to long-term population decline as a consequence of both hearing loss and displacement effects.

Representing the worst case assumptions (10 m diameter piles, no noise mitigation), the following input parameters were fed into the PCoD model:

- population size: 230,000 individuals,

- number of piling events: 20,

- period between each piling event: 3 days,

- effect of disturbance due to pile driving is asumed to last until one day after pile driving,

- number of animals affected by cumulative pile driving noise (691 for risk of PTS and 2,818 for TTS / avoidance), these numbers are derived from the original noise modelling (NIRAS, 2015), and are as such worst case compared to the numbers based on the newest recommedations (NIRAS, Rambøll, DHI, 2015).

- other population parameters as defaults given by the model.

Some of the parameters used are just rough estimates. Since the number of disturbed harbour porpoises was not modelled for cumulating pile driving noise at Vesterhav Syd, the modelled number of animals exposed to the risk of TTS in the worst case was used instead. The latter might be close to the actual number of disturbed animals.

Figure 46 shows the resulting output of the PCoD model. According to the model the local population of 230,000 harbour porpoises would decline by roughly 500 individuals due to the pile driving activity at Vesterhav Syd (worst case scenario). The maximum effect on the population would occur 15 years after construction. A population decline of around 500 individuals would represent 0.2 % of the current population size. Furthermore, 500 animals would constitute 40 % of the PBR mentioned by ICES (2014). However, PCoD and PBR cannot be compared directly as PCoD shows a possible long-term influence on the population whereas PBR describes the potential annual removal.

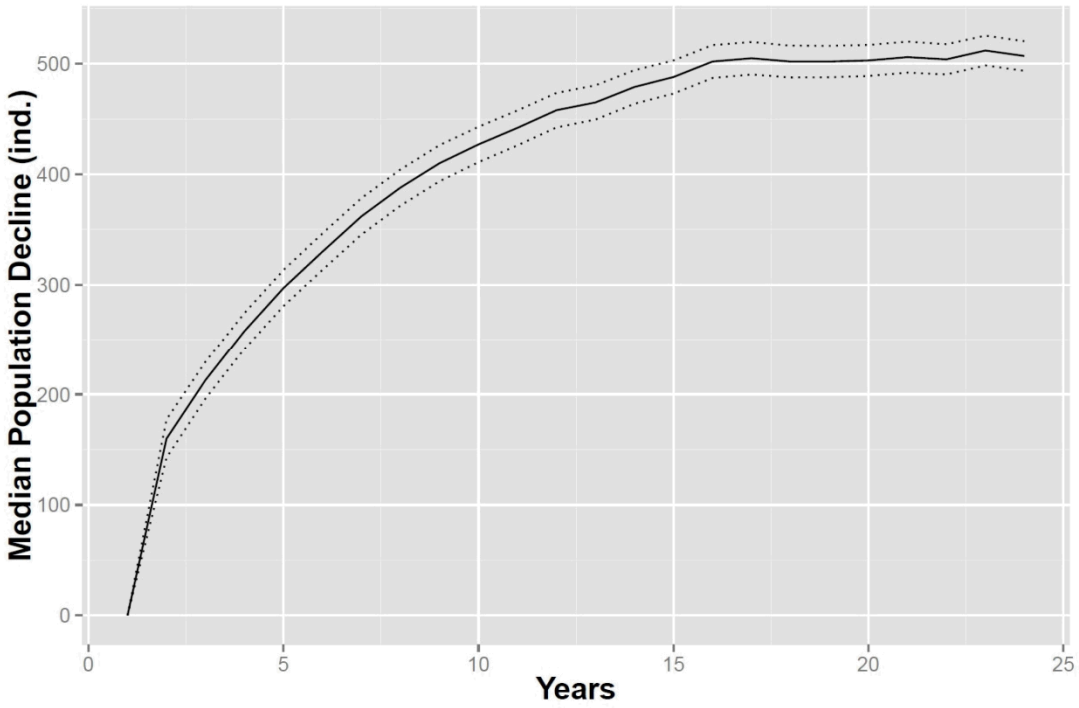


Figure 46: Modelled population decline of harbour porpoises in the North Sea subpopulation caused by pile driving in the Vesterhav Syd area according to Harwood et al. (2014). Dotted lines indicate the lower and higher 95 % confidence intervals.

The result of the model indicates that the project Vesterhav Syd might cause an insignificant decline in the porpoise population.

According to a mathematical model developed by Nabe-Nielsen et al. (2014) avoidance caused by existing wind farms can cause a population decline of 10 %. However, this is based on the assumption that all OWPs have the same effect on porpoises as Nysted which is not the case actually. The erection of further wind farms does not necessarily add a further decrease.

For the assessment of fairly short-term impacts at population level due to behavioural effects and avoidance the more conservative 1 % criterion is still used for precautionary reasons as the parameter value for the “likelihood of occurrence” (see below).

Impact assessment (worst case scenario)

The degree of disturbance in the case of hearing injuries is generally ranked as high because PTS and TTS may have serious consequences for the affected individuals. In the case of behavioural responses it is ranked as medium as the relevant impact range will not be totally avoided.

For harbour porpoises, the importance of the impact is ranked as regional in the worst case for short-term hearing injuries (TTS). Because of the vast potential impact area of cumulating noise the importance may reach an international level regarding behavioural responses. The impact on seals is expected to be of regional importance in the worst case as the range of potential hearing injuries and behavioural responses would be smaller.

The likelihood of occurrence is assessed as low for PTS, but expected to be high for TTS and behavioural responses of harbour porpoises as more than 1 % of the population could be affected (seals: medium).

The persistence of the impact is generally ranked as short-term for hearing injuries as the risk only exists during the actual pile driving phases. In contrast, behavioural responses may lead to a prolonged avoidance behaviour of harbour porpoises in the central part of the impact area. Therefore the effect is expected to be temporary despite the period with pile driving activity, which will probably be shorter than one year.

The overall magnitude of pile driving effects on marine mammals in the area is assessed as moderate for the worst case (Table 20). The latter is characterised by persistant avoidance behaviour of harbour porpoises at the wind farm site throughout the construction phase and beyond.

In the case of moderate negative impacts, mitigation measures have to be integrated into the assessment (see Table 6). Deterrence measures before and during the start of pile driving as well as noise mitigation measures are recommended (chapter 15). These measures would decrease the risk of hearing injuries and would substantially reduce the size of the impact area. Furthermore, it is possible to reduce the impact by using smaller monopiles than the 10 m piles that are presumed in the worst case scenario.

With mitigation measures applied, the overall magnitude of pile driving effects could be reduced to a minor impact in the worst case (see Table 20).

8.2.2 Ship traffic

The main effects on seals and harbour porpoises which might occur in the context of shipping are the masking of communication signals (Clark et al. 2009) and the changing of diving and foraging patterns (Richardson et al. 1995) (see also chapter 7.1.5).

The degree of disturbance is ranked as medium in the worst case as only a fraction of the marine mammals in the area would be affected by ship traffic. (Also in view of the fact that the wind farm area is adjacent to highly frequented shipping lanes, the additional impact of construction related ship traffic might be small.) The importance of the effect is considered as local as mainly a limited area around the current location of ships is affected. The likelihood of occurrence is ranked as low as only a small proportion of the mammal population will be affected. The persistence is considered as temporary because the increase in ship traffic will probably endure throughout the construction phase and possibly remains on an elevated level afterwards.

The overall assessment characterizes the magnitude of impact on marine mammals in the worst case due to ship traffic (Table 20) as “minor”.

8.3 Sedimentation and turbidity

As regards to increased suspended sediment in the water, pile driving has relatively low effects compared to other foundation construction techniques. For example Engell-Sørensen & Skyt (2001) as-

sumed 1,000 m³ sediment spill for Rødsand I in total (72 foundations). Sediment spill figure for gravitation foundations was assumed to be higher (2,000-4,000 m³) and foundation drilling resulted in total to 7,000 m³ sediment spill. However, this will be dependent on the sediment characteristics at the piling location as well as on the piling size. The worst case scenario postulates 66 turbines erected with pile drilling. Adjustments for differing wind farm sizes would yield a total sediment spill of around 6,500 m³ for Vesterhav Syd.

The degree of disturbance is ranked as low as porpoises can still hunt in turbid waters and prey availability is thought to decrease only slightly. The importance of the effect is considered as local as mainly the area around the piling location is affected. In areas further away the suspended sediment is diluted by the North Sea water and settlement of suspended sediments is marginal. The likelihood of occurrence is ranked as medium as numerous mammals will encounter waters that are at least slightly affected by these sediments. Most of the suspended sediment will settle within a short time, the persistence is therefore considered as short-term. Therefore, a negligible magnitude of impact (Table 20) may be deduced.

