# Kriegers Flak Offshore Wind Farm

Marine Mammals
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June 2015

NIRAS

AARHUS UNIVERSITET
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DHI

This report is prepared for Energinet.dk as part of the EIA for Kriegers Flak Offshore Wind Farm. The report is prepared by Danish Center for Environment and Energy (DCE) at Aarhus University and DHI in collaboration with NIRAS.

# MARINE MAMMALS

## Investigations and preparation of environmental impact assessment for Kriegers Flak

**DCE - Aarhus University, Roskilde**
**DHI, Hørsholm**

**June 2015**



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# 1 Summary

Energinet.dk has commissioned NIRAS and subcontractors to conduct the environmental impact assessment (EIA) for the construction and operation of the largest offshore wind farm, called Kriegers Flak, in Denmark to date. The preliminary study area of 180 $km^2$ around the projected wind farm is located approximately 15 km east of the east coast of Zealand, in the South-western part of the Baltic bordering the EEZ (Exclusive Economic Zone) of Sweden and Germany. The exact wind farm area will consist of two sections, 44$km^2$ to the west and 88 $km^2$ to the east of the study area. As part of the EIA, DCE/Aarhus University and DHI have conducted the baseline studies on marine mammals to assess the impacts of the construction and operation of a wind farm at Kriegers Flak. Three species of marine mammals are known to occur regularly in the area of Kriegers Flak: harbour porpoises (*Phocoena phocoena*), harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus gryphus*). All three species are protected by international agreements and legislation, including the EU Habitats Directive, the Convention for protection of Migratory Species (Bonn-convention), ASCOBANS, HELCOM as well as national legislation. The purpose of this report is to outline the baseline conditions for the marine mammals occurring in the Kriegers Flak area by providing detailed information on their spatial and temporal use of the area, and to evaluate the potential effects of the construction, operation and dismantling of the planned wind farm on the marine mammals.

For harbour porpoises, information on distribution was obtained from 99 porpoises that have been tracked by Argos satellite transmitters by Aarhus University (former NERI) in most inner Danish waters since 1997. Data from 15 individuals, present in the south-Western Baltic, were used to construct a map of habitat suitability for Kriegers Flak and surrounding waters. This was verified using data from C-PODs collected as part of the EU LIFE+, "SAMBAH"-project. The pods were deployed in the area during 2011-2013. It should be noted that this assessment only includes data for the distribution and abundance of the Kattegat, Belt Sea and Western Baltic population, as no reliable data exists for the endangered Baltic Sea population.

For harbour and grey seals, no information was available from the area, apart from a few (n=6) previously tagged grey seals that have migrated into the area. Therefore, 10 harbour and 5 grey seals were tagged with GPS/GSM transmitters at the nearest haul-out site at Måkläppen on Falsterbo in Sweden, and data were collected from November 2012 to June 2013. To predict marine mammal habitat use in the area, tracking data were modelled in relation to the importance of a number of physical properties of the South-western Baltic Sea.

In general, the impact of the wind farm construction are divided into disturbing factors, which have direct negative impacts on the animals; changes to the habitat, which can have both positive and negative effects and exclusion of fishery, which is mostly positive. Specific effects of pile driving have been documented for both seals and porpoises, and this activity is likely to be the single most disturbing and possibly injuring activity during construction.

The biology and sensory systems of the three marine mammal species have been reviewed in order to provide a background of their sensitivities to the expected impacts. Existing information about distribution were also reviewed.

The results of the modelling studies are presented. For harbour porpoises, the most important habitats within the studied area are in the south-western part of the study area, in the waters between Møn, Falster and Germany and along the coast of Zealand. For harbour seals, the most intensively used areas were located north of the construction site during autumn and somewhat more to the east during winter. For the grey seals, the areas that were predicted to be intensely used were mostly located along the coasts of Sweden and Germany, but also in the relatively shallow waters in the northern part of the construction site and just north and east of the site. All three species showed seasonal variation in their distribution and movements.

Experiences from other offshore wind farms were reviewed and worst case scenarios for the construction period were assessed. Construction of gravitational foundations is unlikely to cause physical damages as such, while behavioural disturbance at the wind farm site during construction and possibly also during operation must be expected. Some piling may be needed in order to stabilise the seabed below the concrete foundations with a sheet pile wall or similar. This type of piling produces much less energy than monopiles, and will therefore not have the same environmental impact. Steel monopile and jacket foundations, will produce significant impacts because of the intense underwater noise.

The detailed assessment was undertaken following a worst case scenario for a 10 MW 10 m diameter pile. For harbour porpoises, the range of permanent physical impact (Permanent Threshold Shift; PTS) due to the exposure of cumulative pile driving strikes extends to 17 km from the source. Temporary noise induced hearing threshold shifts (TTS) may occur at considerable distances, up to 49km from the noise source. By estimating the proportions of the population exposed from the model, PTS is likely to occur in 1 465 individuals (3.6 %) and TTS may be induced on 4 748 individuals (11.7 %). The proportion of affected animals within the model area will be substantial in summer and autumn (PTS: up to 13 %, TTS: up to 55 %). Although TTS is only a temporary effect, the effect on a population level will be substantial. The range of behavioural impact was based on the noise effect of single pile strike. A single strike will potentially induce avoidance behaviour in 47 % of the individuals in the modelled area during summer and autumn, effectively displacing almost half of the individuals in the area. On the scale of the population, 10.7 % (4 311 individuals) would be displaced into areas where they would have to compete with other porpoises. The short-term effect is therefore quite severe. The use of pingers and seal-scarers and a 16 dB reduction in source level, achieved by the use of bubble curtains or other similar mitigation measures would most likely prevent any porpoises from permanent hearing impairment. Although the ranges for TTS (22 km) and behavioural effects are still large, this reduction will reduce the affected number of individuals significantly.

In seals, PTS due to exposure to cumulative pile strikes is restricted to an area relatively close to the source (approx. 590 m). TTS however, can occur at considerable distances (approx. 28 km) from the noise source for cumulative strikes. The affected number of harbour seals experiencing PTS would be very low (approx. 1 %; 6 individuals) but very high for TTS (49 %; 226 individuals). The percent of animals at risk of TTS within the modelling area would be up to 64 % in winter. The impacts on the local harbour seal population, as well as on the total management unit are therefore very high. However, TTS is a short-term effect and will only occur during construction and when the seals are in the water, as noise travels much further in water than air. It should be noted that harbour seals has a very local distribution with few alternative haul-out sites, which means that they may not be able to find alternative sites during construction.

For grey seals, less than 1 % of the individuals would be at risk of inducing PTS in the studied area during any season (annually up to 267 individuals). For the whole year, 5.5 % of the total population or 1 644 individuals are at risk of developing TTS. This proportion would be between 10 and 26 % of the animals within the modelling area when looking at the different seasons.

For the seals, no studies have estimated behavioural changes from pile driving activities. Behavioural responses of seals will likely have a moderate impact, though depending on whether the effect is evaluated on a local or regional scale, and depending on the expected time of return for the displaced animals it may become a major impact. The mitigation measures described above for porpoises will essentially remove the risk of developing PTS in seals, and greatly diminish the range of TTS. If a seal was 10 m from the source, it would only require an 8 dB reduction of noise exposure to avoid PTS. A slow ramp-up will make it possible for the animals to swim away but probably not remove the chance of developing TTS.

During the operation period, noise from the turbines will only likely be a disturbing factor to the harbour porpoises, as the post-construction noise from turbines that is audible to porpoises only slightly exceeds ambient noise levels. Noise associated with maintenance activities such as boat traffic will also only have a minor effect, and it is unlikely that the electromagnetic fields will have any significant effect. Changes in habitat are unlikely to be detrimental, but there is no evidence that changes may be positive to marine mammals, although it remains a possibility around the foundations.

The impact assessment we present here comes with a number of uncertainties, especially regarding the construction phase. We have shown that impact ranges for multiple strikes will be larger than for single strikes. But based on the uncertainties of the criterions for multiple strikes as well as the validity of the underlying assumptions, these ranges are associated with uncertainty.

Cumulative effects of other anthropogenic disturbances on top of those related to the new wind farm may further increase the impacts assessed in this report. The German wind farm EnBW Baltic II constructed in 2014 not far from Kriegers Flak will likely have some impact on the marine mammals here as well as the planned Swedish wind farm at Kriegers Flak. However, with the present knowledge and models it is not possible to assess cumulative effects on local or population level. Dredging activities in the middle of the Kriegers Flak bank will contribute to the cumulative disturbances in the area, but the type of activities and the noise produced is not known.

The decommissioning of the wind farm may constitute impacts comparable to construction or less, depending on the methods employed. Decommissioning methods may cause effects similar to those described for construction, and will likely extend over a longer period, which will increase the impact. If the foundations are not removed, these impacts would be greatly reduced. There is no evidence of adverse effects from the foundations. Steel monopile foundations would be less problematic to remove, and this could be done in a shorter time-span, reducing the impact on seals and porpoises.

# 2 Introduction

Energinet.dk has been commissioned the construction and operation of the largest offshore wind farm in Denmark to date in the Baltic region called Kriegers Flak. The preliminary study area of 180 $km^2$ for the wind farm is located approximately 15 km east of the coast of Denmark in the south-western part of the Baltic bordering the EEZ of Sweden and Germany. The exact wind farm area will consist of two sections, 44 $km^2$ on the west side and 88 $km^2$ on the east side of Kriegers Flak. The installed power output is planned to be 600 MW and will consist of 60 – 200 wind turbines depending on the size of the chosen turbines (3 – 10 MW). Germany is building EnBW Baltic II wind farm in 2013/14 and Sweden is planning a wind farm in their respective part of Kriegers Flak. The Danish wind farm is expected to be in place before 2020.

As part of the EIA for the Kriegers Flak wind farm, Energinet.dk has commissioned DCE / Aarhus University and DHI to conduct the baseline studies on marine mammals and to assess the impacts of the construction and operation of a wind farm in this area. Three species of marine mammals are known to occur regularly in the area of Kriegers Flak: harbour porpoises (*Phocoena phocoena*), harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus gryphus*).

Harbour porpoises are protected by a number of international agreements and legislation, like the EU Habitats Directive, the ASCOBANS agreement (Agreement on Conservation of Small Cetaceans of the Baltic and North Seas) under the Convention for Protection of Migratory Species (Bonn Convention). Harbour porpoises are listed on annex IV of the Habitats Directive and are thus subject to an assessment of strictly protected species in relation to Article 12 of the Directive. Both grey and harbour seals are protected under Annex II in the EU Habitats directive, where member states are obliged to assign protected areas (Natura 2000). Seals are also protected under the Convention for the Protection of Migratory Species (Bonn Convention), the HELCOM agreement of the Baltic Sea as well as national legislation.

Discussion of impact of the wind farm is restricted to these three species in this assessment, although other species of seals and whales may on rare occasions find their way to the region.

## 2.1 Purpose of this report

The purpose of this report is to outline the baseline conditions for marine mammals in the Kriegers Flak area, and to provide detailed information on the spatial and temporal use of Kriegers Flak. The objective was therefore to collect data on seasonal abundance, distribution and habitat use of harbour porpoises, harbour seals and grey seals in the project area and adjacent waters. This information is used in the assessment of the possible impacts of construction and operation of a wind farm at Kriegers Flak on the three marine mammal species.

For harbour porpoises, information on distribution was obtained from satellite telemetry. Harbour porpoise (n=99) have been tagged with satellite transmitters by Aarhus University (former NERI) and been monitored in most inner Danish waters since 1997. It was agreed to use these data to assess the usage of the Kriegers Flak area. Also, an agreement with the ongoing SAMBAH, EU LIFE+ project enabled the inclusion of the recent results on acoustic porpoise activity obtained from C-PODs in this area.

No information was available for harbour and grey seals from this area, apart from a few (n=6) previously tagged grey seals migrating through the area. Therefore, both harbour and grey seals were tagged with GPS transmitters at the nearest haul-out site at Falsterbo, Sweden, and data were collected from November 2012 – June 2013. The harbour seal GPS transmitters were funded by this assessment, whereas the additional grey seal transmitters were funded by the Swedish Museum of Natural History, Stockholm. This report describes the results of the combined tracking, dive and haul-out datasets.

The relationship between occurrence of marine mammals and static and dynamic environmental parameters was used to construct habitat suitability and habitat usage models of the Kriegers Flak area for each species.

The assessment of the noise-affected area in relation to the construction of 10 MW monopiles (worst case scenario) was based on a noise model constructed by NIRAS as part of the Kriegers Flak EIA (NIRAS, 2014). The recommendations of exposure limits were later updated based on the newest findings regarding the effects of noise on marine mammals (Working Group, 2015).

Also, mitigation measures are discussed.

# 3 Project description

This chapter outlines the proposed technical aspects encompassed in the offshore-related development of the Kriegers Flak Offshore Wind Farm (OWF) which are relevant in relation to the assessment of potential impacts on marine mammals. The text is extracted from the full technical project description (Energinet.dk, 2014).

## 3.1 Kriegers Flak

The planned Kriegers Flak OWF (600 MW) is located app. 15 km east of the Danish coast in the southern part of the Baltic Sea close to the boundaries of the exclusive offshore economic zones (EEZ) of Sweden, Germany and Denmark (see appendix 1). At the neighbouring German territory an OWF Baltic II is currently under construction, while pre-investigations for an OWF have already been carried out at Swedish territory, however further construction is currently on standby.

The area delineated as pre-investigation area covers an area of app. 250 $km^2$, and encircles the bathymetric high called “Kriegers Flak” which is a shallow region of approximately 150 $km^2$. Central in the pre-investigation area an area (c. 28 $km^2$) is reserved for sand extraction with no permission for technical OWF components to be installed. Hence, wind turbines will be separated in an Eastern (110 $km^2$) and Western (69 $km^2$) wind farm. Allowing for 200 MW on the western part, and 400 MW on the eastern part. According to the permission given by the DEA, a 200 MW wind farm must use up to 44 $km^2$. Where the area is adjacent to the EEZ border between Sweden and Denmark, and between Germany and Denmark, a safety zone of 500 meters will be established between the wind turbines on the Danish part of Kriegers Flak and the EEZ border.

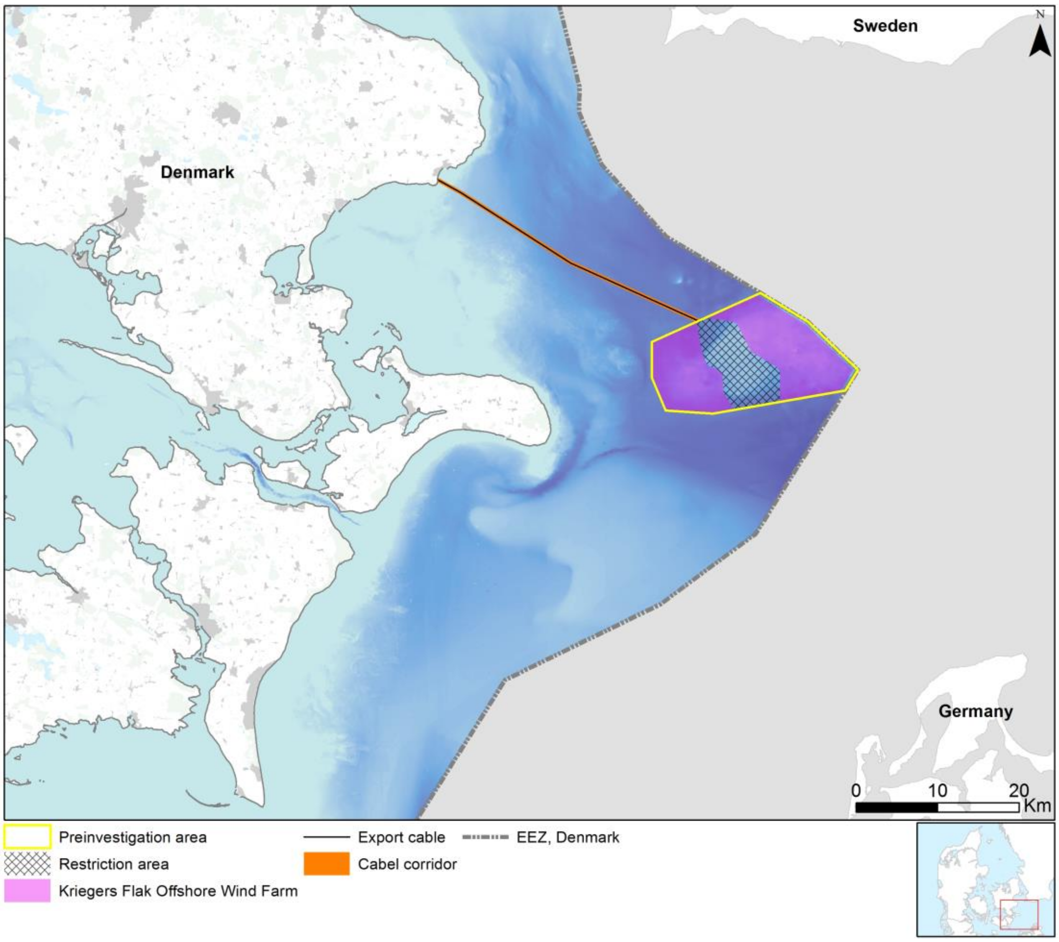



*Figure 1: The planned location of Kriegers Flak Offshore Wind Farm (600 MW) in the Danish territory. Approximately in the middle of the pre-investigation area an area (c. 28 km$^2$) is reserved for sand extraction with no permission for technical OWF components to be installed.*

**Physical Characteristics**

The water depth at the central parts of the Kriegers Flak is generally between 16 and 20 m, while it is between 20 and 25 m along the periphery of the bank, and more than 25-30 m deep waters along the northern, southern and western edges of the investigation area (Figure 2).

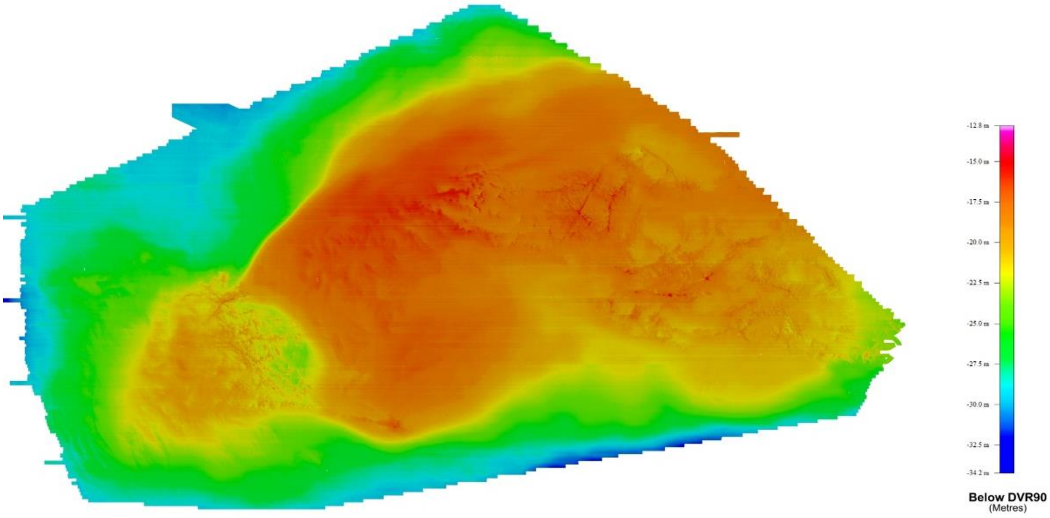



*Figure 2: Overview of the Kriegers Flak area showing water depth variations by graded colour (based on the geophysical survey).*

### 3.2 Wind Farm Layout

As input for the Environmental Impact Assessment (EIA), possible and likely layouts of the offshore wind farm at Kriegers Flak have been assessed and realistic scenarios are used in the EIA. It must be emphasized that the layouts may be altered by the signed developer. Possible park layouts with a 3.0 MW wind turbine (Figure 3) and a 10.0 MW wind turbine (Figure 4) can be seen below.