8.4 Total impact during construction

The assessment of potential impacts during construction of the wind farm is summarised in Table 20. The magnitude of impact on marine mammals is assessed to be moderate in the worst case. The latter is characterised by a high risk of TTS and persistant avoidance behaviour of harbour porpoises throughout the construction phase, in response to the noise emitted by the driving of 10 m piles without mitigation measures. If mitigation measures are applied, the overall magnitude of pile driving effects can be reduced to a minor impact.

Table 20: Total impact on marine mammals during construction of the wind farm (worst case scenario).

Source of impact	Impact	Degree of disturbance	Importance	Likelihood of occurence	Persistence	Magnitude
Harbour porpoise						
Preliminary measures	**Behavioural response**	medium	local	low	short-term	negligible
Pile driving noise (no mitigation applied)	**PTS**	high	local	low	short-term	negligible
	TTS	high	regional	high	short-term	moderate
	Behavioural response	medium	international	high	temporary	moderate
Pile driving noise (mitigation applied)	**PTS**	high	local	low	short-term	negligible
	TTS	high	local	medium	short-term	negligible
	Behavioural response	medium	regional	medium	short-term	minor
Ship traffic	**Behavioural response**	medium	local	low	temporary	minor
Sedimentation / Turbidity	**Behavioural response**	low	local	medium	short-term	negligible
Seals						
Preliminary measures	**Behavioural response**	medium	local	low	short-term	negligible
Pile driving noise (no mitigation applied)	**PTS**	high	negligible	low	short-term	negligible
	TTS	high	local	low	short-term	negligible
	Behavioural response	medium	regional	medium	short-term	minor
Pile driving noise (mitigation applied)	**PTS**	high	negligible	low	short-term	negligible
	TTS	high	negligible	low	short-term	negligible
	Behavioural response	medium	regional	medium	short-term	minor
Ship traffic	**Behavioural response**	medium	local	low	temporary	minor
Sedimentation / Turbidity	**Behavioural response**	low	local	medium	short-term	negligible

9 IMPACT ASSESSMENT OF THE OPERATING PHASE

The lifetime of the wind farm is expected to be around 25-30 years. This chapter describes the impact of different factors which are assumed to affect marine mammals during the wind farm operation. The Impact assessment is listed in Table 21. Arguments relevant to the evaluation of the degree of disturbance are discussed in separate subchapters.

9.1 Underwater Noise

9.1.1 Operational noise

The operational noise of wind turbines can be transmitted into the water through the pile and the foundation. Compared to the construction noise, the level of operational noise will be much lower. However, it will be permanently present during the whole operating phase, except for brief periods without wind or during storms. (The turbines will begin generating power when wind speed at hub height is between 3 and 5 m/s and achieve their rated output at wind speeds above 12 m/s. They shut down automatically when the average wind speed exceeds 25 m/s to 30 m/s for extended periods.)

The impact range of operational underwater noise is limited as previous assessments indicate (Tougaard & Teilmann 2007). In most cases the source levels reached values of 10 – 20 dB above the background noise levels in the area, but also some higher levels are reported for turbines in full load operation (Wahlberg & Westerberg 2005, Elmer et al. 2007). In view of the measured sound levels the turbine noise can be heard by porpoises at maximum distances of around 100 m. Because of their better hearing capability at low frequencies, seals will hear the noise at longer distances.

Harbour porpoises as well as seals have been observed in operating offshore wind farms in numbers comparable with those before construction (Tougaard et al. 2006, Scheidat et al. 2011). As the worst case turbine type for Vesterhav Syd (10 MW) is larger than the turbines in the above mentioned reports, it cannot be excluded that the source level of operational noise occasionally exceeds the harbour porpoises avoidance threshold. The corresponding impact radius is precautionary assumed to be 100 m in the worst case (see chapter 7.1.3). Based on this the total impact area of 20 turbines would be 0.6 km² within the wind farm. However, as the noise is not harmful and of a permanent character, the porpoises will probably become accustomed to it. Although seals can hear the operational noise from wind turbines in principle better than porpoises, it was shown that harbour seals forage close to wind turbines (Russell et al. 2014). Therefore, for harbour seals and grey seals no avoidance behavior is expected.

As only few harbour porpoises would show behavioural reactions in the worst case, the degree of disturbance is low. The effect is restricted to a fraction of the wind farm and therefore the importance is considered to be negligible. The likelihood of occurrence at population level is low. The persistence is considered to be permanent as the turbine sounds will be present throughout the operating phase.

The overall magnitude of impact on harbour porpoises caused by operational noise is assessed as negligible (Table 21).

9.1.2 *Maintainance*

Linked to maintenance and service during the operation phase, underwater noise will mainly be produced by ships. This includes crew transfer and transport of equipment, mostly by small vessels or motorboats. Shipping activity will be less frequent than during the construction phase. It is expected that the normal servicing interval for the turbines will be approximately 6 months. In the case of unscheduled maintenance due to sudden defects, helicopters may also be used in combination with the vessels. Since external ship traffic will be regulated and thereby limited by the Danish Maritime Authority in the wind farm area, marine mammals are overall less exposed in this area. The regular boat trips for maintenance might lead to an adaption to the traffic.

Since maintainance ships are usually small, the amount of traffic limited and the density of marine mammals fairly low, the degree of disturbance is rated as low, the importance of the impact as negligible and the likelihood as low. The maintainment traffic is not permanently present in the wind farm, so the persistence of the impact is assumed to be short-termed.

The overall magnitude of impacts on marine mammals due to the maintainance of the wind farm is assessed as negligible (Table 21).

9.2 Habitat Changes

Harbour porpoise

In the case of 66 3 MW wind turbines with a monopile and the scour protection with the greatest dimensions, a seabed of up to 105,600 m² would be occupied. This would correspond to 0.18 % of the planning area (0.105 km² coverage of 60 km²). If 20 turbines with 10 MW are installed, the footprint caused by scour protection will be reduced to 40,000 – 42,000 m². This would correspond to 0.07 % of the planning area. Presumable, the worst case scenario for habitat change will therefore be 66 3 MW wind turbines.

Even in the worst case scenario most of the planning area will remain unaffected, and assuming that there will be only slightly reductions in numbers of demersal fish (if any reduction at all), the degree of disturbance is low. The effect is restricted to a fraction of the wind farm area and therefore the importance is considered to be negligible. The likelihood of occurrence of negative effects is considered as low. The persistence is considered to be permanent as hard substrate will remain in the water beyond the operation phase. Therefore, the magnitude of impact caused by negative effects is evaluated as negligible (Table 21).

These assessments did not take into account positive effects. Hard substrate may also be the basis of structures resembling artificial reef structures where sessile organisms can settle. Additionally, young fish are attracted by the shelter of these structures. The exclusion or regulation and limitation of fishery would also support the enhancement of the young fish population (Gutow et al. 2014). Taking both effects together the overall amount of food will probably increase, attracting opportunistic feeders like the harbour porpoise.

Seals

Depending on the scenario a coverage of up to 105,600 m² of scour protection is imaginable which is here considered as the worst case scenario (see above).

The impact assessment for both seals matches that of the porpoises. The degree of disturbance is considered even smaller than that for porpoises as harbour seals are opportunisticly piscivorous and their diet reflects the fish abundance present in the foraging territories. Therefore, the degree of disturbance is still low. The argumentation for all other categories reflects that of porpoises: importance is negligible, likelihood of occurrence is low and the persistence is permanent. This results again in a magnitude of impact which is negligible (Table 21).

Once again only negative effects were considered in the assessments. However, positive effects will occur as well. These will be the result of the artificial reef effects and the exclusion or regulation and limiataion of fishery. Harbour seals benefit from wind farms as they can target pile structures during foraging. Grey seals are known to search other anthropogenic structures and are likely to behave like to harbour seals in this respect. Therefore, we assume that grey seals benefit from structures resembling artificial reefs too.

9.3 Electromagnetic fields from high voltage cable

The effect of electromagnetic fields has been widely discussed but evidence that electromagnetic fields have an effect on organisms is scarse. High voltage cables that produce fields with a frequency of 50 Hz seem to have no effect on the orientation abilities of animals (Engels et al. 2014). Therefore, the degree of impact is regarded as low. The strength of electromagnetic fields decreases rapidly with the distance from the source. Therefore, it is assumed that the effect (if any) is very localized at the cables and does not cover the entire wind farm, and the importance is therefore negligible. Only very few porpoises will be in this possibly affected area and it is not likely that an effect will occur. Evidences that seals use the magnetic field are missing and so for pinnipeds assessments of possible effects are even more speculative. The likelihood of occurrence is low. However, the cables and the electromagnetic fields will remain during the entire operation phase and are therefore permanent. This results in a magnitude of impact that is ranked as negligible (Table 21).

9.4 Total impact during operation

The assessment of potential impacts during operation of the wind farm is summarised in Table 21. The magnitude of impact on marine mammals is assessed to be negligible for all potential effects.

Table 21: Total impact on marine mammals during operating phase

Source of impact	Impact	Degree of disturbance	Importance	Likelihood of occurence	Persistence	Magnitude
Harbour porpoise						
Operational noise	**Behavioural response**	low	negligible	low	permanent	negligible
Maintainance	**Behavioural response**	low	negligible	low	short-term	negligible
Habitat change	**Habitat loss**	low	negligible	low	permanent	negligible
Electromag-netic fields	**Behavioural response**	low	negligible	low	permanent	negligible
Seals						
Operational noise	**Behavioural response**	low	negligible	low	permanent	negligible
Maintainance	**Behavioural response**	low	negligible	low	short-term	negligible
Habitat change	**Habitat loss**	low	negligible	low	permanent	negligible
Electromag-netic fields	**Behavioural response**	low	negligible	low	permanent	negligible

10 IMPACT ASSESSMENT DURING DECOMMISSION

The method for decommissioning the wind farm will follow best practice and the legislation at that time. It is unknown at this stage how the wind farm may be decommissioned. This chapter describes the impact of different factors which are assumed to affect marine mammals during decommissioning. The impact assessment is listed in Table 22. Arguments related to the evaluation of the degree of disturbance are discussed in separate subchapters.

10.1 Underwater noise

During decommissioning of the offshore wind farm impacts on marine mammals similar to those experienced during construction are to be expected. This includes the underwater noise emissions due to the decommissioning work and the increase in ship traffic. However, the decommissioning of the wind turbines is expected to be less noisy than the pile driving during construction. As the decommissioning procedure is not known yet and no experience from other projects is available, the impact of the decommissioning noise on marine mammals can hardly be assessed.

For the assessment it is assumed that noise emissions during decommissioning tend to be less intense than during pile driving. The risk of a permanent hearing injury due to decommissioning noise is considered as unlikely but the degree of disturbance might be high in case of TTS. Regarding behavioural responses it is ranked as medium as the potential impact range would not be totally avoided. Owing to the average densities of harbour porpoises and seals, the importance of the impact is assumed to be regional and the likelihood to be medium.

Considering the short-term persistence of effects, the overall magnitude of decommissioning impacts on marine mammals is assessed as minor (Table 22).

Should the underwater noise during decommissioning be as intense as during pile driving, the impact assessment of the latter (Table 20) would also apply for decommissioning. The same holds true for the application of mitigation measures, which could be necessary if explosives are used.

10.2 Habitat changes / loss

All scour protection will remain in the planning area. Cables will either be removed or left in the seabed. If they are removed, this will cause sediment dispersion and an increase in water turbidity. However, this will be restricted to a small temporal and spatial scale. Alternatively, the cables could be protected by rock dumping. Rock sizes used for this purpose normally vary between 10 and 40 cm. The width of the band of dumped rocks along the cable is between 2 and 3 metres. Then, the area covered with hard substrates is made of the former scour protection that remains in the sea and the additional rocks that are used for protecting the cables.

After decommission hard substrate will remain from foundations plus scour protection and possibly rock dumping on cables. They constitute structures resembling artificial reefs. Therefore, remaining hard structures are very unlikely to constitute habitat impairment for marine mammals. As described before mammals, especially seals, probably benefit from such structures or these structures have to be con-

sidered as at least neutral (Russell et al. 2014). When rocks are used for cable dumping, the area covered with hard substrate increases again compared to the operation phase. This could increase negative effects on the benthic organisms of the soft bottom and possibly demersal fish and sandeels could theoretically decrease slightly. In fact, only small changes of sandeel occurrence were documented in the Horns Rev area. In a short-term period, numbers of adult and juvenile sandeels increased, in a long term period numbers of juvenile fish decreased. This effect was mainly restricted to Great Sandeel (Hyperoplus lanceolatus) (van Deurs et al. 2012).

However, as this effect does not substantially add to the total effect, the impact assessment for the habitat changes remains constant compared to the operation phase for all mammal species. The degree of disturbance is low, the importance is negligible, the likelihood of occurrence is low and the persistence is permanent. This all adds up to a negligible impact (Table 22).

10.3 Sedimentation and turbidity

It is assumed that the amount of sediment spilled during decommissioning of the wind farm will be the same as that during pile driving. Therefore, the impact assessment is also the same (chapter 8.3). The degree of disturbance is considered as low, the importance is local, the likelihood of occurrence is medium and the persistence is short-term. The magnitude of impact is therefore negligible (Table 22).

10.4 Total impact during decommissioning

The assessment of potential impacts during decommissioning is summarised in Table 22. The magnitude of impact on marine mammals is assessed to be minor in the worst case. Since there is no previous experience regarding decommissioning effects on marine mammals, simply because there has been no decommissioning of wind farms yet, the impact can hardly be assessed. Should explosives be used, the same impact assessment as for pile driving (see Table 20) would be more or less applicable to decommissioning.

Table 22: Total impacts of the wind farm decommissioning on marine mammals

Source of impact	Impact	Degree of disturbance	Importance	Likelihood of occurence	Persistance of impact	Magnitude of impact
Harbour porpoises						
Decommission-ing noise	**TTS**	high	local	low	short-term	negligible
	Behavioural response	medium	regional	medium	short-term	minor
Habitat change	**Habitat loss**	low	negligible	low	permanent	negligible
Sedimentation & turbidity	**Behavioural response**	low	local	medium	short-term	negligible
Seals						
Decommission-ing noise	**TTS**	high	local	low	short-term	negligible
	Behavioural response	medium	regional	medium	short-term	minor
Habitat change	**Habitat loss**	low	negligible	low	permanent	negligible
Sedimentation & turbidity	**Behavioural response**	low	local	medium	short-term	negligible

11 IMPACTS DUE TO CABLE LAYING

The main impacts in the context of cable laying are noise caused by increased boat traffic and installation tools. Additionally, sedimentation due to the cable laying itself can cause temporary loss of orientation and decreasing foraging success due to poor visibility. Arguments related to the evaluation of the degree of disturbance are discussed in separate subchapters. The impact assessment is listed in Table 23.

11.1 Underwater noise

Installation tools

The impact of noise due to cable laying itself depends on the installation tool which is used. In deeper waters tools may be used such as the vertical injector, which buries the cable by applying moderate water pressure. In some areas installation with vibrating tools e.g. vibro-sword or vibro-plow might be needful. These vibrating tools create sounds at low frequencies. Since harbour porpoises are more sensitive to high frequencies, a low impact can be assumed. Seals on the other hand are sensitive to sounds at lower frequencies, and disturbance due to cable installation might occur. Since the cable installation phase normally takes place over a period of a few weeks only, the impact is short-term.

Ship traffic

During cable installation and supply small, fast ships as well as bigger barges and pontoons will be used. These vessels are known to produce noise in a frequency range below 1 kHz (Richardson et al. 1995, Robinson et al. 2011). As there may still be noise at high frequencies, shipping could affect seals on the lower sound levels as well as harbour porpoises at high sound levels. The severity of disturbance depends on the number of vessels and number of trips. As discussed in previous chapters, the Vesterhav Syd area is surrounded by heavily congested shipping lanes, and a relatively small amount of additional shipping will not add considerably to the existing disturbances. A permanent displacement is not to be expected, especially in view of the fact that heavily trafficked areas can show high abundance of Harbour porpoise. In the Øresund area between Denmark and Sweden a high concentration of prey is assumed to cause high porpoise abundance despite the intense vessel activity in the area (Sveegaard et al. 2012).

Counts of seals revealed relatively low numbers occurring in the Vesterhav Syd area (33 in total). No important haul-out sites have been found in the area or at the adjacent coast.

Disturbance due to light emissions during cable laying by night is comparable with the light emissions of shipping at night. This is assessed to be very low. Taking into account the relatively low number of harbour porpoises and seals in the area and the distance to haul-out sites, no negative impact on marine mammals in the context of light emissions is expected.