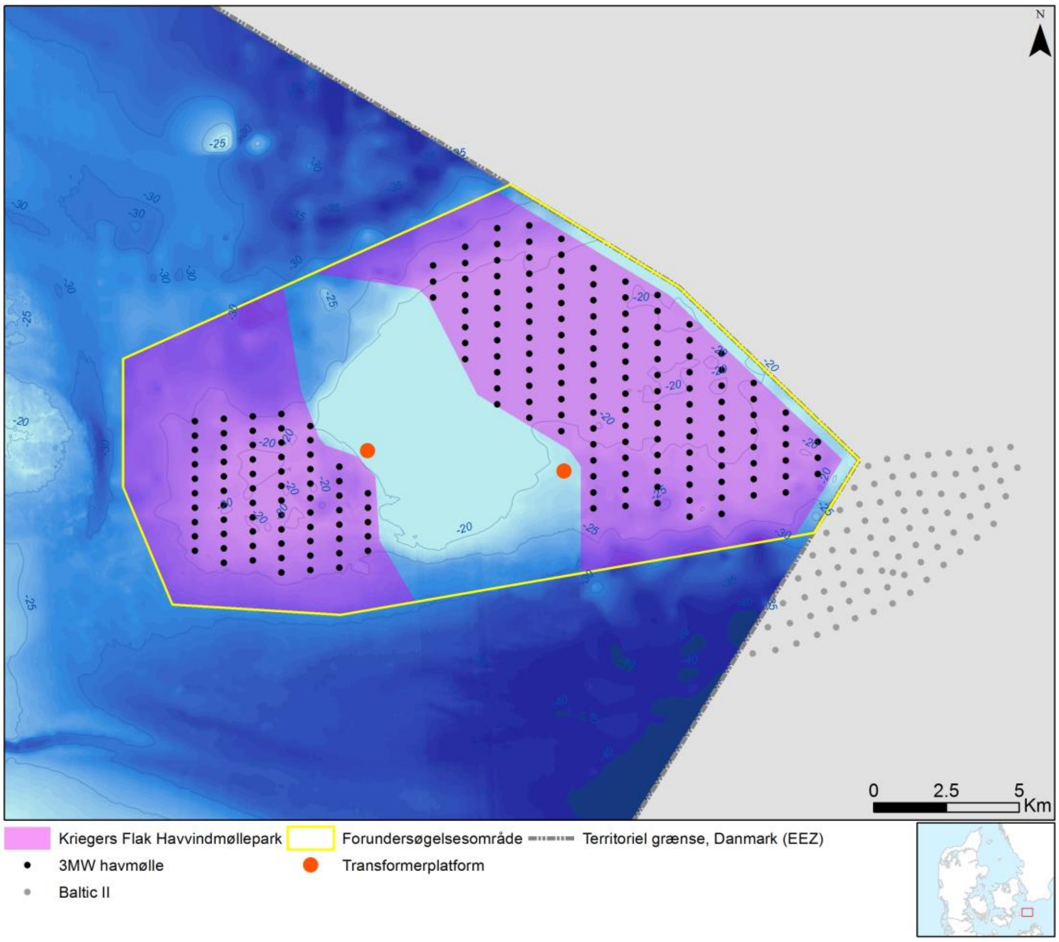



*Figure 3: Suggested layout for 3.0 MW turbines at the eastern and western part of the planned wind farm (purple polygons) at Kriegers Flak at Danish territory. The two red spots indicate the position of the offshore sub-station platforms. The yellow line delineates the pre-investigation area. In the south-eastern part of the map turbines within the German Baltic II OWF are shown.*

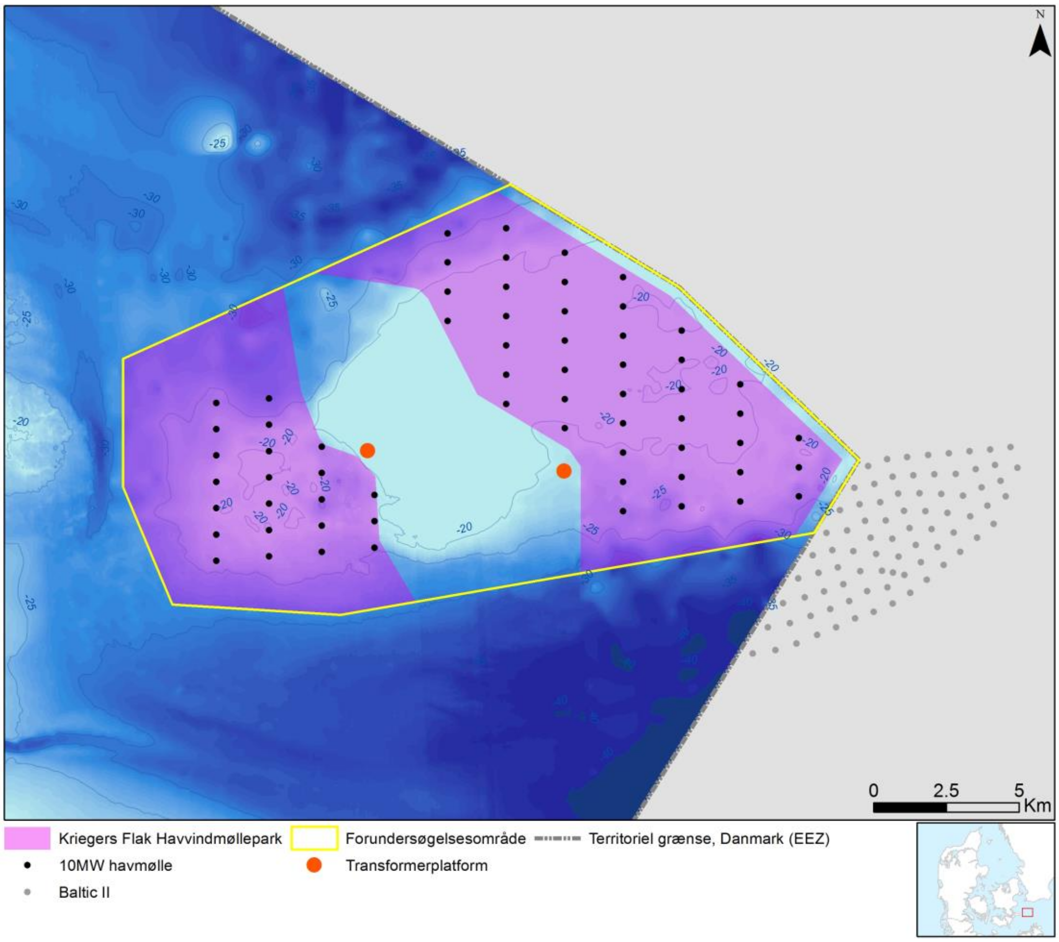



*Figure 4: Suggested layout for 10.0 MW turbines at the eastern and western part of the planned wind farm (purple polygons) at Kriegers Flak at Danish territory. The two red spots indicate the position of the offshore substation platforms. The yellow line delineates the pre-investigation area. In the south-eastern part of the map turbines within the German Baltic II OWF are shown.*

## 3.3 Wind turbines at Kriegers Flak

**Description**

The installed capacity of the wind farm is limited to 600 MW. The range for turbines at Kriegers Flak is 3.0 to 10.0 MW. Based on the span of individual turbine capacity (from 3.0 MW to 10.0 MW) the farm will feature from 60 (+4 additional turbines) to 200 (+3 additional turbines) turbines. Extra turbines can be allowed (independent of the capacity of the turbine), in order to secure adequate production even in periods when one or two turbines are out of service due to repair. The exact design and appearance of the wind turbine will depend on the manufactures.

As part of this technical description, information has been gathered on the different turbines from different manufactures. It should be stated that it is the range that is important; other sizes and capacities from different manufactures can be established at Kriegers Flak, as long as it is within the range presented in this technical description.

The wind turbine comprises tubular towers and three blades attached to a nacelle housing containing the generator, gearbox and other operating equipment. Blades will turn clockwise, when viewed from the windward direction.

The wind turbines will begin generating power when the wind speed at hub height is between 3 and 5 m/s. The turbine power output increases with increasing wind speed and the wind turbines typically achieve their rated output at wind speeds between 12 and 14 m/s at hub height. The design of the turbines ensures safe operation, such that if the average wind speed exceeds 25 m/s to 30 m/s for extended periods, the turbines shut down automatically.

**Dimensions**

Preliminary dimensions of the turbines are not expected to exceed a maximum tip height of 230m above mean sea level for the largest turbine size (10.0 MW).

Outline properties of present day turbines are shown in the table below.

*Table 1: Typical dimensions for offshore wind turbines between 3.0 MW and 10.0 MW. *MSL Mean Sea Level.*

| Turbine Capacity (MW) | Rotor diameter (m) | Total height (m) | Hub height above MSL* (m) | Swept area ($m^2$) |
|---|---|---|---|---|
| 3.0MW | 112m | 137m | 81m | 9 852 $m^2$ |
| 3.6MW | 120m | 141.6m | 81.6m | 11 500$m^2$ |
| 4.0MW | 130m | 155m | 90m | 13 300$m^2$ |
| 6.0MW | 154m | 179m | 102m | 18 600 $m^2$ |
| 8.0MW | 164m | 189m | 107m | 21 124$m^2$ |
| 10.0 MW | 190m | 220m | 125m | 28 400 $m^2$ |

## 3.4 Installation of wind turbines

**Jack-up barges**

Although offshore contractors use varying construction techniques, the installation of the wind turbines will typically require one or more jack-up barges. These vessels will be placed on the seabed and create a stable lifting platform by lifting themselves out of the water. The total area of each vessel's spud cans is approximately 350 $m^2$. The legs will penetrate 2 to 15 m into the seabed depending on seabed properties. These foot prints will be left to in-fill naturally.

The wind turbine components will either be stored at an adjacent port and transported to site by support barge or by the installation vessel itself, or transported directly from the manufacturer to the wind farm site by a barge or by the installation vessel. The wind turbines will typically be installed using multiple lifts. A number of support vessels for equipment and personnel jack-up barges may also be required.

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

## 3.5 Foundations

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

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

**Driven steel monopile**

This solution comprises driving a hollow steel pile into the seabed. Pile driving may be limited by deep layers of coarse gravel or boulders, and in these circumstances the obstruction may be drilled out. A transition piece is installed to make the connection with the wind turbine tower. This transition piece is generally fabricated from steel, and is subsequently attached to the pile head using grout.

Grouting is used to fix transition pieces to the piled support structure. Grout is a cement based product, used extensively for pile grouting operations worldwide. Grout (here: Ducorit®) consists of a binder which is mixed with quartz sand or bauxite in order to obtain the strength and stiffness of the product. Grout is similar to cement and according to CLP cement is classified as a danger substances to humans (H315/318/335). Cement is however not expected to cause environmental impacts. The grout which is expected to be used for turbines at Kriegers Flak OWF will conform to the relevant environmental standards. The grout will either be mixed in large tanks aboard the jack-up platform, or mixed ashore and transported to site. The grout is likely to be pumped through a series of grout tubes previously installed in the pile, so that the grout is introduced directly between the pile and the walls of the transition piece. Grout is not considered as an environmental problem. Methods will be adopted to ensure that the release of grout into the surrounding environment is minimised, however some grout may be released as a fugitive emission during the process. A worst-case conservative estimate of 5%, (up to 160 t) is assumed for the complete project.

The dimensions of the monopile will be specific to the particular location at which the monopile is to be installed. The results of some very preliminary monopile and transition piece design for the proposed Kriegers Flak OWF are presented in Table 2.

*Table 2: Typical dimensions of monopiles and transitions pieces. *Outer diameter at and below the seabed level. Above the seabed the diameter normally decrease resulting in a conical shape of the mono-pile (see Figure 5). **Very rough estimate of quantities.*

| MONOPILE | 3.0 MW | 3.6 MW | 4.0 MW | 8.0 MW | 10.0 MW** |
|---|---|---|---|---|---|
| *Outer Diameter at seabed level* | 4.5-6.0m | 4.5-6.0 m | 5.0-7.0 m | 6.0-8.0m | 7.0-10.0m |
| Pile Length | 50-60m | 50-60 m | 50-60m | 50-70m | 60-80m |
| Weight | 300-700t | 300-800 t | 400-900t | 700-1 000t | 900-1 400t |
| Ground Penetration (below mud line) | 25-32m | 25-32m | 26-33m | 28-35m | 30-40m |
| Total pile weight (203/170/154/79/64 monopiles) | 60 900-142 100 t | 51 000-136 000 t | 61 600-138 600 t | 55 300-79 000 t | 57 600-89 600 t |
| TRANSITION PIECE | | | | | |
| Length | 10–20m | 10-20m | 10–20m | 15-25m | 15-25m |
| Outer Diameter (based on a conical shaped monopile) | 3.5-5.0m | 3.5-5.0 m | 4.0-5.5 m | 5.0-6.5 m | 6.0-8.0 |
| Weight | 100-150t | 100-150 t | 120-180t | 150-300t | 250-400t |
| Volume of Grout per unit | 15-35m³ | 15-35m³ | 20-40m³ | 25-60m³ | 30-70m³ |
| Total weight (203/170/154/79/64 transition pieces) | 20 300-30 450 t | 17 000-25 500 t | 18 480-27 720 t | 11 850-23 700 t | 16 000-25 600 t |
| Scour Protection | | | | | |
| Volume per foundation | 2,100m³ | 2,100m³ | 2,500m³ | 3,000m³ | 3,800m³ |
| Foot print area (per foundation) | 1,500m² | 1,500m² | 1,575m² | 1,650m² | 2,000m² |
| Total Scour (203/170/154/79/64 mono piles) | 426 300 m³ | 357 000 m³ | 385 000 m³ | 237 000 m³ | 243 200 m³ |
| Total foot print scour area (203/170/154/79/64 monopiles) | 304 500 m² | 255 000 m² | 242 550 m² | 130 350 m² | 128 000 m² |

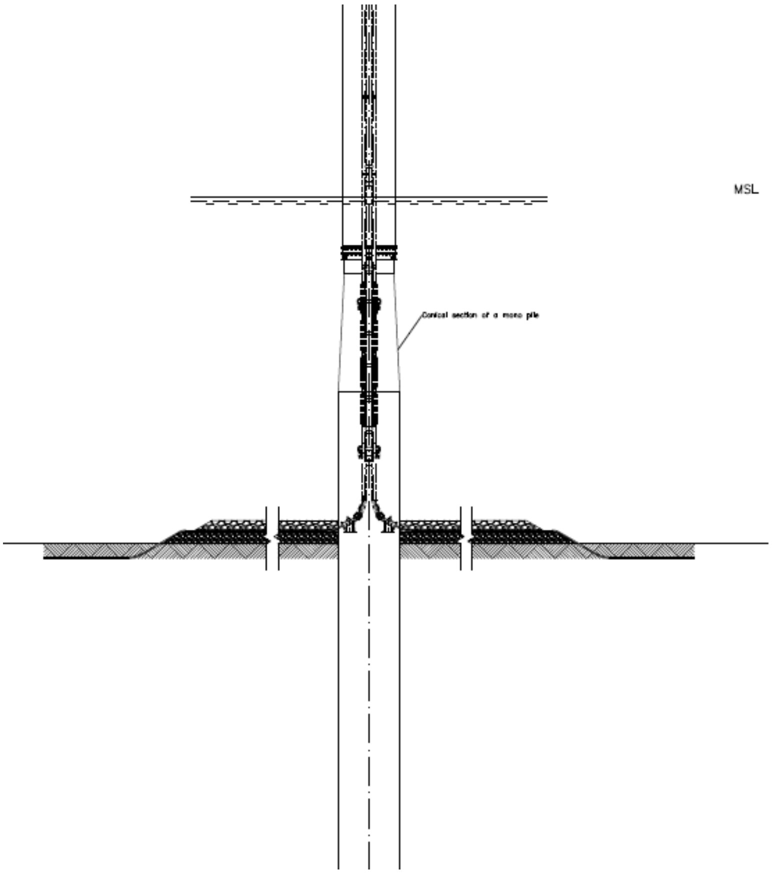



*Figure 5: The conical part of a monopile.*

The monopile concept is not expected to require much preparation works, but some removal of seabed obstructions may be necessary. Scour protection filter layer may be installed prior to pile driving, and after installation of the pile a second layer of scour protection may be installed (armour layer). Scour protection of nearby cables may also be necessary.

The installation of the driven monopile will take place from either a jack-up platform or floating vessel, equipped with 1-2 mounted marine cranes, a piling frame, and pile tilting equipment. In addition, a small drilling spread, may be adopted if driving difficulties are experienced. A support jack-up barge, support barge, tug, safety vessel and personnel transfer vessel may also be required.

The expected time for driving each pile is between 4 and 6 hours. An optimistic estimate would be one pile installed and transition grouted at the rate of one per day.

An average monopile driving intensity will be around 200 impacts per meter monopile. Considering that the piles will be around 35m each, this will be around 7,000 impacts per monopile. When this is divided regularly over the 6 hours pile driving activity, this leads to approximately 20 impacts per minute during the 6 hours pile driving activity.

**Concrete gravity base**

A concrete gravity base is a concrete structure that rest on the seabed because of the force of gravity. These structures rely on their mass including ballast to withstand the loads generated by the offshore environment and the wind turbine.

The seabed will require preparation prior to the installation of the concrete gravity base. This is expected to be performed as described in the following sequence, depending on local conditions:

- Removal of the upper seabed layer to a level where undisturbed soil is encountered, using a back-hoe excavator on a barge. The material will be loaded on split-hopper barges for disposal;
- Gravel is deposited in the hole to form a firm level base.

In Table 3 are the quantities for an average excavation depth of 2 m given, however large variations are foreseen, as soft bottom is expected in various parts of the area. Finally the gravity structure (and maybe nearby placed cables) will be protected against development of scour by installation of a filter layer and armour stones.

*Table 3: Quantities for an average excavation depth of 2 m (3.0 – 10.0 MW). *For excavation depths of further 4 to 8m at 20% of the turbine locations, the total excavated material would by increased by around 100%. **Very rough quantity estimates.*

| | 3.0 MW | 3.6 MW | 4.0 MW | 8.0 MW | 10.0 MW** |
|---|---|---|---|---|---|
| Size of Excavation (approx.) | 23-28m | 23-30m | 27-33m | 30-40m | 35-45m |
| Material Excavation (per base) | 900-1 300m³ | 1 000-1 500m³ | 1 200-1 800m³ | 1 500-2 500m³ | 2 000-3 200m³ |
| Total Material Excavated (203/170/154/79/64 turbines)* | 182 700-263 900m³ | 170 000-255 000m³ | 184 800-277 200m³ | 118 500-197 500m³ | 128 000-204 800m³ |
| Stone Replaced into Excavation (per base) – stone bed | 90-180m³ | 100-200m³ | 130-230m³ | 200-300m³ | 240-400m³ |
| Total Stone Replaced (203/170/154/79/64 turbines) | 18 270-36 540m³ | 17 000-34 000m³ | 20 020-35 420m³ | 15 800-23 700m³ | 15 360-25 600m³ |
| Scour protection (per base) | 600-800m³ | 700-1 000m³ | 800-1 100m³ | 1 000-1 300m³ | 1 100-1 400m³ |
| Foot print area (per base) | 800-1 100m² | 900-1 200m² | 1 000-1 400m² | 1 200-1 900m² | 1 500-2 300m² |
| Total scour protection (203/170/154/79/64 turbines) | 121 800-162 400m³ | 119 000-170 000m³ | 123 200-169 400m³ | 79 000-102 700m³ | 70 400-89 600m³ |
| Total foot print area (203/170/154/79/64 turbines) | 162 400-223 300m² | 153 000-204 000m² | 154 000-215 600m² | 94 800-150 100m² | 96 000-147 200m² |

The approximate duration of each excavation of average 2m is expected to be 3 days, with a further 3 days for placement of stone. The excavation can be done by a dredger or by excavator placed on barge or other floating vessels.

A scour protection design for a gravity based foundation structure is shown in Figure 6. The quantities to be used will be determined in the design phase.  The design can also be adopted for the bucket foundation.

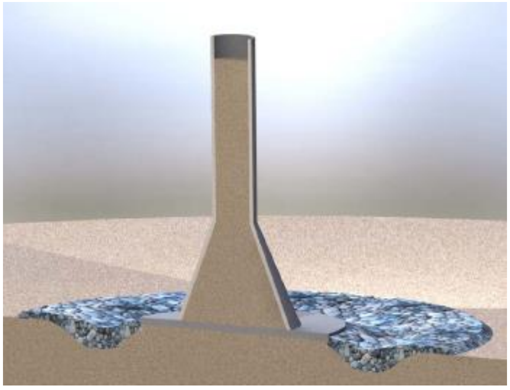


*Figure 6: Example on scour protection of a concrete gravity base (drawing: Rambøll).*

The ballast material is typically sand, which is likely to be obtained from an offshore source. An alternative to sand could be heavy ballast material (minerals) like Olivine, Norit (non-toxic materials). Heavy ballast material has a higher weight (density) that natural sand and thus a reduction in foundation size could be selected since this may be an advantage for the project. Installation of ballast material can be conducted by pumping or by the use of excavators, conveyers etc. into the ballast chambers/shaft/conical section(s). The ballast material is most often transported to the site by a barge.

The results of the preliminary gravity base design for the proposed Kriegers Flak OWF are presented below. Table 4 gives estimated dimensions for five different sizes of turbines.

*Table 4: Estimated dimensions for different types of turbines. *Very rough quantity estimates. Depends of loads and actual geometry/layout of the concrete gravity foundation.*

| GRAVITY BASE | 3.0 MW | 3.6 MW | 4.0 MW | 8.0 MW | 10.0 MW* |
|---|---|---|---|---|---|
| Shaft Diameter | 3.5-5.0m | 3.5-5.0m | 4.0-5.0m | 5.0-6.0 m | 6.0-7.0m |
| Width of Base | 18-23m | 20-25m | 22-28m | 25-35 m | 30-40m |
| Concrete weight per unit | 1 300-1 800t | 1 500-2 000t | 1 800-2 200t | 2 500-3 000t | 3 000-4 000t |
| Total concrete weight (t) | 263,000-364,000t | 254,000-338,000t | 274,000-335,000t | 193,000-230,000t | 186,000-248,000t |
| **BALLAST** | | | | | |
| Type | Infill sand | Infill sands | Infill sands | Infill sands | Infill sands |
| Volume per unit ($m^3$) | 1 300-1 800 $m^3$ | 1 500-2 000$m^3$ | 1 800-2 200$m^3$ | 2 000-2 500$m^3$ | 2 300-2 800$m^3$ |
| Total volume ($m^3$) (203/170/154/79/64 turbines) | 263 900-365 400 $m^3$ | 255 000-340 000 $m^3$ | 277 200-338 800 $m^3$ | 158 000-197 500 $m^3$ | 147 720-179 200 $m^3$ |

The installation of the concrete gravity base will likely take place using a floating crane barge, with attendant tugs and support craft. The bases will either be floated and towed to site or transported to site on a flat-top barge or a semi-submergible barge. The bases will then be lowered from the barge onto the prepared stone bed and filled with ballast.

**Jacket foundations**

Depending on the local conditions preparation of the seabed can be necessary prior to installation of jacket foundations, e.g. if the seabed is very soft due to sand banks.

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

The jacket construction itself is transported to the position by a large offshore barge. At the position a heavy floating crane vessel lifts the jacket from the barge and lowers it down to the preinstalled piles and hereafter the jacket is fixed to the piles by grouting.

On top of the jacket a transition piece constructed in steel is mounted on a platform. The transition piece connects the jacket to the wind turbine generator. The platform itself is assumed to have a dimension of approximately 10 x 10 meters and the bottom of the jacket between 20 x 20 meters and 30 x 30 meters between the legs.

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

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

The jacket legs are then attached to the piles by grouting with well-known and well-defined grouting material used in the offshore industry. One pile will be used per jacket leg.

For installation purposes the jacket may be mounted with mud mats at the bottom of each leg. Mud mats ensure bottom stability during piling installation. Mud mats are large structures normally made out of steel and are used to temporary prevent offshore platforms like jackets from sinking into soft soils in the sea bed. Under normal conditions piling and placement of mud mats will be carried out from a jack-up barge in the wind farm area. Mud mats will be left on the seabed when the jackets have been installed as they are essentially redundant after installation of the foundation piles. The size of the mud mats depends on the weight of the jacket, the soil load bearing and the local wave and currents conditions.

Scour protection at the foundation piles and cables may be applied depending on the soil conditions. In sandy soils scour protection is necessary for preventing the construction from bearing failure. Scour protection consists of natural well graded stones or blasted rock.

The dimensions of the jacket foundation will be specific to the particular location at which the foundation is to be installed, Table 5.

*Table 5: Dimensions for jacket foundations. *Very rough estimate of quantities.*

| Jacket | 3.0 MW | 3.6 MW | 4.0 MW | 8.0 MW | 10.0 MW* |
|---|---|---|---|---|---|
| Distance between legs at seabed | 18 x 18m | 20 x 20m | 22 x 22m | 30 x 30m | 40 x 40m |
| Pile Length | 40-50m | 40-50m | 40-50m | 50-60m | 60-70m |
| Diameter of pile | 1 200-<br>1 500mm | 1 200-<br>1 500mm | 1300-<br>1600mm | 1 400-<br>1 700mm | 1 500-<br>1 800mm |
| Scour protection volume (per foundation) | 800m$^3$ | 1 000m$^3$ | 1 200m$^3$ | 1 800m$^3$ | 2 500m$^3$ |
| Foot print area (per foundation) | 700m$^2$ | 800m$^2$ | 900m$^2$ | 1 300m$^2$ | 1 600 m2 |
| Total scour protection (203/170/154/79/64 turbines) | 162 400 m$^3$ | 170 000 m$^3$ | 184 800 m$^3$ | 142 200 m$^3$ | 160 000 m3 |
| Total foot print area in m$^2$ (203/170/154/79/64 turbines) | 142 100 m$^2$ | 136 000 m$^2$ | 138 600 m$^2$ | 102 700 m$^2$ | 102 400 m$^2$ |

**Suction Buckets**

The bucket foundation combines the main aspects of a gravity base foundation and a monopile.

The plate diameter from the gravity based structure will be used as foundation area. It is further anticipated that the maximum height of the bucket including the lid will be less than 1 m above sea bed. For this project the diameter of the bucket is expected to be the same as for the gravity based foundation structures.

The foundations can be tugged in floated position directly to its position by two tugs where it is upended by a crane positioned on a Jack-Up.

The concept can also be installed on the jack-up directly at the harbour site and transported by the jack-up supported by tugs to the position.

Installation of the bucket foundation does not require seabed preparations and divers. Additionally, there are reduced or no need for scour protecting depending on the particular case.

**Corrosion protection**

Corrosion protection on the steel structure will be achieved by a combination of a protective paint coating and installation of sacrificial anodes on the subsea structure.

The anodes are standard products for offshore structures and are welded onto the steel structures. Anodes will also be implemented in the gravity based foundation design. The number and size of anodes would be determined during detailed design.

The protective paint should be of Class C5M or better according to ISO 12944. Some products in Class C5M, contain epoxy and isocyanates which is on the list of unwanted substances in Denmark. Further it can be necessary to use metal spray (for metallization) on exterior such as platforms or boat landings. The metal spray depending on product can be very toxic to aquatic organisms. It is recommended, that the use of protective paint and metal spray is assessed in relation to the usage and volume in order to evaluate if the substances will be of concern to the environment.

**Scour protection**

Scour is the term used for the localized removal of sediment from the area around the base of support structures located in moving water. If the seabed is erodible and the flow is sufficiently high a scour hole forms around the structure.

There are two different ways to address the scour problem; either to allow for scour in the design of the foundation (thereby assuming a corresponding larger water depth at the foundation), or to install scour protection around the structure such as rock dumping or fronded mattresses.

The decision on whether to install scour protection, in the form of rock, gravel or frond mats, will be made during a detailed design.

If scour protection is required the protection system normally adopted consists of rock placement. The rocks will be graded and loaded onto a suitable rock-dumping vessel at a port and deployed from the host vessel either directly onto the seabed from the barge, via a bucket grab or via a telescopic tube.

**Offshore sub-station platforms at Kriegers Flak**

For the grid connection of the 600 MW offshore wind turbines on Kriegers Flak, two HVAC platforms will be installed. One (200 MW) on the western part of Kriegers Flak and one (400 MW) on the eastern part of Kriegers Flak.

The HVAC platforms are expected to have a length of 35-40 m, a width of 25-30 m and height of 15-20 m. The highest point is of a HVAC platform is expected to be 30-35 m above sea level.

The Kriegers Flak platforms will be placed on locations with a sea depth of 20-25 metres and approximately 25 -30 km east of the shore of Møn.

The foundation for the HVAC platforms will be either a jacket foundation consisting of four-legged steel structure or a gravity based structure (hybrid foundation) consisting of a concrete caisson with a four-legged steel structure on the top of the caisson.

The installation of a platform with jacket foundation will be one campaign with a large crane vessel with a lifting capacity of minimum 2000 tonnes. The time needed for the installation of jacket plus topside will be 4 - 6 days with activities ongoing day and night.

Prior to installation of a gravity foundation the seabed preparation will start with removal by an excavator aboard a vessel or by a dredger of the top surface of the seabed to a level where undisturbed soil is encountered. The excavated material is loaded aboard a split-hopper barge for disposal at appointed disposal area. Finally the foundation is protected against development of scour holes by installation of filter and armour stones. When the seabed preparation has finished the hybrid foundation or the Gravity Based Substation will be tugged from the yard and immersed onto the prepared seabed. This operation is expected to take 18 - 24 hours.

When the hybrid foundation is in place it will be ballasted by sand, the ballasting process is expected to take 8 – 12 days.

## 3.6 Submarine cables

**Inter-array Cables**

A medium voltage inter-array cable will be connected to each of the wind turbines and for each row of 8-10 wind turbines a medium voltage cable is connected to the offshore sub-station platform. The array cables will be buried to provide protection from fishing activity, dragging of anchors etc.

## 3.7 Wind farm inspection and maintenance

The wind farm will be serviced and maintained throughout the life of the wind farm possibly from a local port in the vicinity to the wind farm. Following the commissioning period of the wind farm, it is expected that the servicing interval for the turbines will be approximately 6 months.

The strategy for maintenance of the offshore substation platforms will be similar to the wind farm, normally one visit during day time per month is planned for planned maintenance.

## 3.8 Wind farm decommissioning

The lifetime of the wind farm is expected to be around 25 years. It is expected that two years in advance of the expiry of the production time the developer shall submit a decommissioning plan. The method for decommissioning will follow best practice and the legislation at that time.

It is unknown at this stage how the wind farm may be decommissioned; this will have to be agreed with the competent authorities before the work is being initiated.

The following sections provide a description of the current intentions with respect to decommissioning, with the intention to review the statements over time as industry practices and regulatory controls evolve.

**Extent of decommissioning**

The objectives of the decommissioning process are to minimize both the short and long term effects on the environment whilst making the sea safe for others to navigate. Based on current available technology, it is anticipated that the following level of decommissioning on the wind farm will be performed:

1. Wind turbines – to be removed completely.
2. Structures and substructures – to be removed to the natural seabed level or to be partly left in situ.
3. Inter array cables – to be either removed (in the event they have become unburied) or to be left safely in situ, buried to below the natural seabed level or protected by rock-dump.
4. Scour protection – to be left in situ.

**Decommissioning of wind turbines**

The wind turbines would be dismantled using similar craft and methods as deployed during the construction phase. However the operations would be carried out in reverse order.

**Decommissioning of offshore sub-station platform**

The decommissioning of the offshore sub-station platforms is anticipated in the following sequence:

- Disconnection of the wind turbines and associated hardware.
- Removal of all fluids, substances on the platform, including oils, lubricants and gasses.
- Removal of the sub-station from the foundation using a single lift and featuring a similar vessel to that used for construction. The foundation would be decommissioned according to the agreed method for that option.

**Decommissioning of buried cables**

Should cables be required to be decommissioned, the cable recovery process would essentially be the reverse of a cable laying operation, with the cable handling equipment working in reverse gear and the cable either being coiled into tanks on the vessel or guillotined into sections approximately 1.5 m long immediately as it is recovered. These short sections of cable would be then stored in skips or open containers on board the vessel for later disposal through appropriate routes for material reuse, recycle or disposal.

**Decommissioning of foundations**

Foundations may potentially be reused for repowering of the wind farm. More likely the foundations may be decommissioned through partial of complete removal. For monopoles it is unlikely that the foundations will be removed completely, it may be that the monopole may be removed to the level of the natural seabed. For gravity foundations it may be that these can be left in situ. At the stage of decommissioning natural reef structures may have evolved around the structures and the environmental impact of removal therefore may be larger than leaving the foundations in place. The reuse or removal of foundations will be agreed with the regulators at the time of decommissioning. The suction bucket can fully be removed by adding pressure inside the bucket.

**Decommissioning of scour protection**

The scour protection will most likely be left in situ and not be removed as part of the decommissioning. It will not be possible to remove all scour protection as major parts of the material are expected to have sunk into the seabed. Also it is expected that the scour protection will function as a natural stony reef. The removal of this stony reef is expected to be more damaging to the environment in the area than if left in situ. It is therefore considered most likely that the regulators at the time of decommissioning will require the scour protection left in situ.

# 4 Description of activities that could result in an impact on marine mammals

## 4.1 Factors affecting marine mammals

The central question in the context of offshore wind farms and marine mammals is whether the construction, operation and dismantling of these will have a net impact (positive or negative) on the abundance in the area and ultimately the population size, and whether this is acceptable or not.

Even if the ultimate goal may be to assess the impact at the population level, this is often difficult unless all factors related to the population structure and abundance of the animals, as well as all other factors affecting their survival in relation to direct and indirect impacts are known. In this study, information on the animals using the impacted area and the status of the populations are relatively well known, however, the assessment of the impacts from the construction and operation of the wind farm is based on some uncertainties and assumptions.

Types of potential effects are the same for seals and porpoises in the waters surrounding the wind farm (Figure 7), whereas an additional set of factors are present for the potential impact on seals at nearby haul-out areas (Figure 8).

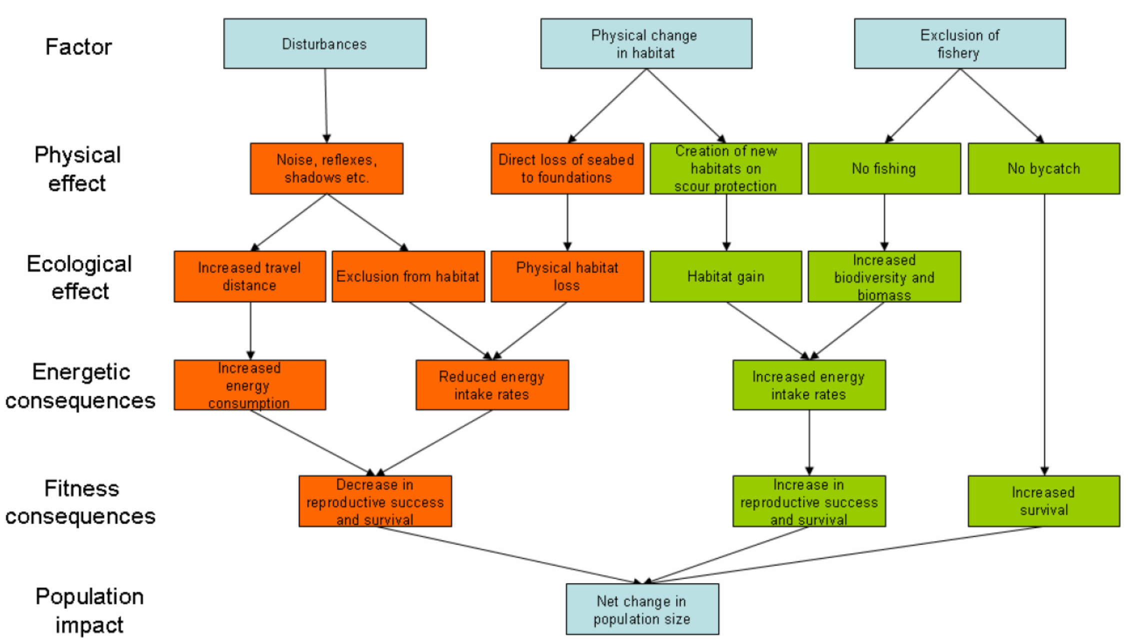



*Figure 7: Potential effects of offshore wind farms on marine mammals in the surrounding waters. Factors with negative effect are shown in red; factors with positive effects are shown in green. Disturbance is the dominant factor during construction, whereas all three factors may play a role during operation of the wind farm. Source: (Tougaard & Teilmann, 2007).*

In general, the affecting factors are divided into 1) disturbing factors, which one way or the other all have a negative impact on the animals, 2) changes to the habitat, which can be both positive and negative, 3) exclusion of fishery, which is mostly positive. Factors affecting haul-out of seals are divided into 1) disturbances, which are all negative and 2) physical changes to the haul-out site, which is negative, but may theoretically have some positive side effects (Figure 8).

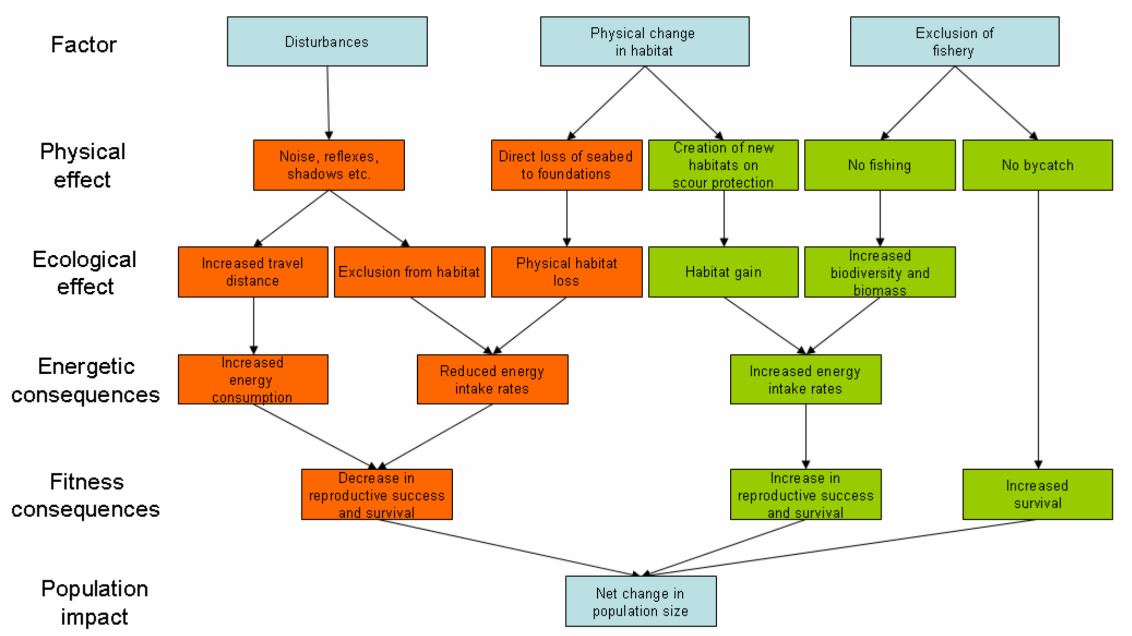



*Figure 8: Potential effects of construction and operation of an offshore wind farm on seals at a nearby haul-out site. Negative effects are shown in red, positive effects in green. Disturbance is the only relevant factor during construction whereas all factors could contribute during operation. Source: (Tougaard & Teilmann, 2007).*

## 4.2 General effects of noise of marine mammals

Generally, the effect of noise on marine mammals can be divided into four broad categories that largely depend on the individuals' proximity to the sound source:

- Zone of audibility
- Masking
- Behavioural changes/Cessation of normal behaviour
- Physical damages

It is important to note that the limits of each zone of impact are not sharp, and that there is a large overlap between the different zones. Behavioural changes and masking also critically depend on the background noise level, and all impacts depend on the age, sex and general physiological and behavioural states of the animals (Popov, Supin, Wang, Wang, Dong, & Wang, 2011), (Southall, et al., 2007).

The zone of audibility or the detection range is of great importance when discussing masking effects. Masking happens when a given noise impact makes it difficult for the animal to detect other vital sounds. However, masking is not a directly relevant issue for pulsed sounds (see Madsen, Wahlberg, Tougaard, Lucke, & Tyack (2006)). This impact assessment is therefore mainly focused on physical damages and behavioural changes.

Behavioural changes are inherently difficult to evaluate. Changes range from very strong reactions, such as panic or flight, to more moderate reactions where the animal may orient itself towards the sound or move slowly away or will cease an on-going behaviour. Additionally, the animals' reaction may vary greatly depending on season, behavioural state, age, sex, as well as the intensity, frequency and time structure of the sound causing behavioural changes.

Physical damages to the hearing apparatus lead to permanent changes in the animals' detection threshold (permanent threshold shift, PTS). However, hearing loss is usually only temporary (temporary threshold shift, TTS) and the animal will regain its original detection abilities after a recovery period. For PTS and TTS the sound energy is an important factor for the degree of hearing loss. In addition, the duration of impact will affect the duration of the recovery time (Popov, Supin, Wang, Wang, Dong, & Wang, 2011).

## 4.3 Affecting factors during construction

Construction of an offshore wind farm is an operation of considerable magnitude and includes several components which may potentially affect seals and porpoises. Negative effects on the local abundance of harbour porpoises and to a lesser degree seals have been documented at previous construction works (see sections 7.1 and 7.2 below). A long-term negative effect of wind farm construction has been suggested for porpoises only. Specific effects of pile driving have been documented for both seals (Edrén, Wisz, Teilmann, Dietz, & Söderkvist, 2010) and porpoises (Tougaard, Carstensen, Teilmann, Skov, & Rasmussen, 2009) (Brandt, Diederich, Betke, & Nels, 2011) and this activity is likely to be the most disturbing and possibly injuring activity during construction. Therefore, pile driving will be assessed as the worst case scenario.

The seabed inside the wind farm area is inevitably disturbed during construction. This disturbance occurs by direct removal and redistribution of sediment in connection to establishment of foundations and burying of cables. Suspension of bottom material is unlikely to affect seals and porpoises directly, but may have an indirect effect on local fish and bottom fauna on which these marine mammals feed.

No significant chemicals harmful or unpleasant to seals and porpoises are likely to be released into the water during normal construction activities and thus will not constitute a risk to marine mammals. Therefore, effects of chemicals are not dealt with specifically in this assessment. However, accidental spills of oil or other substances released due to errors or accidents during construction could potentially cause considerable damage to the local ecosystem and hence also seals and porpoises.

**Noise from pile driving**

Below, general descriptions of two types of pile driving are considered, however, for the actual impact assessment, only the worst case scenario of 10 MW monopiles is considered. The two types are piling of steel monopile foundations and jacket foundations. Even if gravitational foundations are used, some piling may also be needed in order to stabilise the seabed below the concrete foundations with a sheet pile wall or similar, as was the case for a single foundation out of 72 during construction of Nysted Offshore Wind Farm. The magnitude of sound emission of this type of piling is much lower compared to steel monopiles.

Pile driving, by which steel monopiles are driven into the seabed with a large hydraulic hammer, generates very high sound pressures. Measurements made at Horns Reef II Offshore Wind Farm during piling of one foundation; a 4m diameter steel monopile, shows that peak to peak sound pressure levels are over 190 dB re 1 µPa at 720 meters form the construction site (Figure 9).

Most energy of the pile driving sounds is at low frequencies, where especially porpoises and to a lesser degree seals have poor hearing. It is nevertheless evident from the spectra in Figure 9, that there is significant energy present in the signals well into the range of best hearing for porpoises and seals (see Figure 20 and Figure 48).

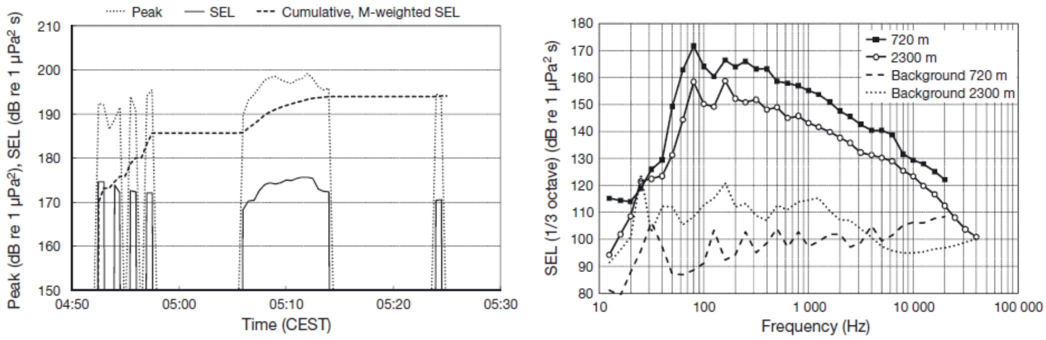



*Figure 9: Left: Peak level and single-stroke Sound Exposure Level (SEL) for the whole pile driving operation of one monopile at Horn Reef II measured at 720 m distance. Also shown is the M-weighted (frequency weighting procedure to take the hearing abilities of marine mammals into account) cumulative SEL (added energy of multiple exposures). The difference between the non-cumulative unweighted and M-weighted SEL varied from ~4 to 7 dB. Right: Spectra of pile driving noise at two measurement locations, averaged from 24 blows (locations can be seen at Figure 72). Source: Brandt, Diederich, Betke, & Nels, (2011).*

Construction of jacket foundations will also require some piling, but the sound pressure level will be lower than for steel monopiles because of the smaller diameter of the pile (see also section 7.1). There is a general correlation between pile size and source sound pressures (Figure 10).