Overall, the degree of disturbance due to cable installation and shipping noise is ranked as medium in the worst case (harbour porpoise) as only a small proportion of the marine mammals in the area would be affected. The importance of the effect is considered as local as impacts are limited to the vicinity of the current cable laying location at any given time. The likelihood of occurrence is ranked as low as only

a small proportion of the mammal population will be affected. Since the cable laying operation slowly moves along its route, the persistence is short-term at any one location.

Overall, the magnitude of impacts on marine mammals due to cable laying noise and ship traffic is assessed as negligible (Table 23).

11.2 Sedimentation and turbidity

In addition to sediment spill during the establishment of the foundations (pile driving, pile drilling or gravity foundation etc.) sediment spill is also caused by cable laying. Cables will be buried to a depth of 1 to 1.5 metres. Sediment spill will occur along the cable route. This sediment in suspension will drift because of currents but will at the same time become attenuated. Areas of significant turbidity will remain local. The impact assessment is similar to that of piles erecting (chapter 8.3). The degree of disturbance is considered as low, the importance is local, the likelihood of occurrence is medium and the persistence is short-term. The magnitude of importance is therefore again negligible (Table 23).

11.3 Total impact during cable laying

The assessment of potential impacts during cable laying is summarised in Table 23. For all pressures the magnitude of impact on marine mammals is assessed to be negligible.

Table 23: Total impact on marine mammals during cable installation.

Source of impact	Impact	Degree of disturbance	Importance	Likelihood of occurence	Persistence	Magnitude
Harbour porpoise						
Installation noise	**Behavioural response**	medium	local	low	short-term	negligible
Ship traffic	**Behavioural response**	low	local	low	short-term	negligible
Sedimentation & turbidity	**Behavioural response**	low	local	medium	short-term	negligible
Seals						
Installation noise	**Behavioural response**	low	local	low	short-term	negligible
Ship traffic	**Behavioural response**	low	local	low	short-term	negligible
Sedimentation & turbidity	**Behavioural response**	low	local	medium	short-term	negligible

12 IMPACTS DUE TO EMISSION AND DISCHARGES

During cable laying, wind farm construction and decommissioning as well as due to maintainance in the operation phase, some emissions from vessels and helicopters working in the wind farm area will be released into the atmosphere. It is required that all vessels working in the wind farm area comply with the Marine Environmental Act (Havmiljøloven nr. 963 from 03/07/2013) (Miljøministeriet Naturstyrelsen 2013). These emissions are not considered to be markedly higher than emissions from the normal daily shipping traffic in the surrounding area (Figure 21). No effect of emissions and discharges on marine mammals is expected.

The risk of marine mammals being affected by other pollutants in terms of discharges e.g. oil or other chemicals is extremely low. According to the Danish law act N°. 267 of 18 April 2008 (Ministry of the Environment, 2008), oil and other hazardous substances must not be discharged in Danish territorial waters. As there is a minor risk of accidental discharges or spill from the turbines or vessels associated with the construction and decommissioning, it would be desirable to minimize potential environmental pollution by use of environment friendly oil and lubricants (e.g. Panolin hydraulic oil).

13 NATURA 2000 ASSESSMENT

13.1 Natura 2000 sites

The effects of cumulative noise on the behaviour of marine mammals has not been modelled, but the noise emitted has the potential to disturb mammals at rather long distances from the Vesterhav Syd area (see chapter 8.2.1), therefore potential impacts on marine mammals in surrounding Natura 2000 areas have to be taken into account. The Natura 2000 “Site of Community Interest” (SCI) “Sandbanker ud for Thorsminde” (DK00VA341) is possibly within the impact area of cumulative noise. However, the conservation objectives of the area refer to sand bank habitats and not to marine mammals. Therefore, no significant impact on conservation objectives can occur regarding marine mammals.

Owing to the great distance to the SCI’s DK00AY176 “Wadden Sea” and DK00VA347 “Southern North Sea” the risk of hearing damage (PTS/TTS) can be excluded for marine mammals in these areas. Based on the worst case assumptions, it cannot be excluded that cumulative noise levels of more than 140 dB SEL will reach the Natura 2000 sites and cause behavioural responses in harbour porpoises. As the noise immissions would exceed the threshold by a minor extent and would be of short duration, a significant effect on the conservation objectives is very unlikely.

Because of the distance to the SCI DK00EY133 “Agger Tange, Nissum Bredning, Skibsted Fjord & Agerø” and the fact that the Limfjord waters are shielded from the North Sea, no effects of underwater noise emissions from pile driving at Vesterhav Syd are expected inside this Natura 2000 area.

During the operation of Vesterhav Syd, impacts on Natura 2000 sites can be generally excluded because of the very limited range of potential effects. The decommissioning of the wind farm is expected to cause less or at least no more noise emissions than its construction. It is thus concluded that the construction, operation and decommissioning of the Vesterhav Syd offshore wind farm will not result in significant effects on marine mammal conservation objectives in any Natura 2000 area.

13.2 Species protection

13.2.1 Assessment of Article 12 (1) (a)

The construction, operation and decommissioning of the Vesterhav Syd offshore wind farm will not lead directly to the killing of marine mammals. However, the causing of a permanent hearing threshold shift (PTS) through intense noise emissions would have the potential to lower the fitness and increase the mortality risk of affected harbour porpoises. The animals are dependent on their hearing sense for foraging and orientation.

The driving of 10 m diameter monopiles (worst case) would emit underwater noise which might cause PTS in a number of harbour porpoise (see Section 8.2.1 and (NIRAS, Rambøll, DHI, 2015)). However, the risk of inducing PTS in harbour porpoises could be reduced by deterrence and active mitigation measures which lower the noise levels during pile driving (see chapter 15 below).

As harbour porpoises are constantly present in the Vesterhav Syd area, it cannot be excluded that some animals will be exposed to cumulative noise levels causing PTS. It is thus concluded that construction work at Vesterhav Syd might lead to a higher mortality risk of harbour porpoises in the area

and that the obligation of Article 12 (1) (a) might be violated by the project unless active noise mitigation is applied. This evaluation is based on the worst case scenario described (10 m diameter piles). If smaller piles or fewer strikes are used to install the piles, consequences would be less severe. It is also based on a PTS limit value of 183 dB SEL (see Table 14). If the PTS onset level after cumulative noise would be 195 dB SEL, as a recent study of Kastelein (2015) indicates, violation of Article 12 (1) (a) could be generally excluded.

13.2.2 Assessment of Article 12 (1) (b)

The noise emissions of the construction activities at Vesterhav Syd, especially pile driving, might lead to a short-term disturbance of harbour porpoises within a radius of more than 30 km. Within a closer range this might lead to avoidance behavior, resulting in total avoidance in the vicinity of the wind farm. It is expected that a decrease of harbour porpoise presence in the latter area will overshoot the end of the construction phase by some weeks, but this is assumed to be a fully reversible effect.

The potential impact area has average porpoise densities and no important ecological function for the species. As, furthermore, the disturbance effects are fully reversible, it is concluded that construction work at Vesterhav Syd would not lead to a significant disturbance of the local harbour porpoise population. Thus, the obligations of Article 12 (1) (b) would not be violated by the project.

14 CUMULATIVE EFFECTS

The assessment of cumulative effects is based on the impact assessment combined with other local or regional activities and projects which may contribute to a cumulative environmental impact. In the case of Vesterhav Syd this could be the simultaneous construction of another wind farms (Horns Rev 3, Vesterhav Nord), the extraction of raw materials and ocean dumping. Cumulative effects are defined as combined effects which are larger than the sum of the contributing individual effects.

Cumulative effects on marine mammals may arise during construction. During operation they are assumed to be so low that no additional impacts are expected. The construction-related noise emissions can lead to both spatially and temporally cumulative effects if the construction phase of Vesterhav Syd overlaps with construction works at an adjacent site.

A spatial accumulation occurs when noisy construction works in Vesterhav Syd, especially pile driving, takes place simultaneously with comparable measures in neighbouring projects. In this case the individual impact zones may add up to a connected impact area from which marine mammals can not flee as quickly as from a single impact zone. A temporal accumulation occurs when the pile driving is carried out at intervals which theoretically would allow an interim return of porpoises. In this case the proportion of avoidance time would increase in the overlapping impact zone of neighbouring projects. The cumulative duration of noise exposure would also affect the duration of the subsequent avoidance reaction (“waiting time").