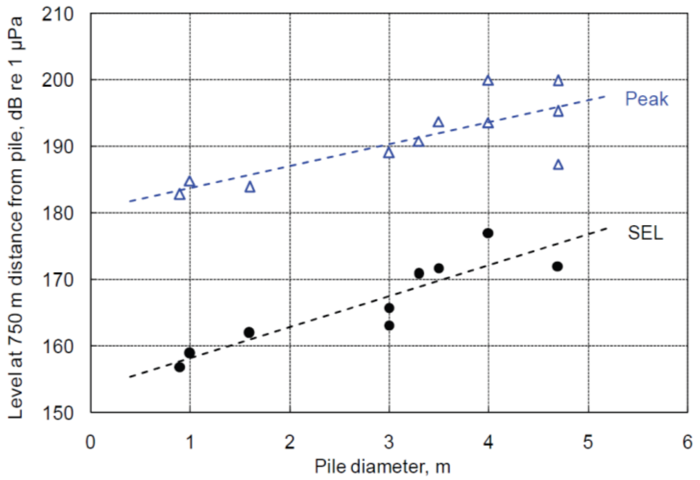



*Figure 10: Measured peak levels and broadband SELs at 750 m versus pile diameter from various pile driving operations. Compiled by Matuschek & Betke (2009).*

**Noise from ship traffic**

During construction there will be an increased traffic of smaller and larger boats and ships to and from the construction site. The most significant impact from this traffic will be elevated levels of underwater noise. The effect of ship noise on marine mammals is not well studied, so no good estimates of the magnitude of impact can be given. However, small and fast service vessels are likely more disturbing, due to the higher speed and frequencies emitted, than larger ships with slowly revolving propellers and lower frequency noise. In general, the faster the propellers are rotating, the higher the pitch of the noise (Richardson W. , Greene, Malme, & Thomson, 1995) (Erbe, 2002) and thus the more audible it is to seals and especially porpoises (see sections 6.1 and 6.5 below). The background noise in the Kriegers Flak area is generally dominated by low frequency shipping noise illustrated by the heavy traffic as seen in Figure 11.

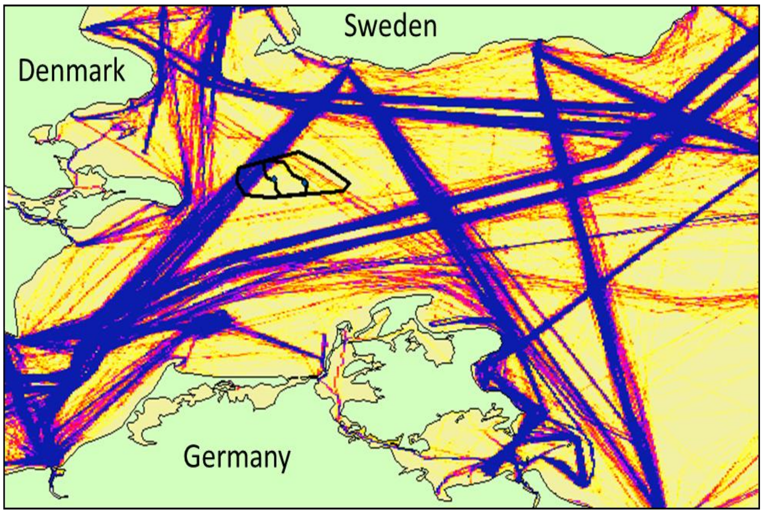



*Figure 11: Overview of the ship traffic in the area around Kriegers Flak. Yellow-red-blue lines indicate shipping lanes with increasing load.*

**Other sources of underwater noise**

Several other sources of underwater noise of variable nature will be present throughout the whole or parts of the construction site. This includes side-scan sonars, echosounders, Doppler logs, Doppler current profilers and underwater communication with divers. All of these, apart from underwater communication, include emission of very powerful sounds in various frequencies, of those <180 kHz will be detectable for porpoises and seals. Side-scan sonars are likely to constitute the biggest impact on harbour porpoises that are capable of hearing in the high frequency range up to around 150 kHz. Source levels are often very high and as signals are pointed forward and/or sideways, instead of downwards as in normal echo sounders, may affect both porpoises and seals in an area in front/sideways of the boat, particularly in narrow channels. A case of mass strandings and deaths of melon-headed whales (*Peponocephala electra*) in relation to the use of hydrographic survey sonar have been well documented (Southall, Rowles, Gullard, Baird, & Jepson, 2013). The precise causal link between sonar and strandings is however not clear.

## 4.4 Affecting factors during operation

The construction and operation of the turbines create changes in the physical environment which may influence seals and porpoises directly or indirectly. It is possible that the physical presence of the turbines has a negative effect, i.e. that animals will be reluctant to enter an area with new large unfamiliar structures. Most concern surrounds possible effects of low frequency underwater noise from operating turbines, but also visual appearance of the rotating wings has been suggested as a factor potentially affecting porpoises (Teilmann & Carstensen, 2012).

**Noise from operating wind farms**

Based on measurements of existing offshore wind turbines, the noise from the operating wind turbines is expected to be of relatively low intensity and frequency. A number of measurements from different turbines exist and all share common features of low absolute sound levels and no significant energy at frequencies lower than 1000 Hz (Betke, 2006) (Madsen, Wahlberg, Tougaard, Lucke, & Tyack, 2006) (Tougaard, Henriksen, & Teilmann, 2009). Apparently, there is little difference in the radiated underwater noise from monopile and gravitational foundations. One example from Horns Reef is shown in Figure 12. One measurement which stands out is from Utgrunden wind farm (Ingemansson Technology AB 2003). Noise from these turbines is considerably higher in intensity (approx. 10 dB) and with considerably more energy at higher frequencies than emissions from the other wind farms. The reason why these turbines differ from the rest is unknown, but may have to do with the foundation on solid bedrock, in contrast to the hard sand at the other wind farms.

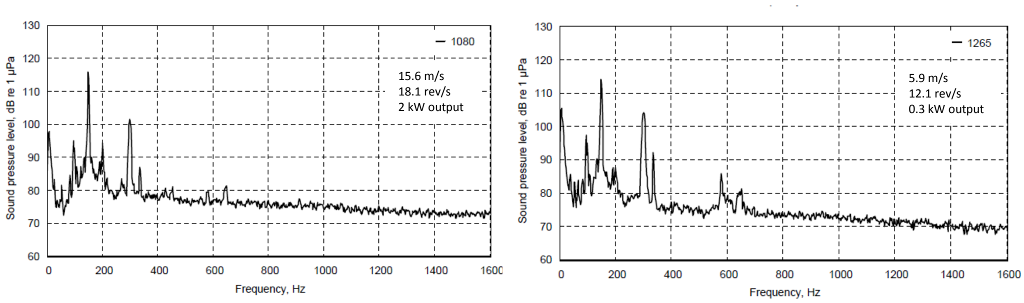



*Figure 12: Measurements of noise from turbine in Horns Reef Offshore Wind Farm running close to maximum power rating (left) and at low level (right). Turbine noise consists of multiple peaks at discrete frequencies, which rise above the background noise. From: Betke (2006).*

**Noise from service and maintenance activities**

Another potentially disturbing factor during operation of the wind farm is service and maintenance of the turbines, where small, fast boats commute between land and the wind farm, as well as between the wind turbines. Although activity levels will be much lower than during construction, the nature of this disturbance is nevertheless likely to be qualitatively similar to ship traffic during construction.

## Electromagnetic fields

Any cable carrying current will be surrounded by an electromagnetic field. The magnetic part of this field adds to the natural magnetic field of the earth and thus has the potential to interfere with magnetic and electric orientation in the vicinity of the cable.

The cables at Kriegers Flak will consist of three conductors carrying three phases of alternating current (AC). Each conductor generates its own alternating field and in theory the three fields should cancel out each other. Due to the geometry of the cable, they do not cancel out completely, but the total field is nevertheless considerably weaker than from a single conductor cable. The size of the magnetic field from the same type of sea-cable connecting Nysted Offshore Wind Farm to land has been calculated to approximately 5 µT on the sea bottom one meter above the cable when the wind farm runs at maximal capacity (cable carrying 600 A (Eltra, 2000)). The natural magnetic field in Denmark is approximately 50 µT (EnergiNet.dk). The magnetic anomaly introduced by the cable is thus limited and local around the cable.

## Visual appearance

The foundations below water and the turbines above water represent a change to the visual scene of the area and it could be hypothesized that this could deter seals and porpoises from the area. The visual impact underwater is likely to be minimal in the operating wind farm. Underwater parts of the foundation and scour protection quickly become overgrown with algae and epifauna and will thus visually resemble other reef-like structures in the sea. In air, the more than 100 m high turbines with their rotating wings represent a major change to the visual scene and shadows cast by the wings in bright sunshine will be visible in the water and hence perceptible to seals and porpoises.

## Changes in the habitat

The construction of an offshore wind farm on sandy bottom will inevitably cause changes to the habitat. First of all is the direct loss of habitat to foundations and scour protection. The absolute size of the area covered by foundations and scour protection is marginal however, and any effects on the habitat are likely to be overshadowed by the changes that will occur as a consequence of introduction of hard substrates, that extend up into the water column. These will inevitably be colonised by algae and filter feeding epifauna and create an artificial reef (Petersen & Malm, 2006) and represent a permanent enrichment of biomass and biodiversity. Studies on colonisation of foundations at Nysted Offshore Wind Farm have shown that the species composition on the turbine foundations is identical to the species composition at a proximate natural stone reef (Schönheiders Pulle; (Birklund, 2005)).

## Exclusion of fishery

For reasons of safety (for fishermen and installations) restrictions on bottom trawl inside the wind farm are likely to be imposed. This will possibly increase fish diversity and density and thus add to the improvement of the habitat, also because of the turbine foundations that are likely to attract fish to the area. Hence, wind farm areas may have a positive effect on the fish community and by extension, marine mammals. However, more fish may increase gillnetting activities which may result in an increase in by-catch of especially porpoises.

**Permanent effects on seal haul-out**

Permanent effects of the wind farm on seal haul-out can occur either through physical changes or through an increased level of disturbance to the seals (Figure 8). Physical changes to the haul-out sites, as a direct consequence of the wind farm, seem very unlikely as the wind farm is located more than 30 km away from the nearest known haul-out site at Falsterbo. Increased disturbance of the seals in the water may result in displacement of animals from the area and hence, from the haul-out site. No long term effect was observed at the seal haul-out site Rødsand as close as 4 km from the Nysted Offshore Wind Farm (Edrén, et al., 2010).

# 5 Methods

## 5.1 Satellite Tagging of Harbour Porpoises

Ninety-nine harbour porpoises have been tagged with Argos satellite tags at Skagen and in the inner Danish waters (bounded by the Skagerrak in the north and the Arkona Basin in the southeast) from 1997 to 2013. Porpoises were caught incidentally in pound nets as described in detail by Sveegaard et al., (2011). Tags were duty cycled to transmit every 1, 2, 3, or 4 days and programmed to give 50–1,000 transmissions per duty day (Teilmann, Sveegaard, Dietz, Petersen, & Berggren, 2008).

**Data Analysis**

Locations are classified by the Argos system into one of six location classes (LC) according to level of accuracy (3, 2, 1, 0, A, B). Studies have shown that there can be significant error in all LCs (up to several kilometres), but that even the low-accuracy locations may provide useful and valid information if they are appropriately filtered (e.g. (Vincent, McConnell, Ridoux, & Fedak, 2002)). Thus, all LCs were used in this study after being filtered by an SAS-routine, Argos-Filter v7.03 (Douglas, 2006). The filter is a Distance-Angle-Rate (DAR) filter and applies user-defined settings for distance between successive locations, turning angles and maximum swim speed to filter out the most unlikely locations. For further description of the method and data handling see (Sveegaard, et al., 2011), and below for processing of seal data. Habitat modelling based on the satellite telemetry data is presented in the section 5.4.

## 5.2 GPS tracking of harbour and grey seals

This chapter describes the methods and results for the investigation of seal movements and behaviour within the Kriegers Flak region. Our study focused on the use of GPS phone tags (Sea Mammal Research Unit, SMRU) and the subsequent data analysis and reporting about the seals' movement patterns and habitat use. The use of GPS allows fine-scale details of animals' usage of specific haul-out sites and foraging areas to be determined. A tagging study using this technology provides the best possible data to allow a critical assessment of habitat use by these animals around Kriegers Flak and any potential responses to the construction and the operation of an offshore wind farm in this area.

**Methods**

We targeted the haul-out site at Måkläppen, Falsterbo where seals haul-out on sand-banks (Figure 13). Other local site haul-out sites consist of individual boulders over a wider and very shallow area with fewer seals, which were less suitable for catching seals.

*Figure 13: Mixed species group (harbour and grey seals) hauled out at Måkläppen, Falsterbo (Photo: DCE).*

The GPS/GSM tag is essentially a data logger that records and stores information about position and diving depth and transmits the information via the GSM mobile phone network at regular intervals using a hybrid GPS system, while the seal is resting on land. Stored location and behavioural data are opportunistically relayed ashore by means of an embedded mobile phone (GSM) modem when the tag comes within mobile phone coverage. Data are recorded continuously, whether or not the tag is within GSM coverage. The advantage of this type of tag is the frequency and accuracy of the GPS locations and the large amount of behavioural data that can be relayed over the high bandwidth mobile phone data channel (Cronin & McConnell, 2008). Detailed information on depths and durations of individual dives are recorded to determine the diving behaviour and potential feeding sites. Also, a wet/dry sensor is used to record when a seal is hauled out (when the sensor is continuously dry for >10 minutes). The advantage of this type of tag is the frequency and accuracy of the GPS locations and the large amount of behavioural data that can be relayed over the high bandwidth mobile phone network (McConnell, Lonergan, & Dietz, 2012). In order to avoid outliers the GPS/GSM data were filtered using the Residual qualifier. The GPS locations were filtered to remove the few, erroneous locations where the residual value was greater than 25 and the number of satellites was less than five. 95% of these filtered locations are within 50 m of the true location (McConnell, Lonergan, & Dietz, 2012).

**Tagged animals**

Ten harbour seals were tagged with GPS/GSM tags for this EIA and another 11 grey seals tagged with the same kind of high resolution tags were made available for this assessment by Aarhus University, Sea Mammal Research Unit and Museum of Natural History, Stockholm (Table 6).

The GPS /GSM tags were mounted on five yearlings, three subadults and two adult harbour seals during the autumn 2012 at Måkläppen, Falsterbo, Sweden. The 11 grey seals consisted of eight yearlings and three subadult seals of which six were tagged at Falsterbo, five at Rødsand and one at a northern Swedish location, Ålandsøerne.

*Table 6: Biological information on the 10 harbour and 11 grey seals used in the present EIA study.*

| Seal # | Tagging date | Last location | Lifetime | Total number of positions | Number of filtered positions | Mean pos. per day | Transmitter mount |
|---|---|---|---|---|---|---|---|
| HS01 | 18-Sep-2012 | 11-Jun-2013 | 266 | 2024 | 2006 | 7.5 | Back |
| HS02 | 18-Sep-2012 | 25-Mar-2013 | 188 | 1254 | 1247 | 6.6 | Back |
| HS03 | 19-Sep-2012 | 24-Oct-2012 | 35 | 323 | 317 | 9.1 | Back |
| HS04 | 20-Sep-2012 | 18-Nov-2012 | 59 | 712 | 694 | 11.8 | Back |
| HS05 | 13-Nov-2012 | 5-Jul-2013 | 234 | 1584 | 1579 | 6.7 | Back |
| HS06 | 14-Nov-2012 | 26-Jun-2013 | 224 | 2952 | 2939 | 13.1 | Back |
| HS07 | 14-Nov-2012 | 9-Jun-2013 | 207 | 1489 | 1482 | 7.2 | Back |
| HS08 | 6-Dec-2012 | 25-May-2013 | 170 | 2562 | 2549 | 15.0 | Neck |
| HS09 | 7-Dec-2012 | 31-May-2013 | 175 | 2075 | 2067 | 11.8 | Neck |
| HS10 | 7-Dec-2012 | 13-May-2013 | 157 | 1732 | 1727 | 11.0 | Neck |
| Sum | | | 1715 | 16707 | 16607 | | |
| Mean | | | 172 | 1671 | 1661 | 10.0 | |
| GS01 | 24-Oct-2009 | 19-Feb-2010 | 118 | 10919 | 10919 | 92.5 | Neck |
| GS02 | 31-Oct-2009 | 2-May-2010 | 183 | 14513 | 14513 | 79.3 | Neck |
| GS03 | 6-Oct-2010 | 29-Mar-2011 | 174 | 25702 | 25127 | 144.4 | Neck |
| GS04 | 7-Oct-2010 | 28-Feb-2011 | 144 | 27966 | 27215 | 189.0 | Neck |
| GS05 | 8-Oct-2010 | 6-Apr-2011 | 180 | 29540 | 27950 | 155.3 | Neck |
| GS06 | 26-Mar-2012 | 22-Aug-2012 | 149 | 7585 | 7585 | 50.9 | Neck |
| GS07 | 13-Nov-2012 | 31-Jan-2013 | 79 | 2985 | 2956 | 37.4 | Back |
| GS08 | 14-Nov-2012 | 27-Feb-2013 | 105 | 2230 | 2052 | 19.5 | Back |
| GS09 | 6-Dec-2012 | 6-Mar-2013 | 90 | 3095 | 3083 | 34.3 | Neck |
| GS10 | 6-Dec-2012 | 11-Mar-2013 | 95 | 3480 | 3470 | 36.5 | Neck |
| GS11 | 7-Dec-2012 | 21-Feb-2013 | 76 | 2472 | 2456 | 32.3 | Neck |
| Sum | | | 1393 | 130487 | 127326 | | |
| Mean | | | 127 | 11862 | 11575 | 79.2 | |
| All sum | | | 3108 | 147194 | 143933 | | |
| All mean | | | 148 | 7009 | 6854 | 46 | |

The GPS /GSM tags mounted on the harbour seals lasted for an average duration of 172 days and produced an average of 10 location fixes per day (Table 7). The number of positions was smaller than those obtained from previous harbour seal and the grey seal taggings with GPS/GSM tags. This is probably because the tags were programmed to last for an entire season of 10 months and because several of the transmitters were placed on the back of seals smaller than 30 kg, from where less contact with satellites can be expected than from the usual tag position on the neck.

The GPS/GSM tags mounted on the grey seals lasted for an average duration of 127 days and produced an average of 79 location fixes per day (Table 7). Most of the grey seals were large enough to carry the GPS/GSM tags on the neck and provided more positions per day than the harbour seals.

*Table 7: Performance and technical details of the 10 harbour and 11 grey seals tags used in the present EIA study.*

| Seal # | Transmitter # | SMRU name | Roto tag | Tagging date | Last location | Lifetime | Total number of positions | Number of filtered positions | Mean pos. per | Transmitter mount |
|---|---|---|---|---|---|---|---|---|---|---|
| HS01 | 11741 | PV46-01b-12 | 37 | 18-Sep-2012 | 11-Jun-2013 | 266 | 2024 | 2006 | 7,5 | Back |
| HS02 | 11746 | PV46-02b-12 | 38 | 18-Sep-2012 | 25-Mar-2013 | 188 | 1254 | 1247 | 6,6 | Back |
| HS03 | 12570 | PV46-05b-12 | 39 | 19-Sep-2012 | 24-Oct-2012 | 35 | 323 | 317 | 9,1 | Back |
| HS04 | 12571 | PV46-07b-12 | 40 | 20-Sep-2012 | 18-Nov-2012 | 59 | 712 | 694 | 11,8 | Back |
| HS05 | 12599 | PV46-10-12 | 43 | 13-Nov-2012 | 5-Jul-2013 | 234 | 1584 | 1579 | 6,7 | Back |
| HS06 | 12587 | PV46-09-12 | 52 | 14-Nov-2012 | 26-Jun-2013 | 224 | 2952 | 2939 | 13,1 | Back |
| HS07 | 12600 | PV46-17-12 | 53 | 14-Nov-2012 | 9-Jun-2013 | 207 | 1489 | 1482 | 7,2 | Back |
| HS08 | 12593 | PV46-16-12 | 54 | 6-Dec-2012 | 25-May-2013 | 170 | 2562 | 2549 | 15,0 | Neck |
| HS09 | 12594 | PV46-14-12 | 57 | 7-Dec-2012 | 31-May-2013 | 175 | 2075 | 2067 | 11,8 | Neck |
| HS10 | 12595 | PV46-12-12 | 58 | 7-Dec-2012 | 13-May-2013 | 157 | 1732 | 1727 | 11,0 | Neck |
| Sum | | | | | | 1715 | 16707 | 16607 | | |
| Mean | | | | | | 172 | 1671 | 1661 | 10,0 | |
| GS01 | 11094 | PV28-04-2009 | 1 | 24-Oct-2009 | 19-Feb-2010 | 118 | 10919 | 10919 | 93 | Neck |
| GS02 | 11162 | PV28-02-2009 | 7 | 31-Oct-2009 | 2-May-2010 | 183 | 14513 | 14513 | 79 | Neck |
| GS03 | 11743 | PV36-04-2010 | BX2137 | 6-Oct-2010 | 29-Mar-2011 | 174 | 25702 | 25127 | 144 | Neck |
| GS04 | 11745 | PV36-05-2010 | - | 7-Oct-2010 | 28-Feb-2011 | 144 | 27966 | 27215 | 189 | Neck |
| GS05 | 11737 | PV36-01-2010 | BX2196 | 8-Oct-2010 | 6-Apr-2011 | 180 | 29540 | 27950 | 155 | Neck |
| GS06 | 11483 | HG23-B11-2011 | - | 26-Mar-2012 | 22-Aug-2012 | 149 | 7585 | 7585 | 51 | Neck |
| GS07 | 11941 | HG23f-B941-11 | 41 | 13-Nov-2012 | 31-Jan-2013 | 79 | 2985 | 2956 | 37 | Back |
| GS08 | 11272 | HG23f-A272-09 | 42 | 14-Nov-2012 | 27-Feb-2013 | 105 | 2230 | 2052 | 20 | Back |
| GS09 | 11270 | HG23f-A270-09 | 55 | 6-Dec-2012 | 6-Mar-2013 | 90 | 3095 | 3083 | 34 | Neck |
| GS10 | 11277 | HG23f-A277-09 | 56 | 6-Dec-2012 | 11-Mar-2013 | 95 | 3480 | 3470 | 37 | Neck |
| GS11 | 11278 | HG23f-A278-09 | 59 | 7-Dec-2012 | 21-Feb-2013 | 76 | 2472 | 2456 | 32 | Neck |
| Sum | | | | | | 1393 | 130487 | 127326 | 91 | |
| Mean | | | | | | 127 | | | | |
| All sum | | | | | | 3108 | 147194 | 143933 | | |
| All mean | | | | | | 148 | 7009 | 6854 | 46 | |

### Database management

The GPS/GSM positions, haul-out data and dive data were extracted from the SMRU webserver and used in R, ArcGIS and Excel for statistical calculations and graphical presentations.

### Tracking data

The maps were generated using ArcMap (version 10.0). The bathymetrical depth contours are based on 1-degree resolution GEBCO data (version 1.00). Hawth's Analysis Tools V3.27 was used as an extension to ArcMap (version 9.3) or Geospatial Environment Modelling for ArcMap (version 10.0) to generate kernel home range and area calculations. To avoid autocorrelation, only one location was sub-sampled from each of the days selected for the duty cycle, for the Kernel Home Range Analysis and for the linear mixed effect model used on the distance from the tagging haul-out side (se details below). Smoothing factor (bandwidth) was set to 20,000 for the harbour seals and the harbour porpoises and 50,000 for the grey seals (due to the high number of positions) and output cell size to 1 $km^2$. This was based on thorough inspection of kernel contours during tests of alternate band-width as recommended by Beyer (2004), the creator of Hawth's Analysis Tools.

A linear mixed effect model using maximum likelihood estimation was applied with distance from the tagging haul-out site as dependent variable, individual as a random or grouping factor and the fixed factors species, age group and season. Distance data were log-transformed prior to analyses to reduce skewness and to approximate normal distribution as recommended in e.g. Zar (1996). The model was successively reduced by exclusion of non-significant factors at a 5% significance level evaluated by the likelihood ratio test.

**Data handling**

The seasonal categories and the exact date for these were defined by shifts in movement patterns (summer: 6 June-15 September; autumn: 16 September-13 December; winter: 14 December-21 February and spring: 22 Februar-5 June) based on information from Dietz, Teilmann, Andersen, Rigét, & Olsen (2012). These categories were used in the subsequent statistical examination. Distance data from the haul-out site was $\log_e$-transformed for the mixed effect modelling as the distribution was highly right-skewed. Possible factors influencing the average distance moved per day were analysed using a linear mixed effect model with age group, season and sex as fixed factors and seal individual as random grouping factor. The interaction factors between season and sex and between age group and sex were also included. Excluding the interaction between age group and sex did not result in a significantly different model (log-likelihood, P=0.051), although it was very close. The data did not allow for testing of the interaction factor between season and age group due to lack of adult seal data during autumn and winter.

## 5.3 Modelling

**Predictor variables**

Data on concentrations of prey to the three species of marine mammals were not available for the entire project area in the required spatial and temporal scale. Therefore, physical properties enhancing the probability for porpoises and seals of encountering prey within the range of their preferred habitats offer the best predictors. We expect that parameters reflecting stability and predictability in prey densities are the elements most important to their distributions. Model results have clearly pointed at the importance of frontal features rather than parameters reflecting structures and processes at larger scales like water masses and currents. The different static and hydrodynamic predictor variables are described in Table 8.

Tracking data on seals and porpoises were combined with the range of static and dynamic predictor variables based on position and time using the DHI Dynamic Data Integration Tool (Figure 14). The tool is written in C#, using the Microsoft .NET Framework. The tool can read one or more tables of data, containing locations and timestamps. Spatiotemporal data are extracted from raster series, with the extracted values depending on both the location of the extraction points and their timestamp. This is technically based on the MIKE DFS .NET API, which has been recently developed by DHI and is not yet publicly available.

The output files of the data integration tool were .txt tables containing all original data from the input tables, and additional columns with the values extracted from static rasters and hydrodynamic model results simultaneously (one for each integrated variable, e.g. water depth, current speed) as well as UTM32 N coordinates.

The hydrodynamic variables were provided by Bolding & Burchard based on the hydrodynamic time series produced as part of ATR 6.  The hourly data were extracted from the surface and bottom layers for the modelled period 2002-2012. Data were available in NetCDF format. In order to make use of the data integration tool the files were transformed into MIKE DFS2 format.

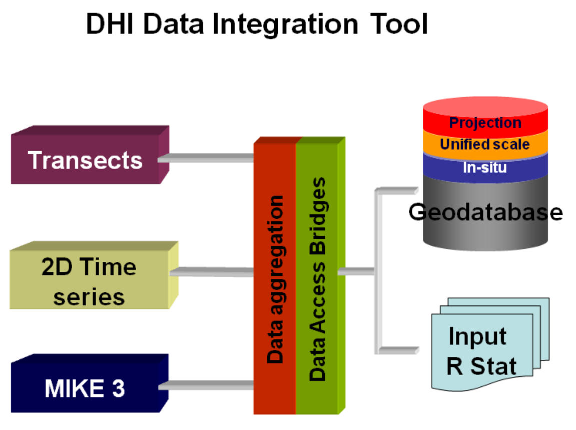



*Figure 14: Dynamic Data Integration Tool (source: DHI).*

*Table 8: List of variables included in the initial models.*

| Predictor | | Description | Rationale for inclusion |
|---|---|---|---|
| **Depth** | DHI | Depth of sea floor taken from DHI 50m bathymetry | Seabed characteristic |
| **Curvature** | DHI | Relief of sea floor showing whether sea floor is concave, convex or flat | Seabed characteristic |
| **Slope** | DHI | Slope (in degrees) of sea floor | Interaction with frontal dynamics which concentrate prey |
| **Sediments** | http://www.helcom.fi/GIS/BalanceData | Surface sediments classified as either bedrock, hard bottom complex, sand, clay or mud | Seabed characteristic |
| **Distance to land** | DHI | Euclidian distance (m) to shore | Disturbance |
| **Distribution of ships** | Danish Maritime Authority | Number of ships taken from a typical period (August-September 2010) | Disturbance |
| **Current gradient** | Bolding&Burchard / DHI | Local horizontal gradient of currents (m/s/m) | Hydrodynamic structure concentrating prey |
| **U velocity** | Bolding&Burchard | Local E-W current velocity component (m/s) | Water mass characteristics |
| **Vorticity** | Bolding&Burchard / DHI | Eddy activity measured as the local vorticity (m/s/m) of the flow | Hydrodynamic structure concentrating prey |
| **V velocity** | Bolding&Burchard | Local N-S current velocity component (m/s) | Water mass characteristic |
| **Temperature** | Bolding&Burchard | Local water temperature (C°) | Water mass characteristic |
| **Salinity** | Bolding&Burchard | Local salinity (psu) | Water mass characteristic |
| **X and Y coordinates** | | An interaction term between X and Y coordinates | Account for unexplained spatial structure |

## 5.4 Modelling porpoise distribution

**Short introduction to the species distribution model MaxEnt**

Potential suitable porpoise habitats in the western part of the Baltic were evaluated by the species distribution model called MaxEnt (Maximum Entropy) (Philips & Dudik, 2008) (Elith, et al., 2006). MaxEnt has been widely used and the predictive performance is consistently competitive with the highest performing methods (Elith, et al. (2006) and references herein). It is especially suitable when only present-data are available, sample size is small (Wisz, Hijmans, Peterson, Graham, Guisan, & Group, 2008) and even with spatial positioning errors (Graham, et al., 2008). The inputs to the model were observations of porpoises in the area and environmental variables in the seascape that we hypothesized could serve as explanatory variables of the porpoise distribution. As observations, satellite telemetry data from porpoises which have been tracked in the area, was used. As environmental variables, also called co-variables, we used the static variable; depth, slope, distance to land, curvature, sediment type and ship traffic. As dynamic variables; front (current gradient), salinity and temperature at bottom, u-velocity (E-W) and v-velocity (N-S) was used (see Table 8).

The basic principle of the MaxEnt method is to compare environmental variables at the positions where porpoises have been observed (presence) with the environmental variables at a random selection of positions in the landscape (backgrounds). The environmental variables at porpoise locations and background locations give two sets of density distributions. MaxEnt then finds a function of the co-variables that minimizes the difference of the density distribution of the environmental variables taken from the porpoise positions from that derived from the background positions. Minimizing from the density distribution of the background environmental variables is sensible, because without any presence data, we would have no reason to expect porpoise to prefer any particular environmental conditions over any others, so we could do no better than predict the occurrence in environmental conditions proportionally to their availability in the seascape. In statistical terms, MaxEnt minimizes the relative entropy between two probability densities.

The function in MaxEnt consists of features in a way similar to applying transformations to a co-variable in e.g. regressions used to describe trends. Six features are available: linear, product, quadratic, hinge, threshold, and categorical. Products are products of all possible pair-wise combinations of co-variables (interactions). Hinge is equivalent to a piecewise linear spline. The choice of features in the model building phase depends on the number of samples. All feature types are used when there are at least 80 samples; from 15 to 79 samples, linear, quadratic and hinge features are used; from 10 to 14 samples, linear and quadratic features are used; below 10 samples, only linear features are used. Since we had more than 80 samples, all feature types were used.

There are constrains on the features in the MaxEnt fitted function in a way that the mean of the features should be close to the mean at the present locations. MaxEnt needs to find features that balance the fit and the complexity in a way that the constraints are being satisfied while not matching them so closely that it over fits. This is done in a complex way, where tuning of the feature parameters based on feature type and setting a maximum allowed deviation from the presence feature means are involved. It also involves a model selection approach based on regularization, which is closely related to Akaike's Information Criterion (AIC, Akaike (1974)). The solution is found by an iterative process starting with a uniform distribution and measuring the "gain" from one iteration to the next, continuing until the gain is below the convergence threshold or until maximum iterations has been performed.

We chose to evaluate the model performance by running 100 bootstrap models, because of the relatively low number of positions evaluable. All features were allowed in the models and the number of background locations was 10,000.

The model is used to produce seasonal habitat suitability maps, which can subsequently be combined with ranges of the expected noise impact zones around the Kriegers Flak construction site.

**Satellite positions**

Since 2006 a total of 1143 satellite positions from 15 porpoises are available from the Western Baltic. Satellite positions from the first 2 days after tagging were excluded to reduce spatial and temporal influence of the release site. In order to reduce autocorrelation within data, one position per day was randomly selected for the analyses. This left 314 positions from 15 porpoises (Table 9). Positions were divided into four seasons in order to be comparable with a previous MaxEnt spatial distribution analysis covering the inner Danish waters (Edrén, Wisz, Teilmann, Dietz, & Söderkvist, 2010). The distribution of seasons and the number of individuals and positions available can be seen in Table 9.

*Table 9: The number of positions and individuals occurring in the Baltic region in the various seasons.*

| Season | No. of positions | No. of individuals |
|---|---|---|
| Dec – Feb (Winter) | **25** | **5** |
| Mar – May (Spring) | **7** | **2** |
| Jun – Aug (Summer) | **111** | **5** |
| Sep – Nov (Autumn) | **171** | **11** |

The MaxEnt model was conducted for all 4 seasons, however for the two periods winter (Dec-Feb) and spring (Mar-May), results were considered too uncertain because of the low number of positions and hence they were left out in the further processing of data. The variables used in the model are listed below (see details in Table 8).

Static variables:

- Depth
- Slope
- Curvature, describing if the bottom is concave (negative value), convex (positive value) or flat (=0) in relation to the surrounding cells.
- Euclidian distance to the shoreline
- Sediment type (five categories)
- Ship traffic (AIS)

Dynamic variables:

- Front (current gradient)
- Salinity (surface)
- Temperature (surface)
- U-Velocity (E-W)
- V-Velocity (N-S)

### 5.5 Acoustical data from harbour porpoises

Acoustic data were kindly made available by the EU LIFE+ project SAMBAH (Static Acoustic Monitoring of the Baltic Sea Harbour Porpoise, http://www.sambah.org). The data comprised of time series of daily DPM values (Detection Positive Minutes; number of minutes with porpoise recordings, Leeney & Tregenza (2006)) from three stations (Figure 15). The two western-most stations were located within the project area. The data were collected by Static Acoustic Monitoring (SAM) devices called C-PODs over a two-three year period (Table 10). The C-PODs detect and log porpoise sonar click activities inside a radius of up to 300 m, for details see http://www.chelonia.co.uk/. The DPM values were based on classified click trains using the so-called Hel 1 filter, which is an acoustic filter which has been specifically developed for improving detection of porpoises in low density areas like most part of the Baltic. The filter is more conservative than the default Kerno classifier including Cet Hi and Cet Mod trains, and is meant to reduce the number of false detections.

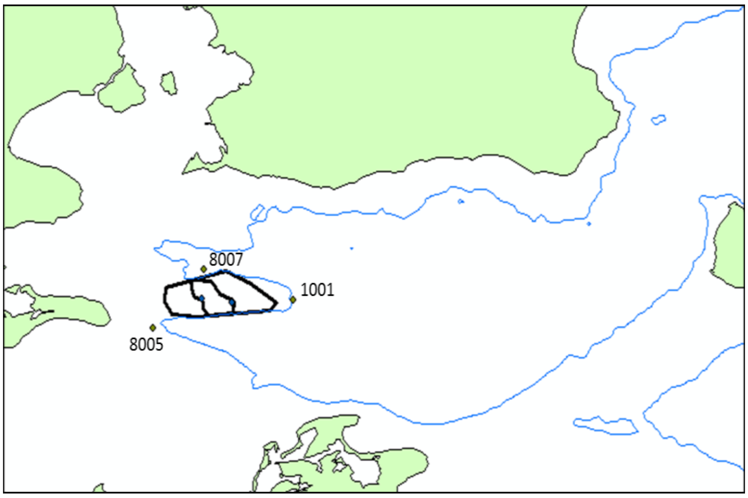



*Figure 15. Location of three SAMBAH stations relative to the wind farm area, from which acoustic data were extracted.*

*Table 10: Logging periods at the three SAMBAH acoustic stations.*

| Deployment | Station 1001 | Station 8005 | Station 8007 |
|---|---|---|---|
| A | 11/4 2011 – 21/7 2011 | 4/25 2011 – 21/6 2011 | 27/4 2011 – 14/7 2011 |
| B | 21/7 2011 – 6/10 2011 | 13/8 2011 – 29/10 2011 | 13/8 2011 – 29/10 2011 |
| C | | 29/10 2011 – 15/2 2012 | 30/10 2011 – 12/2 2012 |
| D | 8/5 2012 – 17/9 2012 | 20/3 2012 – 5/7 2012 | 19/3 2012 – 6/7 2012 |
| E | 17/9 2012 – 16/1 2013 | 5/7 2012 – 6/11 2012 | 6/7 2012 – 8/11 2012 |
| F | 16/1 2013 – 27/6 2013 | | 8/11 2013 – 6/5 2013 |

To make an ecological assessment of the data, serial scale-dependencies were investigated. Serial autocorrelation structures in time series data can reveal at which temporal scales porpoise activity changes, and are therefore useful when attempting to identify controlling environmental patterns and processes. The serial autocorrelation structure in three time series was measured by calculating both the serial autocorrelation and partial autocorrelation of the data. Serial autocorrelation measures the dependence on time lags, including the intermediate elements (those within the lag), while partial autocorrelation measures the dependence with the intermediate elements removed. In other words, the partial autocorrelation is similar to autocorrelation, except that when calculating it, the (auto) correlations with all the elements within the lag are partialled out.

Autocorrelation and partial autocorrelation were measured for continuous segments (i.e. two time series per station) of the C-POD DPM data at the time scale of 1 day and using autocorrelation coefficients following the standard formulas as described in e.g. Box & Jenkins (1970). The analyses were conducted in Statistica 10, Time Series Engine.

## 5.6 Modelling the distribution and habitat use of seals

The aim of this chapter is to identify which habitat types harbour and grey seals predominantly use when foraging in the waters of the Kriegers Flak area. These estimates can be combined with population counts and estimates of time spent foraging at different times of the year in order to evaluate to what extent seals are likely to be affected by noise emitted during the construction of the projected wind farm at Kriegers Flak.

Within the study area, variations in prey densities and hence the foraging behaviour of the seals are likely to be associated with bathymetry and hydrodynamics. It is not known which environmental parameters the seals use for finding the suitable foraging grounds, but they may be primarily guided by static variables such as bathymetry, which would allow them to keep returning to areas of the same kind repeatedly. It is also possible that the seals mostly forage in areas with particular hydrodynamic features, if this is where their prey occurs. In this case the seals should be able to navigate to favourable foraging grounds without being guided by visible environmental features. Furthermore, the animals' choice of where to forage is likely to be influenced by energetic constraints and by anthropogenic disturbances. In order to minimize the amount of energy and time spent travelling, the animals are likely to prefer foraging areas close to their haul-out sites, and they may be foraging more often in areas far from the major ship routes in order to avoid disturbances. Here, we test which of these types of parameters (static environmental, hydrodynamic, energetic/anthropogenic, or a combination) that best explain the distribution of the areas that seals use intensively and where they presumably prefer foraging.

The models are used to produce maps of the intensely used areas, which can subsequently be combined with the zones of the expected noise impact area around the

Kriegers Flak construction site. This can be used to determine if the construction can be expected to affect the seals in the areas that they use most intensely.

**Methods**

The tags were set to transmit one position every time the seals reached the surface, resulting in positions sampled at a highly variable frequency (Figure 16). Data on the variation in bathymetry and hydrodynamic variables for the study site were obtained from DHI (see Table 8).

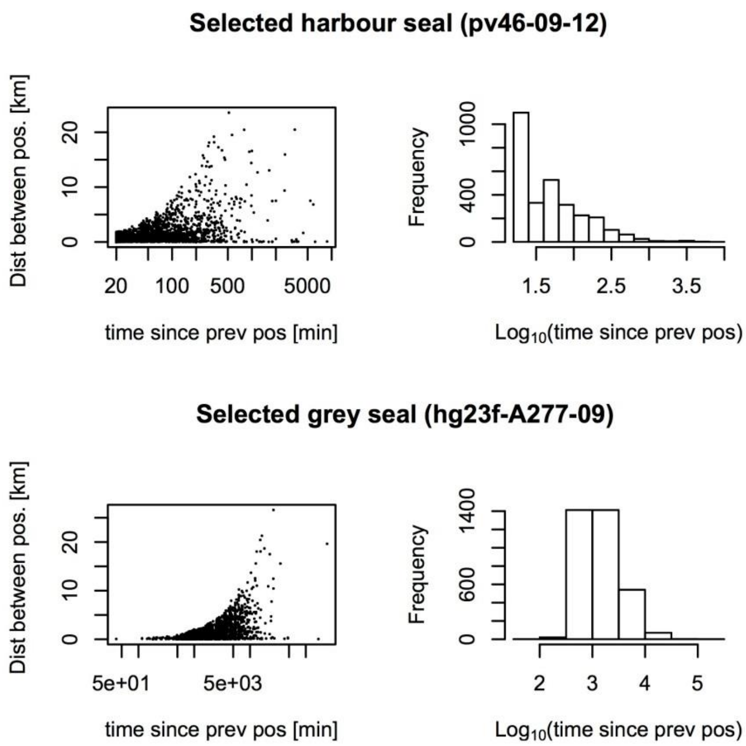



*Figure 16: Example of distribution of time between received positions for one grey seal and one harbour seal.*

In order to quantify how intensively the animals used the different areas they passed on their way we calculated the residence time (RT) for different parts of the animal tracks. Animals that enter profitable areas usually adopt a more tortuous path and/or reduce their speed, which results in increasing residence times (Benhamou & Bovet, 1989). RT is defined as the total time an animal spends within a circle of a given radius (r) drawn around each position in the track (Benhamou & Bovet, 1989). The RT corresponds to the amount of time spent in the vicinity of these positions. It can be seen as an extension of the first crossing duration (Fauchald & Tveraa, 2003), designed to provide a more integrative measure of space use with a clearer biological meaning, by taking additional forward and backward times spent within the circle into account.

The RT values were based on points that were sampled every km along each of the animal tracks, which ensured that the probability of selecting points from any part of the tracks was independent of how intensively a given area was used (Fauchald & Tveraa, 2003). This assumed that animals moved in straight lines between successive GPS positions (Figure 17). Parts of the tracks where positions were recorded >4 hours apart were omitted from the analyses, as a linear interpolation did not appear to be meaningful in these cases. This caused most tracks to be divided into several bursts with data of sufficiently high quality, but interrupted by areas with positions sampled too infrequently. It was not possible to calculate the RT for positions located <r from the end of such bursts.

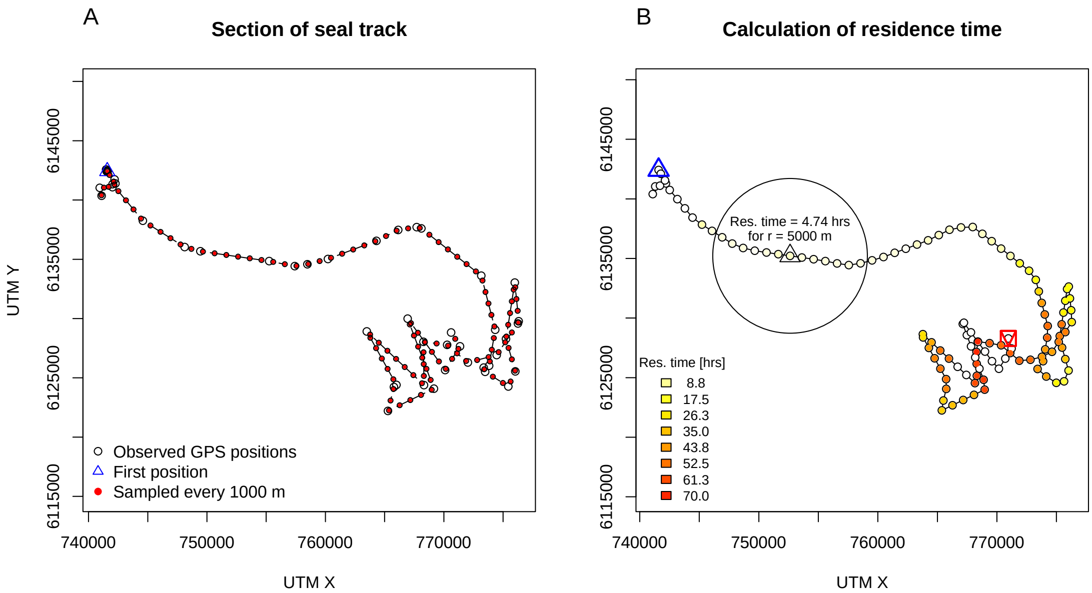



*Figure 17: Analysis of a section of the track for harbour seal HS01. A: Selection of evenly distributed positions along the track based on linear interpolation of observed filtered GPS positions; B: Calculation of residence times for each of the evenly distributed positions based on a circle with radius 5000 m.*

The RT is strongly dependent on r, but increases more with r in the areas where animals spend most of their time. The spatial scale at which an animal concentrates its search effort can therefore be found as the value of r at which the variance in log RT is maximised (this was demonstrated for FPT by Fauchald and Tveraa (2003)). This scale has been termed the area-restricted search (ARS) scale (Pinaud & Weimerskirch, 2005). A small ARS scale may suggest that an individual encounters high resource densities in spite of a small search effort, or that the food is distributed in small patches. We estimated the ARS scale for each species visually as the radius at which the RT ceased to increase. In the subsequent statistical analyses residence time was calculated using r corresponding to the ARS scale.