In the case of simultaneous construction of the wind farms Vesterhav Syd and Horns Rev 3 or Vesterhav Nord respectively, cumulative effects due to pile driving noise would be possible if the other projects emit comparable worst case noise levels. In this case the potential impact areas with TTS and avoidance behaviour could overlap as the distance of Vesterhav Syd to the other two wind farms is around 45 km and the bilateral impact zones may reach distances of more than 30 km. The radiuses would add up to a large connected impact area in front of Jutlands coast. The displacement from one site may also drive animals inside the impact area of another site and increase the overall disturbance effect. However, no detailed predictions can be made. Overlapping impact zones with the risk of permanent hearing damage (PTS) can be excluded. With other wind farm projects no cumulative effects can occur.

Extraction of raw materials and ocean dumping occurs in some designated areas in the vicinity of the Vesterhav Syd offshore wind farm site. Cumulative effects may arise from simultaneous measures which increase the turbidity in the area due to the resuspension or dumping of sediment. As porpoises and seals inhabit mainly coastal regions where the natural turbidity is often high, they are adapted to such conditions and are not dependent on their visual sense. Simultaneous noise emissions from construction works at Vesterhav Syd and dredging of raw materials in the surroundings may also cumulate. Compared to pile driving noise, dredging sounds are quite faint. Diederichs et al. (2010b) found short-term behavioural effects (3 hours) in the close vicinity (below 600 m) of a sand dredging ship but no general avoidance of the extraction area. Overall, the potential effects of raw material extraction and ocean dumping would not contribute significantly to the total impact. Cumulative impacts are expected to be negligible.

15 MITIGATION MEASURES DURING PILE DRIVING

If the impact assessment is evaluated as moderate, mitigation measures have to be considered. If impacts are evaluated as serious, mitigation measures have to be adopted.

Noise during pile driving has negative effects on marine mammals. They can be physically injured if the noise is too loud and if they are located close to the noise emitting source. Additionally, porpoises leave the area of construction suffering a temporary habitat loss. For both problems, it is essential that noise during construction is minimized. If noise is so loud that porpoises can be injured (which is usually the case during impulse driving), they should be expelled from the area where they can be injured.

15.1 Noise mitigation

Noise mitigation can generally be achieved in different ways:

1. Choosing an alternative installation instead of large pipes as foundations or
2. Choosing an alternative installation procedure instead of impulse driving or
3. Adjustment of piling procedure or
4. Installing noise mitigation measures that prevent part of the noise reaching the environment.

15.1.1 Alternative installation

The most common installation procedure uses foundations consisting of large pipes. However, some alternative installations have been developed and prototypes have been installed. **Gravity based foundations** are already applied in practice. They are used mainly in shallower waters. In Denmark they are installed for instance in Nysted and Rødsand II. The seabed surface has to be flat in order to ensure an upright and stable position for the wind turbines. Usually, the seabed surface has to be prepared beforehand, which could be a noise emitting procedure. Frequencies could be shifted into higher ranges that possibly affect porpoises more severely. However, as sound pressure levels are assumed to remain well below that of impulse pile driving, this installation is considered to be a low-noise foundation. The foundation itself is assumed to add only minimally to the total noise emitted (Koschinski & Lüdemann 2013).

Floating wind turbines produce only low noise levels during installations. Only the anchoring system has to be fixed. Most other components are already installed on land. This system is mainly attractive for installations in deeper waters but it is not yet well established (Koschinski & Lüdemann 2013).

A third alternative installation system is the **bucket foundation**. This bucket is open-bottomed. Water is sucked out of the bucket and the foundation then sinks further into the sediment until the final installation depth is reached. Noise is caused mainly by the water pumps. This level of noise emission is considerably less than during impulse driving. This installation process is restricted to sandy soils and this principle is used mainly in the oil exploration industry (Verfuß 2014).

As a general rule, the installation of larger wind turbines with larger piles causes more noise. Koschinski & Lüdemann (2013) show a dependence of the **diameter of the pile** and the emitted noise. Whereas a pile with a diameter of 1 m causes a SEL of less than 160 dB at a distance of 750 m from the construction site, the sound level for larger pipes increases. For piles with a diameter of 4 to 5 m the sound pressure level at the same distance is around 175 dB.

15.1.2 Alternative installation procedure

The most common piling technique is impulse driving. However, this is a highly noise-intensive technique. Several other techniques are currently available but still rarely applied. The technique that is already (partly) used for pile driving is **vibratory pile driving**. This is generally used for smaller piles or as a preparation before the start of the impulse driving. In this way noise emission can be reduced to15-20 dB below that of impulse driving (Elmer et al. 2007).

A second alternative is **pile drilling**. The pile driving technique is technically applicable but not yet established as a standard method. It still emits resounding noises but the level is assumed to be considerably lower than with impulse driving (Koschinski & Lüdemann 2013, Verfuß 2014).

15.1.3 Adjustment of Piling Procedure

As an obvious adjustment the **piling energy** can be reduced. The less energy used for the hydraulic hammer, the less noise is emitted. However, a minimum amount of energy is required especially in hard substrates and the entire piling procedure is prolonged. Therefore, a mitigation of noise level leads to an increase in the time with piling noise (Nehls & Betke 2011, Koschinski & Lüdemann 2013).

Another adjustment can be the **impulse prolongation**. The contact time between the hydraulic hammer and the pile is increased. In this way the energy is transferred over a longer time scale, which reduces the maximum emitted noise. At a distance of 30 m from the construction site this can reduce the noise level by 11 dB (Verfuß 2014).

15.1.4 Installing noise mitigation measures

All noise mitigation procedures described so far are aimed at a reduction of the amount of noise produced and are therefore primary measures. Methods described here aim to reduce the emitted noise and are therefore secondary noise mitigation measures. They are already widely deployed in the construction of offshore wind farms.

The most frequently applied technique uses **bubble curtains**. Normally air is pumped into a hose system at the bottom of the sea. These hoses are perforated and air bubbles leak. The air bubbles form a curtain over the entire water column. The noise is reduced considerably as the sound waves decrease when passing from water to air (and vice versa) or they are reflected. The techniques with which bubble curtains are applied vary greatly. Generally, bubble curtains can be divided in two groups, the Little Bubble Curtain (LBC) and the Big Bubble Curtain (BBC). The Little Bubble Curtain surrounds the pile directly whereas the Big Bubble Curtain is deployed on the sea floor completely surrounding the entire construction site.

For the **Little Bubble Curtain** one problem is to keep the bubbles close to the pile. If bubbles drift away the curtain is not complete and the noise escapes from the holes with no significant reduction. Therefore, several adaptations were developed. Several layers of curtain can be applied or bubbles can be

technically confined to the pile. However, some of the noise cannot be reduced as it spreads via a seismic pathway. During impulse pile driving the earth is shaken and this emits noise from the sea floor beyond the bubble curtain. The Little Bubble Curtain was tested during the construction of BARD Offshore I. Here noise reductions of 9-13 dB were achieved. The reduction of noise increased with increasing noise frequency (Bellmann et al. 2014).

Big Bubble Curtains can mitigate some of the noise of the seismic pathway. The seismic noise is partly emitted already after a few metres into the water. This is already between the pile and the Big Bubble Curtain and can therefore be mitigated by the latter one. Also important in this technique is that the Big Bubble Curtain surrounds the construction site completely leaving no gaps where noise is emitted unhampered. Currents can cause a drift in bubbles but this difficulty can be overcome if the Big Bubble Curtain is installed in an oval rather than a circle. This system was used for example in Borkum West II. Here a noise reduction of on average 11 dB was achieved with the best configuration. This project tested different configurations. The success depended on three parameters: sizes of holes in the hosepipe (determines bubble sizes), distance apart of holes (determines density of bubble curtain) and the amount of air used. The best configuration was found to be with relatively small holes, a short distance apart and using a substantial amount of air (Diederichs et al. 2014).

The effect of a Big Bubble Curtain can be increased if a second Bubble Curtain is installed thereby forming a **Double Big Bubble Curtain** (DBBC). The effect is greatest if the distance between the systems is at least three times the water depth.

To prevent particularly sensitive areas from being affected a **linear bubble curtain** is occasionally applied. This is installed supplementally to other noise mitigation systems in order to reduce noise escaping a one specific direction.

Another group of noise mitigation systems are **Pile Sleeves**. These are systems that are put over the pile itself and contain different kinds of insulators. They are therefore in some ways similar to the Little Bubble Curtain as this also surrounds the pile directly. The noise mitigation relies mainly on the absorption effects of the different insulators. As both systems are very similar and are both deployed directly around the pile, they can also be combined. In one practical application, an air-filled double wall is installed and between this wall and the pile a bubble curtain is applied (**IHC Noise Mitigation System**). This system was used for example at the German wind farm Riffgat. Noise mitigation was assumed to be around 16-18 dB (Verfuß 2014).