In order to evaluate which habitat types the seals spent most of their time in, and that were presumably most important as foraging grounds, we used generalized additive models (GAMs) using an approach resembling the one used by Andersen et al., (2013). For each of the positions where residence times could be calculated, we obtained the corresponding values for a number of hydrodynamic and static environmental variables that are thought to influence the distribution of fish (see e.g. Edrén et al. (2010)), and that were therefore expected to describe variations in seal foraging patterns. The static variables bathymetry, slope, distance to nearest haul-out site, average ship density and distance to coast were included here. The average relative ship density was obtained from transmitters placed on all vessels larger than 300 tonnes using the Automatic Identification System (AIS; www.helcom.com). AIS continuously records the positions of all large vessels and this measure was subsequently converted to area specific relative densities. In this study we used $Log_{10}$ of the average relative AIS values. The modelled hydrodynamic variables included: salinity, temperature, east-west current, north-south current, eddies and fronts. Separate model estimates were included for the top and the bottom of the water column for each of these variables (spatial resolution: 500 x 500 m). RT was the dependent value in the GAMs and the environmental variables were independent continuous variables. For each species and season we investigated whether the distribution of foraging areas was best described by (1) the hydrodynamic variables alone, (2) the static variables alone, (3) by bathymetry, distance to haul-out site and AIS alone, (4) by bathymetry alone or (5) by all 17 parameters, when penalizing the goodness of fit of the models based on the number of parameters used. The selection of the most parsimonious model was based on the Akaike Information Criterion (AIC), and in the case that no single model could be selected (i.e. when the highest Akaike weight, $w_i$<0.9), we averaged the suitable models based on Akaike weights ($w_i$) (Anderson, Burnham, & Thompson, 2000) (Johnson & Omland, 2004).

In this study the seasons were defined according to Dietz, Teilmann, Andersen, Rigét, & Olsen (2012): summer: 6 June-15 September; autumn: 16 September-13 December; winter: 14 December-21 February; and spring: 22 February-5 June.

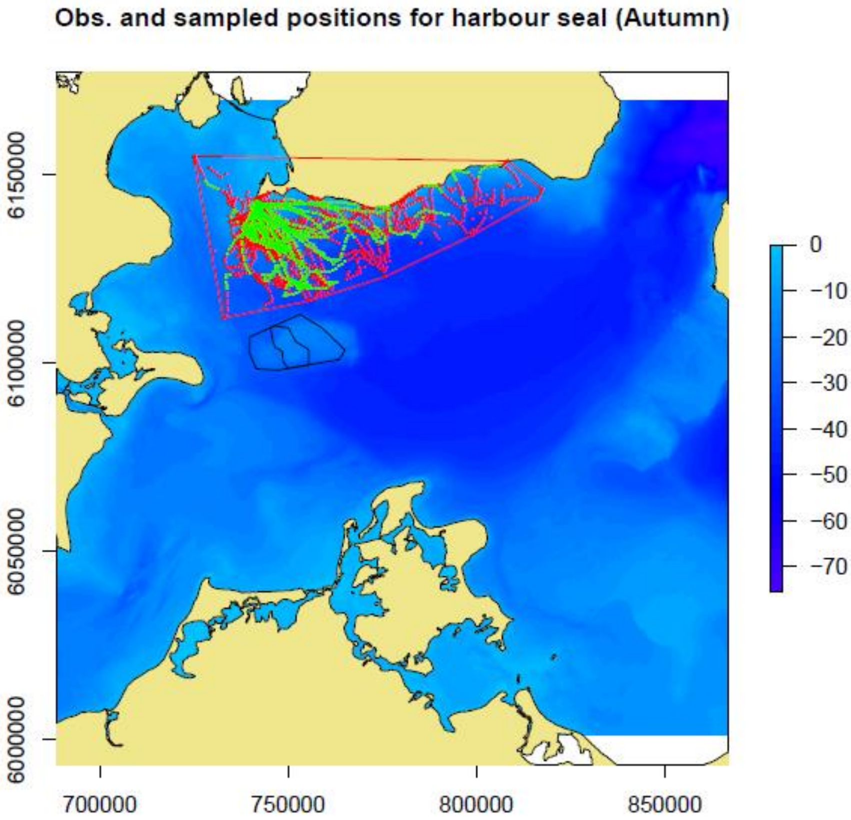



*Figure 18: Harbour seal tracks for the autumn season. Points indicate positions sampled every 1000 m along the tracks; green points indicate the ones where residence times could be calculated. The red line indicates the minimum convex polygon used for estimation of residence times for this season.*

The most parsimonious GAM model provided an estimate of how important the different parts of the study area are for the seals. Separate estimates were calculated for each species and season. As it is questionable to what extent GAMs can be used for making predictions outside the geographic region that they were parameterized for, residence time estimates were only calculated for the area defined by the minimum convex polygon (Calenge, 2006) that covered all the positions where residence times could be calculated (Figure 18).

**Altered turbine layout**

After the first version of this report was done, the turbine layout was changed. All figures have been updated with the new layout, but all the modelling and calculations of affected animals is based on the first layout. It was judged that the changes were so minor, that it would not affect the conclusions of this report.

# 6 Existing conditions

### 6.1 Biology of the harbour porpoise

The harbour porpoise is the most numerous cetacean in European waters with an estimated population size in the North Sea and adjacent waters of about 375,000 (Hammond, et al., 2013). The harbour porpoise is one of the smallest cetaceans, growing to a maximum length of 1.8 m and a maximum weight of 90 kg. It has a short, rotund shape with dark grey back and face and a white or pale grey underbelly. The dorsal fin is triangular, the flippers are slightly rounded and it has no beak. Porpoises are capable of making deep dives down to at least 220 m for around five minutes in duration, although most dives are shallow and last less than two minutes (Westgate, Read, P., Koopman, & Gaskin, 1995), (Otani, Naito, Kawamura, Kawasaki, Nishiwaki, & Kato, 1998). They typically swim alone or in small groups of 2-3 individuals, sometimes occurring in larger groups. They are relatively short lived compared to other cetaceans with a maximum life span of about 15-20 years.

**Reproduction**

Females mature at the age of 3-4 and give birth to a single calf every year. The breeding period begins in late June and ends in late August. The pregnancy period is 11 months and in Danish waters parturition typically takes place in late July (Sørensen & Kinze, 1994). The calves start suckling right away and feed by their mother until around May the following year. Knowledge of specific breeding grounds in Danish waters is insufficient and based on sightings of calves. Calves are seen throughout their range, but there are some proposed “hotspots”, where a larger proportion of calves have been sighted (Figure 19) (Loos, Cooke, Deimer, Fietz, V., & Schütte, 2010).

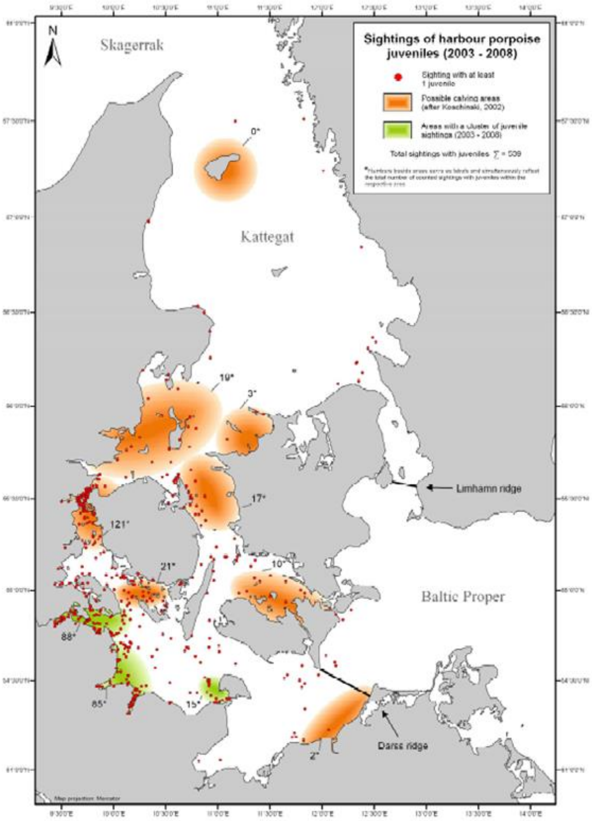



*Figure 19: Sightings of harbour porpoises with juveniles and proposed calving and nursing grounds (Loos, Cooke, Deimer, Fietz, V., & Schütte, 2010).*

**Foraging ecology**

The harbour porpoise is somewhat opportunistic in its choice of prey. Studies of stomach contents from Kattegat to the Western Baltic show the main prey items to be Atlantic herring, Atlantic cod, whiting and gobies whereas sandeel, sprat, Norway pout, eel and eelpout have been found in lower numbers (Aarefjord, Bjørge, Kinze, & Lindsted, 1995), (Sveegaard S. , 2011). The daily food intake is about 3.5–5.5 kg (Lockyer, Desportes, Anderson, Labberté, & Siebert, 2001).

**Echolocation and hearing**

Like other toothed whales (odontocetes), harbour porpoises have good underwater hearing and use sound actively for navigation and prey capture (echolocation). They produce short ultrasonic clicks (130 kHz peak frequency, 50-100 µs duration; (Møhl & Andersen, 1973), (Teilmann, et al., 2002) and are able to orient and find prey even in complete darkness. Data from porpoises tagged with acoustic data loggers indicate that they use their echolocation almost continuously (Akamatsu, Wang, Wang, & Naito, 2005) (Akamatsu, et al., 2006).

Hearing is the key modality for harbour porpoises for most aspects of their life. A few studies have investigated other senses, such as the anatomy and chemistry of the eye (Kröger & Kirschfeld, 1992), (Kastelein, Dubbeldam, Luksenburg, Staal, & van Immerseel, 1997), (Peichl, Behrmann, & Kröger, 2001), but regarding functionality hearing is the only sense that has been investigated to any great extent.

The hearing sensitivity is extremely good and covers a vast frequency range in this species (Figure 20 (Andersen S. , 1970), (Popov V. V., Supin, Wang, & Wang, 1986), (Kastelein, Bunskoek, Hagedoorn, Au, & Haan, 2002), (Kastelein R. A., Hoek, de Jong, & Wensveen, 2010)). The spectral analysis of incoming sounds can be described as using a series of bandpass filters, and in humans these auditory filters have a bandwidth of approximately 1/3 of an octave at frequencies above around 1000 Hz (Moore, 2012). Similar findings have been described for other mammals, including the harbour porpoise (Kastelein, et al., 2009), however, this relationship may be more complicated at very high ultrasonic frequencies (Popov V. , Supin, Wang, & Wang, 2006). The hearing abilities of harbour porpoises become increasingly directional with increased frequency. This improves their echolocation capabilities by making them less susceptible to background noise and clutter echoes (i.e. returning echoes from other objects than the intended target; Figure 21; (Kastelein, Janssen, Verboom, & Haan, 2005)).

Mammals generally do not hear equally well over their entire range of hearing. For sound intensities close to the hearing threshold the audiogram is a good approximation of the perceived sound levels (the loudness of the sound). In marine mammals, there is a great difference in sensitivity between the frequencies of best hearing and those close to the cut-off frequencies. At higher sound intensities, the loudness of the sound becomes greater than what is predicted from the audiogram towards the lower and upper cut-off frequencies (Moore, 2012). This discrepancy in loudness can be estimated by applying an equal-loudness filter. In humans, filters have been developed for low sounds (A-weighting) and loud sounds (C-weighting). Southall et al. (2007) proposed that frequencies should be weighted with a fairly broad weighting function (M-weighting) which only removes very low and very high frequencies, well outside the range of best hearing for the animals. Separate weighting functions were developed for different groups of marine mammals. Others have proposed a more restrictive weighting with a weighting filter function resembling the inversed audiogram (e.g. Terhune (2013)). In the light of this uncertainty and given that TTS thresholds from experiments are given in unweighted levels, the working group established by Energinet.dk to assess noise exposure limit values for marine mammals, decided to recommend unweighted levels, which will be applied for the evaluation of possible physical injuries caused by the noise (Working Group, 2015). This approach being highly precautionary (Southall, et al., 2007).

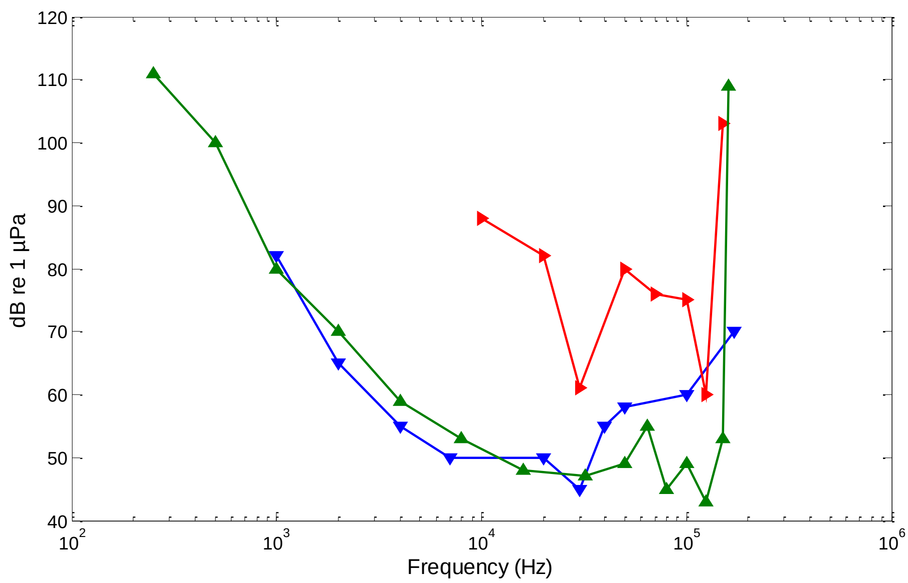



*Figure 20: Audiograms for harbour porpoises modified from Kastelein, Hoek, de Jong, & Wensveen (2010) (green), Andersen (1970) (blue) and Popov V. V., Supin, Wang, & Wang (1986) (red).*

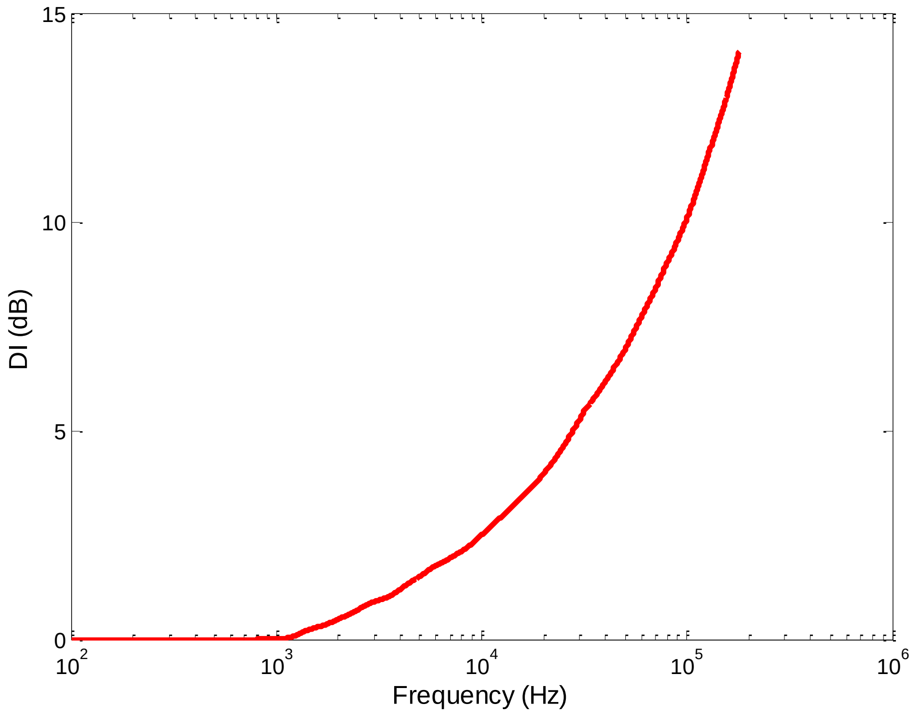



*Figure 21: The directivity index (DI) is a measure of the directional hearing as a function of frequency in the harbour porpoise. Modified from Kastelein, Janssen, Verboom, & Haan (2005).*

### Vision

Cetaceans have good vision, although especially odontocetes have small eyes in relation to their body size, compared to other mammals. The eyes are completely adapted to water and vision under low light conditions. The spherical lens makes the eye highly myopic (short-sighted) in air and they are not likely to be able to see objects sharply in air beyond a few meters. Movement however, such as from rotating turbine wings, should be clearly visible to porpoises, even in air. Porpoises, like other cetaceans and seals, are functionally colour blind (Peich, Behrmann, & Kröger, 2001).

### Other senses

Odontocetes have no sense of smell, whereas taste may play a role, not only in relation to tasting prey, but also in terms of collecting information about the surrounding water. Thus, in the context of anthropogenic impact, it cannot be ruled out that porpoises can taste and will react to harmful and/or distasteful substances in the water.

A magnetic sense, that is the ability to determine the direction of the earth's magnetic field, has only been demonstrated convincingly in a few vertebrates. However, this ability has turned out to be very difficult to explore experimentally (Wiltschko & Wiltschko, 1996) and this sensory modality is not nearly as well understood as the other modalities (vision, hearing, smell, electroreception etc.) and it is thus unclear how common this ability is in vertebrates in general. Thus, so far it remains unknown whether cetaceans have magneto receptive capabilities or not, and it is not even safe to conclude whether we a priori should expect them to have this ability or not (i.e. whether a magnetic sense is the normal condition for vertebrates or it is a rare specialisation).

Until fairly recently it was believed that no mammals had electro receptive abilities, but it has been conclusively demonstrated that the duckbilled platypus has electro receptive organs along the edge of the bill and uses these in prey capture (Proske & Gregory, 2003). Since then, several other mammals have been suspected of possessing electro receptive capabilities. Although marine mammals seem good candidates for electroreception, as they live and find their prey in often dark and murky waters like sharks, there is only limited support to this idea (Czech-Damal, et al., 2011).

## 6.2 Distribution of the harbour porpoise – review of existing knowledge

Porpoises are present throughout almost all Danish waters. Based on genetics, morphometrics and movements of tagged animals, three separate populations have been identified in the transition zone between the North Sea and the Baltic Sea, namely (1) North Sea and Skagerrak, (2) Kattegat, Belt Sea, the Sound and Western Baltic and (3) the inner Baltic (Huggenberger, Benke, & Kinze, 2002), (Galatius, Kinze, & Teilmann, 2011), (Wiemann, et al., 2010). Kriegers Flak is located in the Western Baltic

Harbour porpoises have been observed in the Danish and German regions of the Baltic Sea through aerial and ship-based visual surveys, passive acoustic monitoring using T-PODs and opportunistic observations. Although none of these studies were designed specifically with the purpose to document the use of Kriegers Flak by marine mammals they provide general information about the occurrence of mammals in the region. Several sources of information on animal presence and in some cases also densities are available, all of which will be discussed below. The various sources of data are not directly comparable and most are poorly balanced with respect to surveyed areas and periods of the year.

**Visual Surveys**

The two SCANS surveys, conducted in 1994 and 2005 represent the largest coordinated effort to map the distribution and abundance of cetaceans, including harbour porpoises, in European waters. They were conducted in June-July both years and thus represent summer distribution of animals (Figure 22). No porpoises were sighted south of the Sound or east of Fehmarn Belt in either of these surveys, but effort here was also much lower than in other regions.

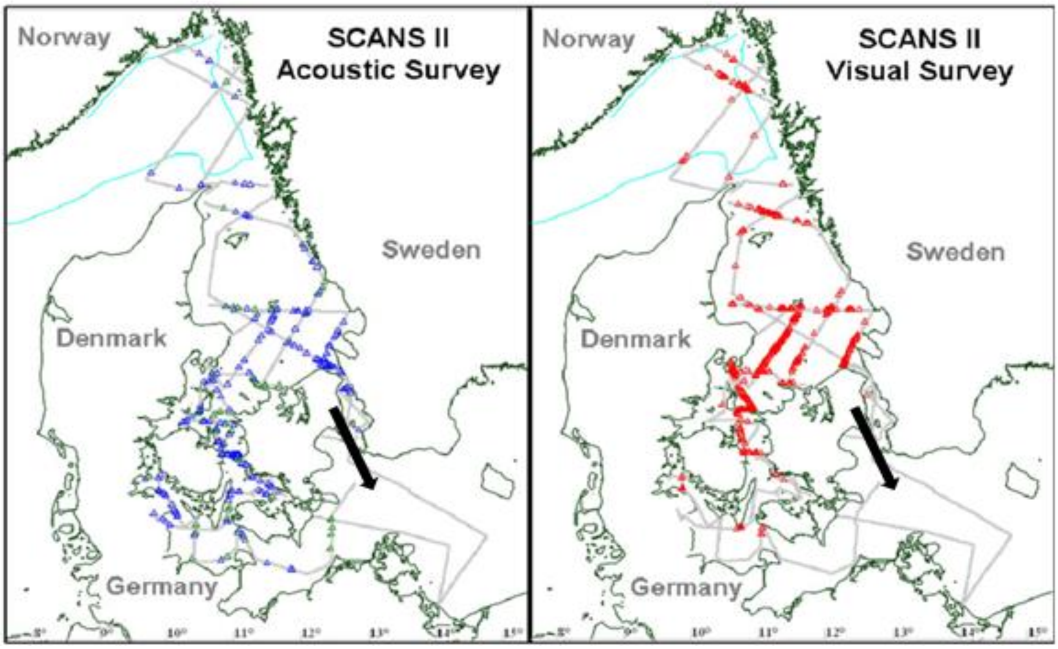



*Figure 22: Survey plot from the vessel 'Skagerak' during the SCANS-II survey 29th of June to 14th of July 2005. Acoustic detections are shown with blue triangles on the left panel. Visual sightings are shown with red triangles on the right panel. The route sailed is shown as a grey line (Teilmann, Sveegaard, Dietz, Petersen, & Berggren, 2008).The black arrow indicates the Kriegers Flak area of interest for this report.*

The miniSCANS ship-based visual survey conducted in July 2012 aimed at estimating absolute abundances of the harbour porpoises in the Kattegat, the Belt Seas, the Sound and the Western Baltic (Figure 23). The population in the Kattegat, Belt Sea, the Sound and Western Baltic was estimated to be 40,475 (CI 25,614-65,041, CV=0,235, (Viquerat, Gilles, Peschko, Siebert, Sveegaard, & Teilmann, 2013).

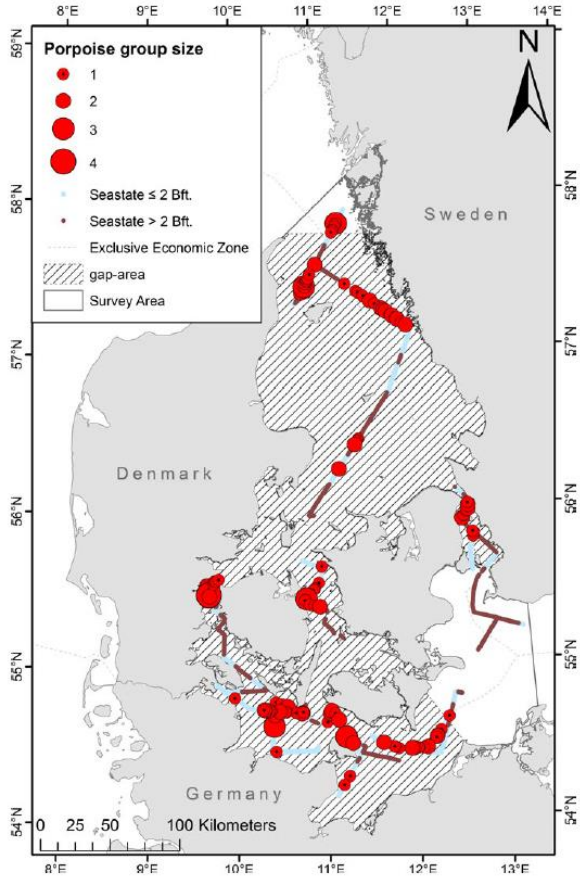



*Figure 23: Map of survey area for miniSCANS in July 2012 showing track-lines and observations of harbour porpoises. The shaded area indicates the area for which the abundance estimate was calculated (Viquerat, Gilles, Peschko, Siebert, Sveegaard, & Teilmann, 2013).*

*Table 11: Details on abundance estimates for the comparable area (30,130 km$^2$) in the Kattegat/Belt Seas of the three SCANS harbour porpoise surveys in 1994, 2005 and 2012. CV=Coefficient of Variation, LCL=Lower 95% Confidence Interval, UCL=Upper 95% Confidence Interval.*

| Survey | Effort (km²) | N | CV | LCL | UCL | Density | Group size |
|---|---|---|---|---|---|---|---|
| SCANS | 607 | 27,923 | 0.46 | 11,916 | 65,432 | 1.13 | 1.61 |
| SCANS-II | 644 | 10,614 | 0.28 | 6,218 | 18,117 | 0.35 | 1.45 |
| MiniSCANS | 516 | 18,495 | 0.27 | 10,892 | 31,406 | 0.61 | 1.51 |

Aerial surveys covering the entire German EEZ in the Western Baltic were carried out in 1995 and 1996 (Figure 24). The mean abundances of harbour porpoises in the German Baltic Sea, divided into two subunits (blocks B and C), were estimated at 980 and 1830 porpoises in block B (in 1995 and 1996 resp.) and at 601 porpoises in block C in 1995 (there were no sightings in block C during the 1996 survey).

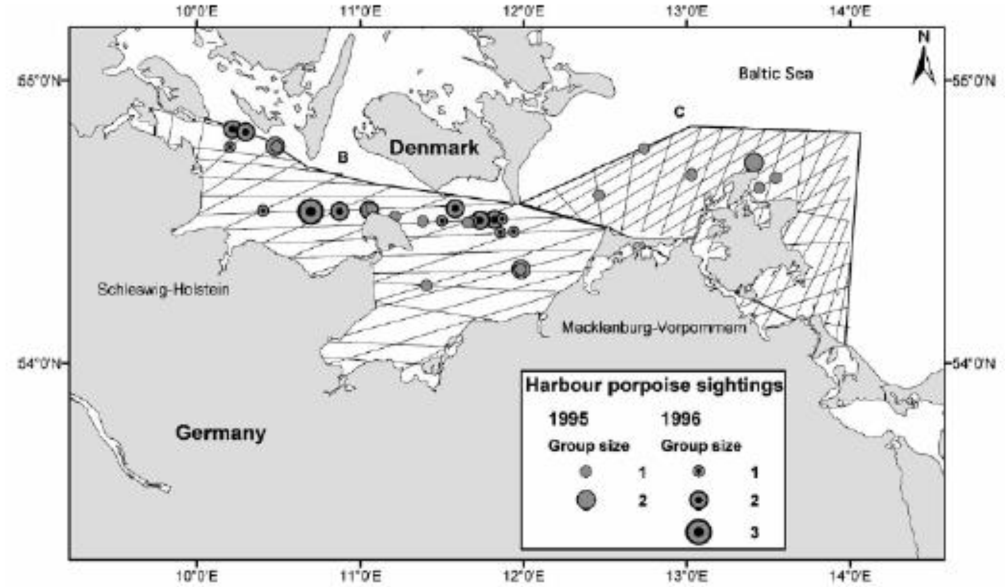



*Figure 24: Sightings on aerial surveys carried out in 1995 (July and October) and 1996 (July) (Siebert, et al., 2006).*

During the MINOS and MINOS+ project, a large number of dedicated aerial surveys were conducted over the years 2002-2005 in the entire Western Baltic, including Danish waters south of Funen and Lolland-Falster, but excluding Swedish waters and The Sound (Figure 25). Average densities were low throughout most of the region, with the exception of summer months, where a higher density was consistently seen west of Fehmarn Belt. The summer peak in densities in Arkona Bay was, however, unusually high due to a high local abundance of porpoises on Oder Bank on a single survey in July 2002. Scheidat, Gilles, Kock, & Siebert (2008) also published these results and calculated an average density of <0.06 porpoises km$^{-2}$ for the entire area east of Møn when excluding the unusual outlier from Oder Bank.

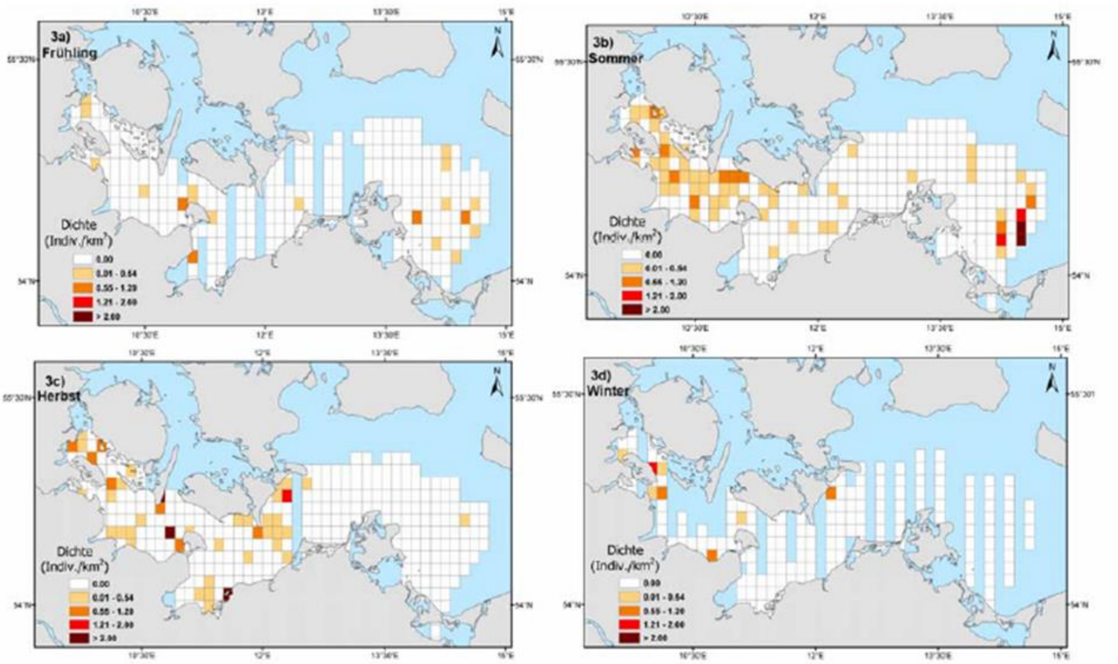



*Figure 25: Density of harbour porpoises calculated from aerial surveys in the period 2002-2005 (Gilles, et al., 2006).*

**Incidental sightings**

In order to supplement current knowledge on trends in harbour porpoise occurrence, incidental sightings of harbour porpoises have been collected in the Baltic Sea with the German initiative ‘Sailors on the Lookout for Harbour Porpoises’. During the seasons 2003 - 2008 a total number of 5561 sightings were collected (Figure 26). The vast majority of sightings were reported in near coastal areas in the summer months. This is most likely due to seasonal peaks in the activity of water sports enthusiasts and probably does not reflect the actual pattern of harbour porpoise occurrence. Only few observations were made east of Møn (Figure 26).

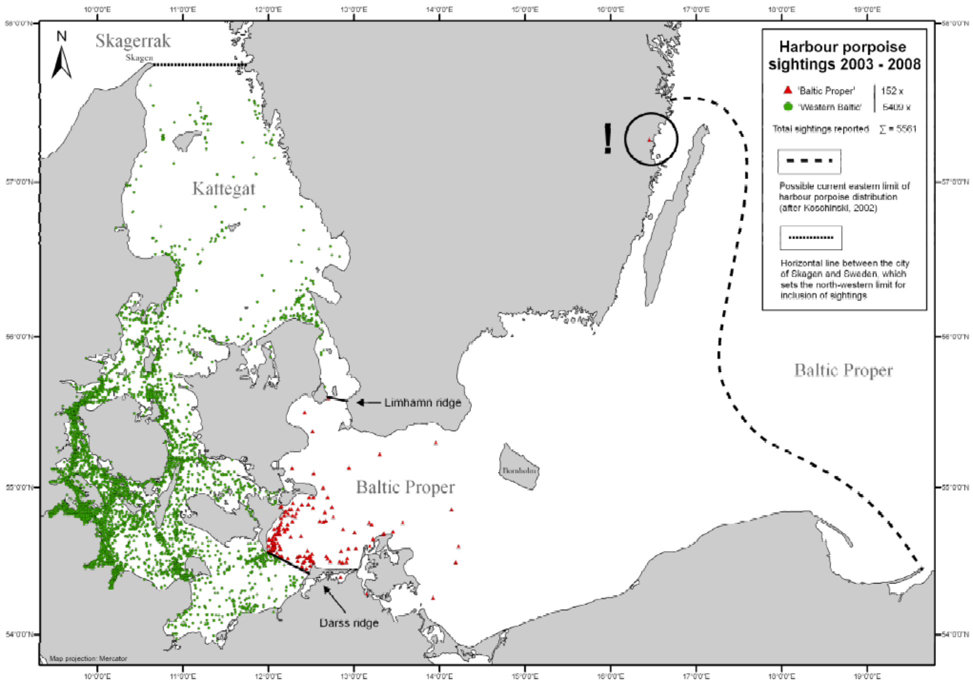



*Figure 26: All reported harbour porpoise sightings (2003-2008) (Loos, Cooke, Deimer, Fietz, V., & Schütte, 2010).*

This outline seems to be in accordance with the reported observations made in Denmark 2000-2002 (Figure 27). The majority of observations were made in April to September, reflecting the seasonal activities of beach guests and yachting (Kinze, Jensen, & Skov, 2003). Only few animals are spotted east of Zealand.

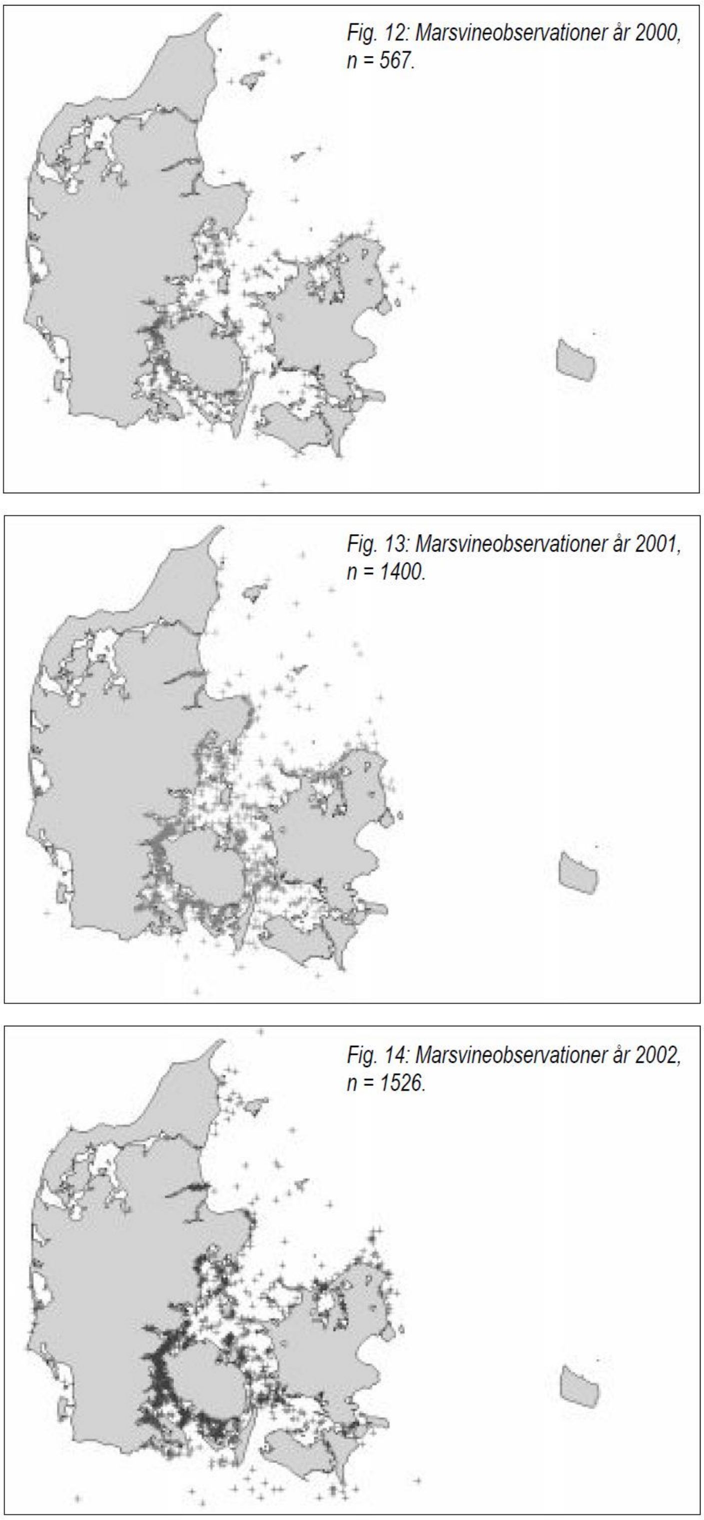



*Figure 27: Reported observations of harbour porpoises in the years 2000-2002 from ship and coast (Kinze, Jensen, & Skov, 2003).*

**Strandings**

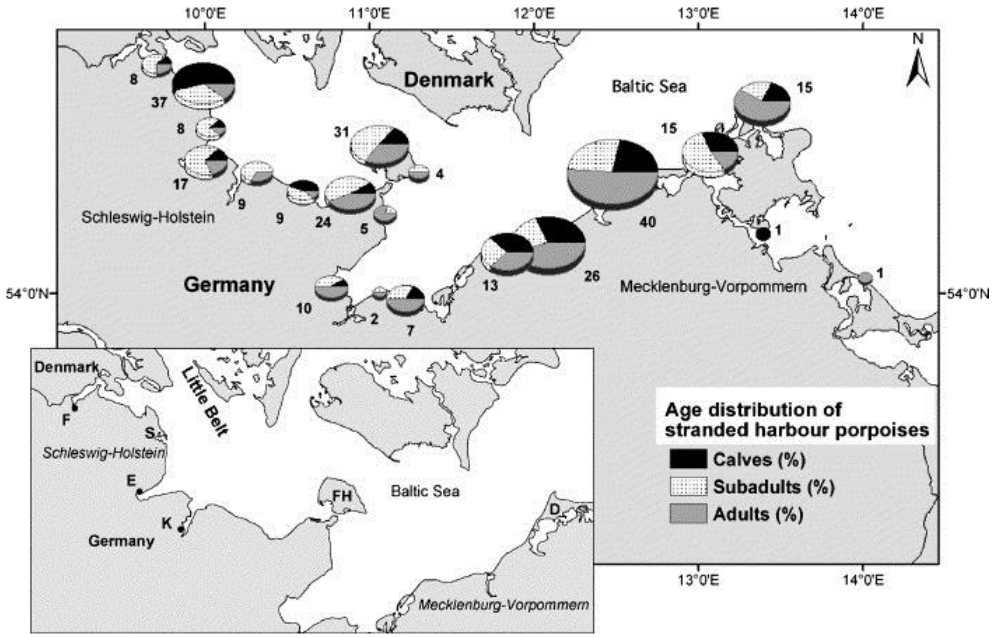



*Figure 28: Strandings of dead harbour porpoises along the German Western Baltic coastline in the period 1990-2001 (Siebert, et al., 2006).*

Two German studies have analysed stranding data along the German Baltic coastline (Schulze, 1991), (Siebert, et al., 2006). One study conducted in 1990-2001 (Figure 28) collected data from the entire coastline, whereas another (Figure 29) only recorded strandings in Mecklenburg-Vorpommern. Stranding data should be interpreted with caution, as dead animals can be transported over large distances by wind and current and thus end up on beaches a long way from their natural habitat and hence, it is difficult to say if these animals have lived in the waters around Kriegers Flak. Nevertheless, both studies show a very strong difference between the number of strandings east and west of Cape Arkona (Rügen). A disproportionably large number of strandings on the shores west of Cape Arkona, down towards Lübeck is probably related to the predominantly westerly winds, but the extremely low numbers on the eastern side of Rügen likely reflects a very low abundance of porpoises in these waters. Calves were found throughout the coastline, but in disproportionably large numbers at the entrance to Flensburg Fjord (Siebert, et al., 2006).

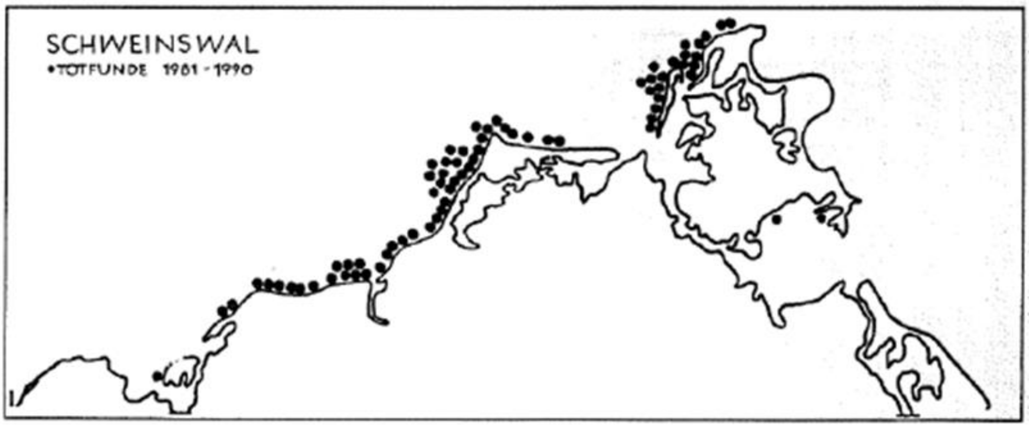



*Figure 29: Strandings recorded along the coast of Mecklenburg-Vorpommern in the years 1981-1990 (Schulze, 1991).*

**Acoustical data**

Several studies have used acoustic dataloggers (T-PODs/C-PODs) that record the echolocation sounds of porpoises to study porpoises in the Western Baltic. One study (Verfuß, Honnef, Meding, Dähne, Mundry, & Benke, 2007) obtained T-POD data from a large number of permanent stations throughout the German EEZ. T-POD data from the German monitoring program are consistent with sighting data, showing a general east-west gradient in abundance with very few animals encountered east of Rügen (Figure 30). The station located close to Kriegers Flak, on the boarder of the German EEZ, demonstrates that porpoises occur in this area but not on a regular basis. Gallus, et al. (2012) continued the monitoring of the eastern part of the same surveillance area until 2007 and they also detected a few porpoises close to Kriegers Flak.

Gillespie, et al. (2012) found similar results from acoustical and visual surveys made from boat in 2001 and 2002. The highest densities were detected in the Kiel Bight and Little Belt, the lowest in the eastern Polish part of the Baltic, resulting in a gradient decreasing from west to east.