Another system (**BEKA-shells**) also uses a system of several walls. Here bubble curtains are also included. The size of bubbles varies. Different sizes of bubbles can mitigate noises of different frequencies. Additionally, industrially developed damper material is used as an additionally layer. The complete system can also be lowered onto the sea bottom in order to mitigate the noise escaping via the seismic pathway (Koschinski & Lüdemann 2013).

The **Hydro Sound Damper** (HSD) is a pile sleeve in which air-filled balloons or robust foam elements have been inserted. Preliminary tests suggest that this pile sleeve technique could reduce the sound by 7-13 dB. The highest efficiency was obtained in the frequency range of 200-500 Hz (Remmers & Bellmann 2013).

Cofferdams are a special type of Pile Sleeve. They also surround the pile. Here the interspace between pile and wall is dewatered. Thus the piling process takes place practically in an aerial environment and noise is mitigated at interfaces between air, metal and water. The sleeves are deemed to reduce noise by around 20 dB. This was also demonstrated in Århus Bugt. However, tests further offshore and in connection with the construction of wind farms have yet to be carried out (Verfuß 2014).

In the impact assessment, the impact of pile driving was ranked as moderate. Therefore, mitigation measures have to be considered. The above mentioned systems could be used. Bubble Curtains are widely used. In order to increase the effect, they are often used in combination with other systems (hydro sound damper, linear bubble curtain or as a double bubble curtain).

15.2 Deterrence

One piling technique that can be used is the **soft start**. At the onset of the piling process the piling strokes are conducted with low energy. The energy per stroke then increases gradually until the full energy per stroke is applied. With increasing amount of energy, the emitted noise increases as well, allowing the porpoises to abandon the construction site before the noise becomes physically dangerous to them (Nehls & Betke 2011).

In addition, before piling begins, special deterrence measures are implemented. These are **pingers and seal scarers**. Pingers were developed in order to keep porpoises away from fishing nets (Culik et al. 2001). They can result in a reduction of porpoise activity up to 500 m. However, habituation may occur (Cox et al. 2001, Carlström et al. 2009).

Seal scarers were developed in order to keep seals away from fishing nets. They can emit noise in a high frequency range. The source level can be 190 dB or higher (Nehls & Betke 2011). (Noise levels at a distance of 750 m from the seal scarer will be lower.) It was found that seal scarers also alarm harbour porpoises (Olesiuk et al. 2002, Johnston 2002). This led to undesired porpoise deterrence in those areas. However, it is now intentionally used during offshore-construction sites. They effectively drive porpoises from the close proximity of the piling site (Brandt et al. 2013b, 2013a).

A combination of pinger and seal scarer could be used in order to warn off the porpoises during piling work and forestall physical injuries. Hereby, the pinger is first used followed some minutes later by the seal scarer.

16 MONITORING / GENERAL ADVICES

Various effects on porpoises produced by the wind farm can be estimated via monitoring programs during the construction and operation phases. Effects on porpoises emanating from the wind farm that might be of interest are the magnitude of disturbance and the physical danger due to construction works and the use made of the operating wind farm by marine mammals. For each question a specific monitoring program can be designed.

As high noise levels can cause a permanent hearing threshold shift in harbour porpoises, which constitutes a physical injury, the primary issue is the risk-assessment of physical danger during pile driving. An effect on porpoises due to pile driving can be assumed if the animals are present close to the construction site and if emitted sound levels during pile driving exceed the limit values. To estimate the actual impacts during construction and operation, monitoring before (as with this study), during and after construction as well as during operation are highly recommended. In the following some monitoring designs with respect to efficiency control and the documentation of disturbances and porpoise reactions are presented.

Most monitoring designs are based on passive acoustic monitoring (PAM) as visual observations are limited to daylight and good weather conditions. However, PAM is not applicable for seals. PAM can be combined with other hydrophones for measuring the emitted sound levels to estimate the size of the impact zones where critical sound levels are exceeded.

Monitoring to ensure the efficiency of mitigation measures

As mentioned in chapter 15, mitigation measures such as bubble curtains, and deterrence devices such as pingers / seal scarers are recommended during pile driving activities. To ensure mitigation and to document the efficiency of noise mitigation and deterrence measures a passive acoustic monitoring system of stationary hydrophones and C-PODs is recommended, deployed in the vicinity of construction sites.

Monitoring for detection and documentation of disturbance effects during pile driving

The effects of disturbance during construction can be assessed in two ways. Firstly, the degree of disturbance due to a single pile driving event can be detected. For this purpose C-PODs and additional hydrophones are placed in the wind farm area as well as at defined distances in order to estimate zones of impact. By this means, avoidance behaviour during single pile driving events as well as between these events can be documented on a spatial scale.

Monitoring for detection and documentation of medium- and long-term wind farm effects

To detect if the construction of the wind farm or the wind farm itself have an effect on abundance and distribution of harbour porpoises in the wider area, monitoring on a longer time scale will be useful. For this, C-PODs have to be placed at fixed positions in the wind farm area before (as was the case in this study), during and after construction. Additionally, C-PODs have to be placed in a comparable control area outside the wind farm area (e.g. Scheidat et al. 2011).

Alternatively, survey flights could be continued as they reveal the spatial distribution of porpoises inside the study area. The abundance and distribution of porpoises then can be compared to the initial results described in this report.

Environmental supervision

During wind farm construction and cable laying, environmental supervision on site could help to avoid unexpected disturbances of marine mammals. For various German cable laying projects in coastal waters environmental supervisors have been appointed (e.g. SylWin1, HelWin1+2, DolWin3). The mission of such a supervision includes monitoring and observation of birds and marine mammals and their reactions to the construction, counselling and clarification in case of unexpected environmental problems, supervision and instruction regarding the restrictions of the official permit and legislation as well as documentation and reporting of construction works. In some other countries specialised "Marine Mammal Observers" (MMO) perform the observation task. However, during pile driving a MMO would not be sufficient to prevent injuries as visual observations are limited in range and time of day.

17 POTENTIAL INSUFFICIENT KNOWLEDGE REGARDING THE ASSESSMENT

In principle the knowledge available for an impact assessment can be improved in two ways. Firstly, analyzed data could be more detailed and more precise, and secondly, knowledge about the effect and its consequences could be improved.

The survey flights and the passive acoustic monitoring are the basis for the impact assessment. 9 flights were distributed along a time scale from November 2013 to July 2014 and provide an overview of the porpoises throughout nearly one year. Data can still be improved; for instance if data were available from all months and over several years to include inter-annual variances. However, the present data allows a fairly well documented overview of porpoise occurrence and is also combined with literature data. Impact assessment is performed conservatively and a worst case scenario is chosen. This also takes into account some uncertainties in the data and is therefore not presumed to underestimate the effects. Passive acoustic monitoring is reported here from December 2013 until October 2014.

The knowledge of impacts of offshore wind farms on marine mammals has improved considerably in recent years. However, there are also some uncertainties. Behavioural effects are nearly always addressed to disturbance behaviour. However, porpoises can also be affected if they remain in the area, e.g. becoming less efficient in foraging due to masking effects. Mother-calf groups could be effected especially severely if the calf is separated from the mother. Therefore, the function of the habitat is included in the impact assessment.

Some effects are not clear. For instance, it is not clear how electromagnetic fields affect porpoises. They could have adverse effects on their magnetic orientation. However, even the sensory basis of this orientation is still unclear. The effects on it are even more complex. It can only be asserted that no direct effects have been observed.

Many effects are complex or site specific. For instance, the redistribution of porpoises in a wind farm during operation is different from site to site. In Dutch waters an above-average usage of wind farms was demonstrated, whereas in a Danish wind farm a porpoise population increased only slowly after construction and failed to reach baseline level. This indicates that site specific factors are involved. Why and how porpoises behave on which site remains speculative. Possibly, porpoises in an environment influenced by human activity accommodate faster and better to new impacts than animals at remote locations. However, in ecology animal behaviour and animal distribution depend on a great variety of factors which makes it hard to predict and assess a single one. One can only give a careful expert judgment based on available data, experiences from other projects and scientific background.

18 CONCLUSION OF THE TOTAL IMPACT

Effects on marine mammals emanating from the project Vesterhav Syd are of short-term or temporary nature during the construction and decommissioning phase and of permanent nature during the operation phase.

The construction-related noise emissions are considered as by far the most important source of potential effects on marine mammals. This applies in particular to pile driving noise emissions which can cause hearing impairment and displacement of marine mammals. The intense vessel traffic associated with the construction activities may also contribute to the impact. If no noise mitigation measures during pile driving are applied the disturbance of a single strike on a foundation might affect approximately 1,121 harbour porpoises or 0.487 % of the population. As no modeling was made for of the impact of cumulative noise on behavioural responses, it can not be excluded that short-term disturbance effects might affect more than 1 % of the population. The avoidance of the wind farm site and the close vicinity would probably outlast the construction phase. Similarly, the installation of one foundation might in the worst case cause TTS in approximately 1,106 harbour porpoises or 0.481 % of the population. Therefore, it cannot be excluded that installation of more than one foundation might affect more than 1 % of the population. The magnitude of construction-related impacts on the porpoise population is rated as "moderate” in the worst case (Table 24).

Based on the worst case scenario, noise mitigation measures should be applied. This would reduce the impact area of hearing impairment and displacement and shorten the after effect period. Consequently, the construction-related effects on harbour porpoises could be reduced to an overall "minor" level. Furthermore, it could be ensured that the effects do not reach protected Natura 2000 sites and the risk of violating the prohibition of killing strictly protected species such as the harbour porpoise (Article 12 (1) (a) Habitats Directive) could be excluded. Moreover, the risk of cumulative effects with other construction activities (e.g. Horns Rev 3 and Vesterhav Nord) would be reduced.

The evaluation of potential impacts due to pile driving is based on a worst case scenario regarding noise emissions and on specific limit values for hearing injuries and avoidance behaviour in marine mammals. If actual noise emissions are lower, for instance due to smaller piles or fewer strikes, or onset levels for injuries are higher (as a recent study indicates), the above mentioned impacts on harbour porpoises during construction would be less severe. Regarding grey and harbour seals the impacts of construction-related noise emissions are generally assessed to be minor, as seals are considered to be more noise-tolerant than porpoises.

Other construction-related effects on marine mammals may arise from increased sedimentation and water turbidity, especially during the installation of foundations and the laying of cables. The more indirect impact of increased water turbidity on marine mammals is rated as negligible.

All operation-related impacts on porpoises and seals are also assessed as negligible. This applies to noise emissions, which arise from operational sounds and maintenance traffic, as well as to magnetic fields and project-related habitat changes. The operational sounds will exceed the normal background noise level only in the close vicinity of each wind turbine. Regarding habitat changes the small direct habitat loss is accompanied by alterations that may lead to an improvement of the food resources for marine mammals (introduction of hard substrate, exclusion or regulation and limiation of fishery).

The decommissioning of the wind farm is assumed to cause somewhat less acute noise emission problems than the construction. All other factors are considered to be comparable. The impact on marine mammals during decommissioning is assessed as minor in the worst case.

Table 24: Worst case magnitude of impact on marine mammals during construction, operation and decommissioning of the wind farm Vesterhav Syd.

Phase / source of impacts	Underwater noise	Habitat change	Sedimentation and turbidity	Electro-magnetic fields	Persistance of worst case effect
Harbour porpoise					
Construction (no noise mitigation)	moderate	-	negligible	-	temporary
Construction (with noise mitigation)	minor	-	negligible	-	short-term
Operation	negligible	negligible	-	negligible	permanent
Decommission	minor	negligible	negligible	-	short-term
Seals					
Construction	minor	-	negligible	-	short-term
Operation	negligible	negligible	-	negligible	permanent
Decommission	minor	negligible	negligible	-	short-term

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20 APPENDIX

Table 25: Transect coordinates in WGS 84, GMS (degrees) for flight transects

Transect N°.	LAT west end	LON west end	LAT east end	LON east end
1	56.233333	7.666944	56.233889	8.120000
2	56.215000	7.666667	56.215556	8.121389
3	56.197222	7.666111	56.198056	8.122778
4	56.179167	7.666667	56.179722	8.115000
5	56.161667	7.666667	56.162222	8.108889
6	56.143889	7.667222	56.144444	8.107500
7	56.125833	7.666111	56.126944	8.103889
8	56.107222	7.666944	56.107778	8.104167
9	56.089444	7.666667	56.090278	8.099167
10	56.071667	7.667222	56.071944	8.095278
11	56.053056	7.666389	56.053333	8.095556
12	56.035833	7.666944	56.036389	8.096944
13	56.018056	7.667222	56.018611	8.101944
14	56.000000	7.666944	56.000556	8.109722
15	55.981944	7.667500	55.983056	8.120556
16	55.964444	7.666944	55.965278	8.129722
17	55.946667	7.666944	55.947222	8.137222
18	55.928333	7.665833	55.929444	8.142222

Table 26: Valid effort for each survey flight (sum of kilometres on both sides of the airplane).

Date	Altitude	Total effort [km]	Valid effort [km]	Valid effort [%]
25.11.2013	250 ft	958	958	100
03.02.2014	250 ft	953	873	92
11.02.2014	250 ft	985	985	100
11.03.2014	250 ft	992	992	100
25.03.2014	250 ft	982	732	75
16.04.2014	250 ft	981	981	100
18.05.2014	600 ft	1,004	957	95
11.06.2014	600 ft	1,003	857	85
07.07.2014	600 ft	1,012	973	96
total	**-**	**8,871**	**8,309**	**94**

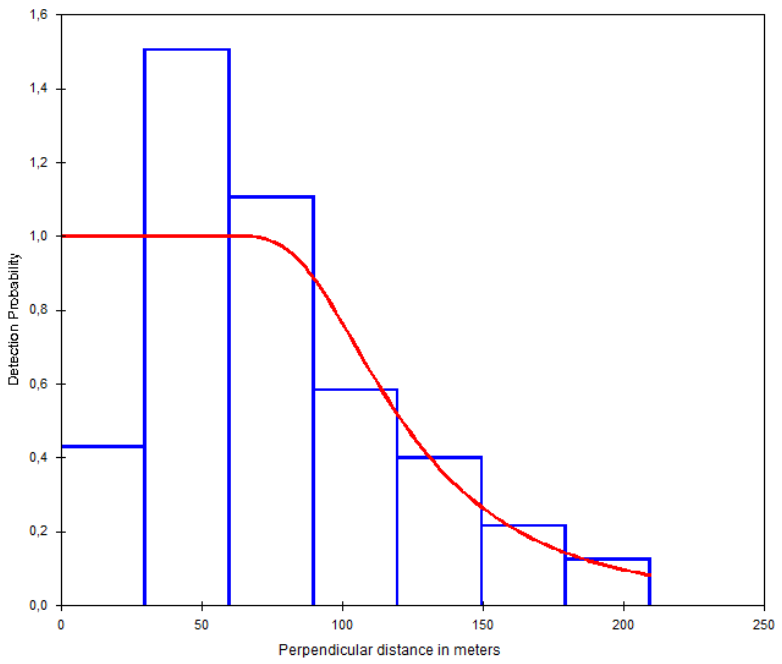

Figure 47: Detection function of observations of harbour porpoises in flights at 250 ft altitude.

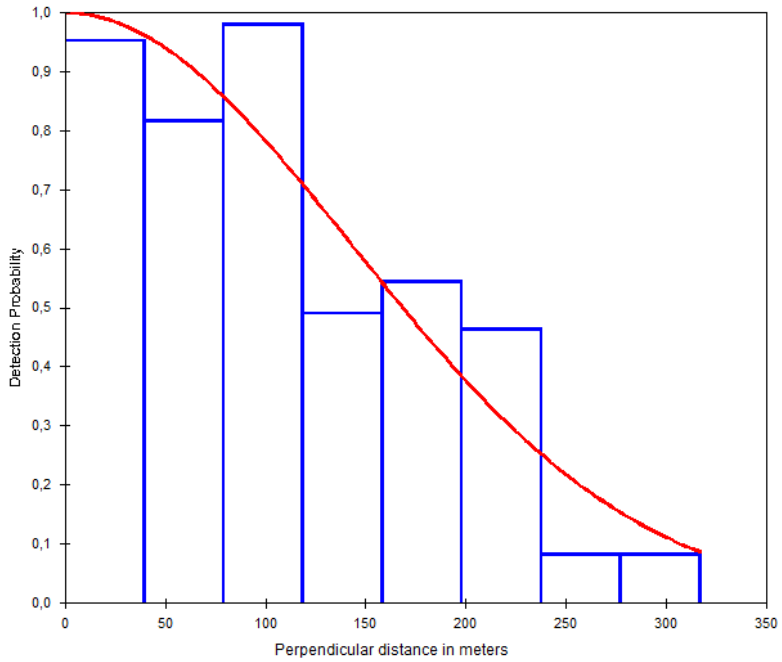

Figure 48: Detection function of observations of harbour porpoises in flights at 600 ft altitude.

Table 27: Effective strip width (ESW) calculated with DISTANCE 6.0 for two different flight altitudes. Lower 95% confidence interval (LCI) and higher 95 % confidence interval (HCI) are given.

Flight altitude	**250 ft**	**600 ft**
ESW (m)	130	175
ESW/LCI (m)	115	153
ESW/HCI (m)	148	200
N observations	142	162
model, key function	hazard-rate	half-normal

Table 28: Monthly mean values for the availability bias and the detection probability g(0) (Availability bias according to Teilmann et al. (2013); g(0) based on the availability bias and the IBL perception bias of 59.8 % for 250 ft flights and 53.4 % for 600 ft flights).

Factor	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Availability bias	0.44	0.38	0.46	0.57	0.53	0.51	0.51	0.45	0.45	0.44	0.44	0.48
g(0) 250 ft	0.26	0.23	0.28	0.34	0.32	0.30	0.30	0.27	0.27	0.26	0.26	0.29
g(0) 600 ft	0.23	0.20	0.25	0.30	0.28	0.27	0.27	0.24	0.24	0.23	0.23	0.26

Tables for determination of the magnitude of impact (assessement methodology).

Table 29: Assessment of degree of impact (high degree of disturbance

Degree of disturbance	Importance	Likelihood of occurrence	Persistence	Magnitude of impact
High	International interests	High (>75 %)	Permanent (> 5 years)	Major
			Temporary (1-5 years)	Major
			Short-term (0-1 year)	Moderate
		Medium (25-75 %)	Permanent (> 5 years)	Major
			Temporary (1-5 years)	Major
			Short-term (0-1 year)	Moderate
		Low (<25 %)	Permanent (> 5 years)	Moderate
			Temporary (1-5 years)	Moderate
			Short-term (0-1 year)	Minor
	National or regional interests	High (>75 %)	Permanent (> 5 years)	Major
			Temporary (1-5 years)	Moderate
			Short-term (0-1 year)	Moderate
		Medium (25-75 %)	Permanent (> 5 years)	Moderate
			Temporary (1-5 years)	Moderate
			Short-term (0-1 year)	Minor
		Low (<25 %)	Permanent (> 5 years)	Moderate
			Temporary (1-5 years)	Minor
			Short-term (0-1 year)	Minor
	Local interests (important for the area directly affected or for the immediate surroundings)	High (>75 %)	Permanent (> 5 years)	Moderate
			Temporary (1-5 years)	Moderate
			Short-term (0-1 year)	Minor
		Medium (25-75 %)	Permanent (> 5 years)	Moderate
			Temporary (1-5 years)	Minor
			Short-term (0-1 year)	Negligible/neutral/no impact
		Low (<25 %)	Permanent (> 5 years)	Minor
			Temporary (1-5 years)	Negligible/neutral/no impact
			Short-term (0-1 year)	Negligible/neutral/no impact
	Negligible/not important	High (>75 %)	Permanent (> 5 years)	Negligible/neutral/no impact
			Temporary (1-5 years)	Negligible/neutral/no impact
			Short-term (0-1 year)	Negligible/neutral/no impact
		Medium (25-75 %)	Permanent (> 5 years)	Negligible/neutral/no impact
			Temporary (1-5 years)	Negligible/neutral/no impact
			Short-term (0-1 year)	Negligible/neutral/no impact
		Low (<25 %)	Permanent (> 5 years)	Negligible/neutral/no impact
			Temporary (1-5 years)	Negligible/neutral/no impact
			Short-term (0-1 year)	Negligible/neutral/no impact

Table 30: Assessment of degree of impact (medium degree of disturbance)

Degree of disturbance	Importance	Likelihood of occurrence	Persistence	Magnitude of impact
Medium	International interests	High (>75 %)	Permanent (> 5 years)	Major
			Temporary (1-5 years)	Moderate
			Short-term (0-1 year)	Moderate
		Medium (25-75 %)	Permanent (> 5 years)	Moderate
			Temporary (1-5 years)	Moderate
			Short-term (0-1 year)	Minor
		Low (<25 %)	Permanent (> 5 years)	Moderate
			Temporary (1-5 years)	Minor
			Short-term (0-1 year)	Minor
	National or regional interests	High (>75 %)	Permanent (> 5 years)	Moderate
			Temporary (1-5 years)	Moderate
			Short-term (0-1 year)	Minor
		Medium (25-75 %)	Permanent (> 5 years)	Moderate
			Temporary (1-5 years)	Minor
			Short-term (0-1 year)	Minor
		Low (<25 %)	Permanent (> 5 years)	Minor
			Temporary (1-5 years)	Minor
			Short-term (0-1 year)	Negligible/neutral/no impact
	Local interests (important for the area directly affected or for the immediate surroundings)	High (>75 %)	Permanent (> 5 years)	Moderate
			Temporary (1-5 years)	Minor
			Short-term (0-1 year)	Minor
		Medium (25-75 %)	Permanent (> 5 years)	Moderate
			Temporary (1-5 years)	Minor
			Short-term (0-1 year)	Negligible/neutral/no impact
		Low (<25 %)	Permanent (> 5 years)	Minor
			Temporary (1-5 years)	Minor
			Short-term (0-1 year)	Negligible/neutral/no impact
	Negligible/not important	High (>75 %)	Permanent (> 5 years)	Negligible/neutral/no impact
			Temporary (1-5 years)	Negligible/neutral//no impact
			Short-term (0-1 year)	Negligible/neutral/no impact
		Medium (25-75 %)	Permanent (> 5 years)	Negligible/neutral/no impact
			Temporary (1-5 years)	Negligible/neutral/no impact
			Short-term (0-1 year)	Negligible/neutral/no impact
		Low (<25 %)	Permanent (> 5 years)	Negligible/neutral/no impact
			Temporary (1-5 years)	Negligible/neutral/no impact
			Short-term (0-1 year)	Negligible/neutral/no impact

Table 31: Assessment of degree of impact (low degree of disturbance)

Degree of disturbance	Importance	Likelihood of occurrence	Persistence	Magnitude of impact
Low	International interests	High (>75 %)	Permanent (> 5 years)	Moderate
			Temporary (1-5 years)	Minor
			Short-term (0-1 year)	Minor
		Medium (25-75 %)	Permanent (> 5 years)	Moderate
			Temporary (1-5 years)	Minor
			Short-term (0-1 year)	Negligible/neutral/no impact
		Low (<25 %)	Permanent (> 5 years)	Minor
			Temporary (1-5 years)	Minor
			Short-term (0-1 year)	Negligible/neutral/no impact
	National or regional interests	High (>75 %)	Permanent (> 5 years)	Moderate
			Temporary (1-5 years)	Minor
			Short-term (0-1 year)	Negligible/neutral/no impact
		Medium (25-75 %)	Permanent (> 5 years)	Minor
			Temporary (1-5 years)	Negligible/neutral/no impact
			Short-term (0-1 year)	Negligible/neutral/no impact
		Low (<25 %)	Permanent (> 5 years)	Minor
			Temporary (1-5 years)	Negligible / neutral/no impact
			Short-term (0-1 year)	Negligible/ neutral/no impact
	Local interests (important for the area directly affected or for the immediate surroundings)	High (>75 %)	Permanent (> 5 years)	Minor
			Temporary (1-5 years)	Negligible/ neutral/no impact
			Short-term (0-1 year)	Negligible/ neutral/no impact
		Medium (25-75 %)	Permanent (> 5 years)	Minor
			Temporary (1-5 years)	Negligible/ neutral/no impact
			Short-term (0-1 year)	Negligible/ neutral/no impact
		Low (<25 %)	Permanent (> 5 years)	Minor
			Temporary (1-5 years)	Negligible/ neutral/no impact
			Short-term (0-1 year)	Negligible/ neutral/no impact
	Negligible/not important	High (>75 %)	Permanent (> 5 years)	Negligible/ neutral/no impact
			Temporary (1-5 years)	Negligible/ neutral/no impact
			Short-term (0-1 year)	Negligible/ neutral/no impact
		Medium (25-75 %)	Permanent (> 5 years)	Negligible/ neutral/no impact
			Temporary (1-5 years)	Negligible/ neutral/no impact
			Short-term (0-1 year)	Negligible/ neutral/no impact
		Low (<25 %)	Permanent (> 5 years)	Negligible/ neutral/no impact
			Temporary (1-5 years)	Negligible/ neutral/no impact
			Short-term (0-1 year)	Negligible/ neutral/no impact