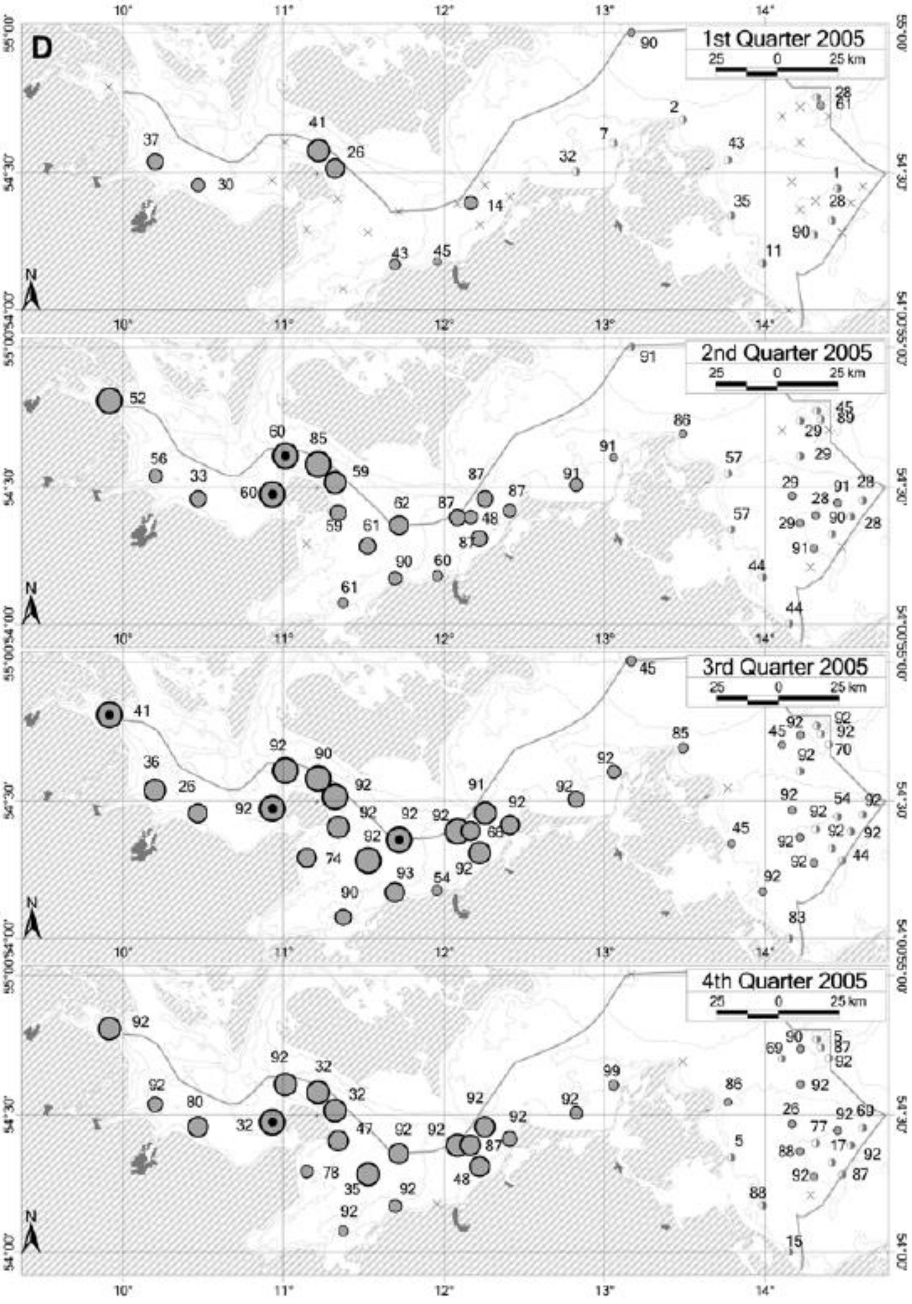



*Figure 30: Percentage of porpoise-positive days per monitoring period at the measuring positions for each quarter of the year 2005. The size of the dots is proportional to the percentage. The number of monitoring days is given next to the dots. Positions at which no data were gathered for the specific quarter are marked with grey crosses (Verfuß, Honnef, Meding, Dähne, Mundry, & Benke, 2007).*

## 6.3 Distribution of harbour porpoises – new results

### SAMBAH acoustical data

For the three SAMBAH stations recording during 2011-13, the temporal variation of the daily DPM (Detection Positive Minutes) values is depicted in Figure 31, Figure 32 and Figure 33. Despite a large degree of variation in daily DPM, the seasonal values reflected by the monthly medians show clear and synchronous patterns at all three stations. Values recorded during summer and autumn months during the years 2011-2013 were almost an order of magnitude higher than during the winter and spring months. A strong east-west increasing gradient in acoustic activity of harbour porpoises in the region was documented by the SAMBAH data (Figure 31). During the summer and autumn months (June-November) the median DPM values were approximately twice as high on the western most station 8005 as on the nearby station 8007. On station 1001 east of the project area, very few animals were recorded and median DPM values were at least 5 times lower than on station 8005.

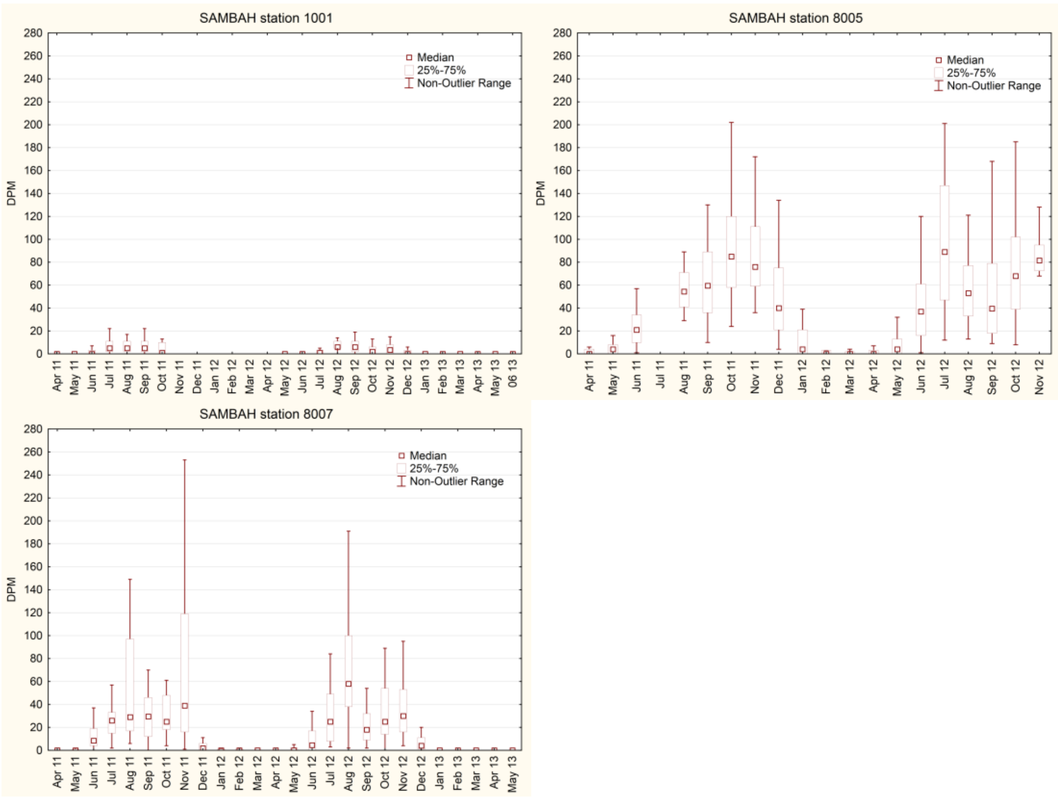



*Figure 31. Monthly median, 25/5 percentile and non-outlier range of daily DPM values recorded at the three SAMBAH stations.*

The daily and weekly DPM values display a high degree of variation within the main period of acoustic activity, and although some peaks occurred during the same days and periods on station 8005 and 8007 the variation was not always synchronous (Figure 32, Figure 33). In spite of this, the temporal patterns at both ‘project’ stations displayed a clear periodicity with distances between peaks typically extending over 6-8 days. The partial serial autocorrelation functions corroborated this, as patterns of autocorrelations showed a wave-like pattern with higher values at time lags of 5-7, 10-14 and so forth (Appendix 1). These peak values were, however, not always significant. The interpretation of these results is the existence of a relatively persistent, yet moderate temporal structure of approximately 7 days length in the acoustic data. This means that although harbour porpoises occur continuously in the project area during the summer and autumn months, their abundance varies over time with pulses of higher abundance occurring at weekly intervals.

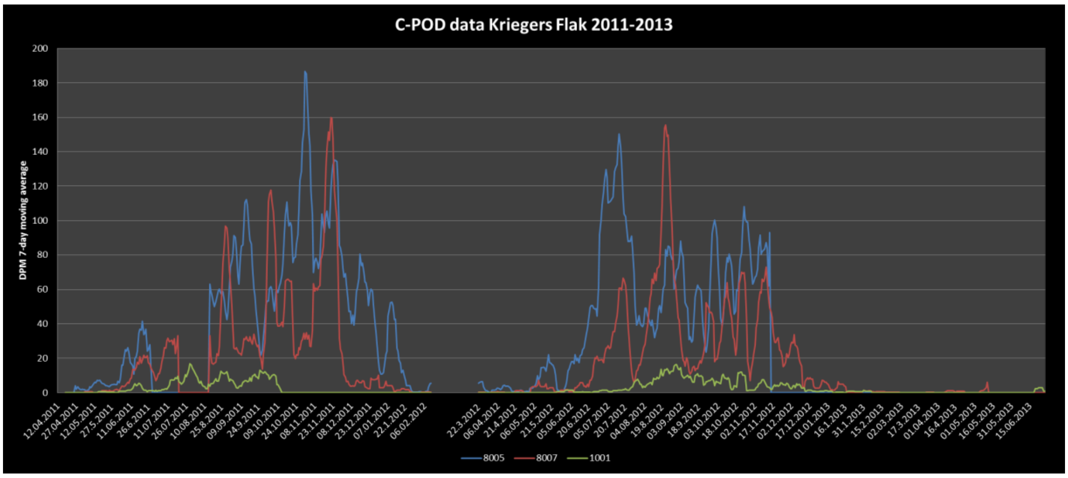



*Figure 32. Seven-day running means of DPM values for the three SAMBAH stations between 12 April 2011 and 15 June 2013.*

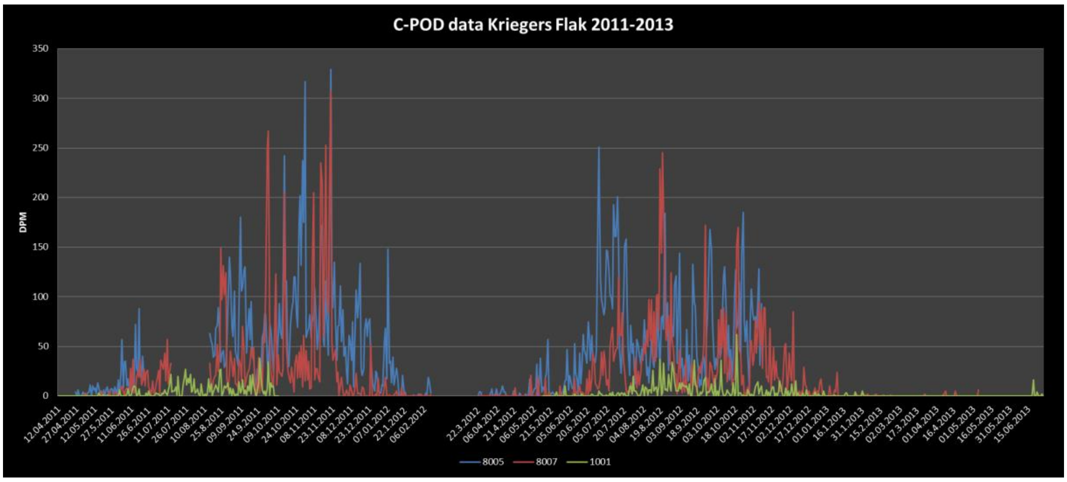



*Figure 33. Daily DPM values recorded at the three SAMBAH stations between 12 April 2011 and 15 June 2013.*

In oceanography, a periodicity of approximately 7 days reflect the mean period between major weather systems (Skov & Thomsen, 2008), (Skov, et al., 2014), which again play a major role in the patterns of inflow of water across the Arkona Basin. In Figure 34 and Figure 35, the recorded DPM values from station 8005 have been overlaid with synoptic modelled U current velocities (E-W) and wind directions. It is clear that although the periodicity in currents and wind directions fit that of the acoustic data, peak DPM values do not always fall in periods with the same current and wind characteristics. Thus, although the weather systems and coupled oceanographic processes may play an important role in driving variation in porpoise acoustics in this region, the nature and timing of these associations is complex.


*Figure 34. Daily recorded DPM values and mean modelled U current velocity (DHI Waterforecast) during two periods at station 8005. U current velocity is given as a vector with positive values indicating east-flowing and (negative values) west-flowing currents.*

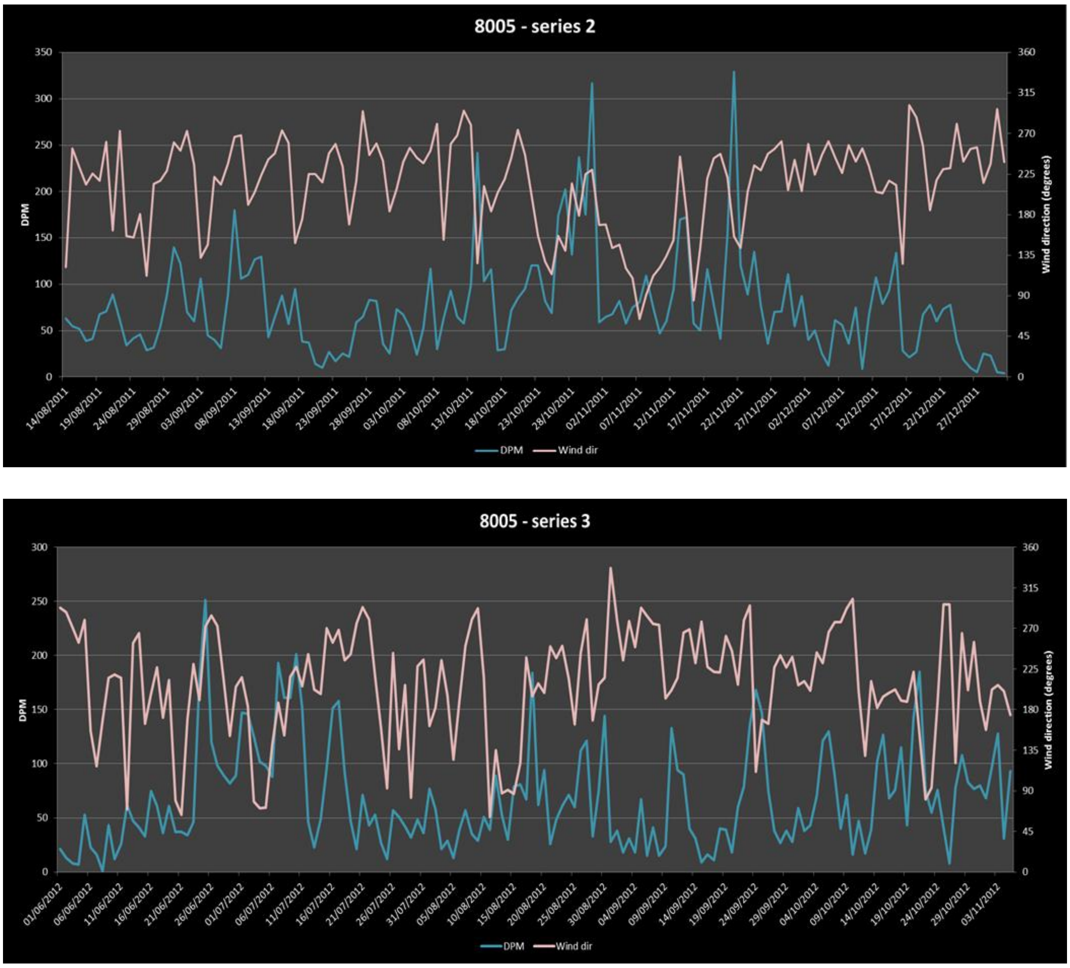



*Figure 35. Daily recorded DPM values and mean modelled wind direction (degrees, DHI Waterforecast) during two periods (14 August – 27 December 2011 and 1 June – 3 November 2012) at station 8005.*

**Harbour porpoise movements from satellite positions**

Over the years from 1997 to 2012 Aarhus University (former NERI) has tracked 99 harbour porpoises. The track lines that constitute the basis for the modelling in the Kriegers Flak area are presented in Figure 36. The Baltic constitutes the eastern range of the tagged porpoises from the inner Danish waters and therefore the densities are lower in the Kriegers Flak region than at identified hotspot areas in the Danish waters.

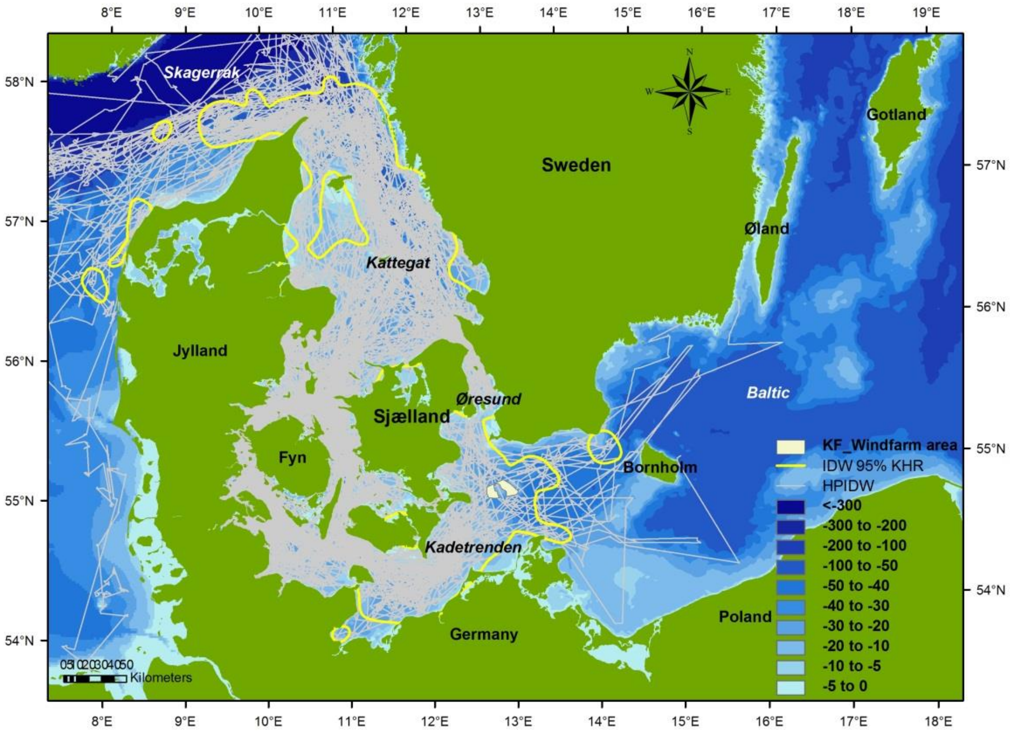



*Figure 36: Map showing the migration routes and the 95% kernel home ranges of the 99 harbour porpoises tagged in Danish Waters between 1997 and 2013 in Danish waters.*

## 6.4 Modelling porpoise distribution from satellite positions

**Results summer (June-August)**

Figure 37 shows a map of suitable habitat areas in the Western Baltic based on the results from 100 bootstrap models. The scale of the colouring can be interpreted as the relative probability of presence of harbour porpoises given the environment. The most important areas are in the south-western part of the study area, in the water between Møn, Falster and Germany. Also, the waters close to the coast of Zealand appear to hold suitable areas. The area west of Kriegers Flak seems to be a better porpoise habitat than that to the east. The observations included in this model likely represent animals coming from the west and staying there for some time (summer/autumn) after which they return west to the inner Danish waters.

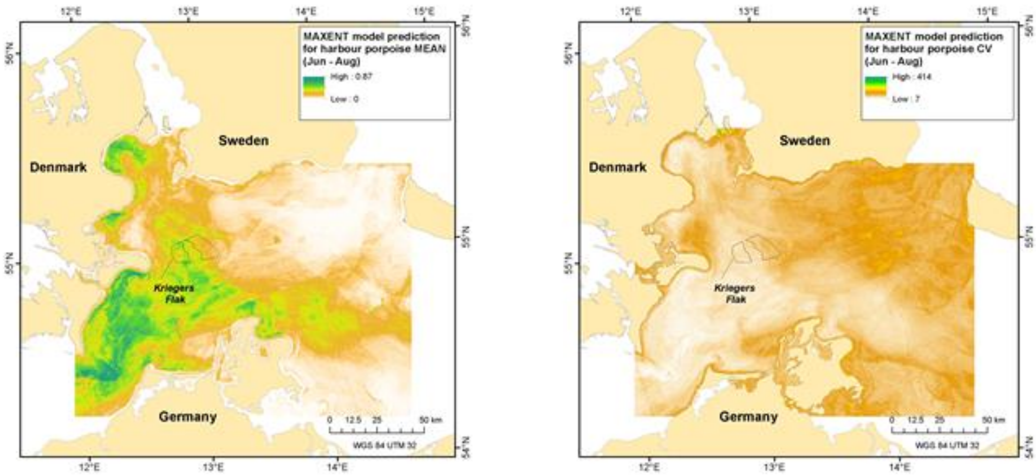



*Figure 37: June-August. Left: Mean prediction of the "probability of presence of harbour porpoise" based on 100 bootstraps model. Right: The uncertainty of the prediction ex-pressed by the coefficient of variations (CV). The construction area is outlined on the map as well as the three SAMBAH C-POD positions (black dots).*

The so-called AUC (Area Under the receiver operating Curve) value can be used to evaluate the model performance. The AUC is the probability that a randomly chosen present site will be ranked in relation to prediction above a randomly chosen background site (see (Philips & Dudik, 2008) for more details). A value of AUC=0.5 means that the model performance is equal to that of a random prediction. The mean AUC for 100 bootstrap models was calculated to be 0.927 (SD=0.011). According to Elith (2002) models with AUC values above 0.75 are considered potentially useful.

The importance of the variables is evaluated by the jack-knife test. First, the gain (improvement of model performance) is measured when one variable is the only variable in the model, and then the decrease in gain, if that variable is omitted from the full model, is measured. As can be seen in Figure 38, salinity and temperature are the most important variables when used in isolation. Distance to land and depth are also important, while front, slope, sediment, curvature and ship traffic appear unimportant. Salinity is also the variable that reduces the gain the most if omitted, and thus appears to have the most information that is not represented by the other variables.

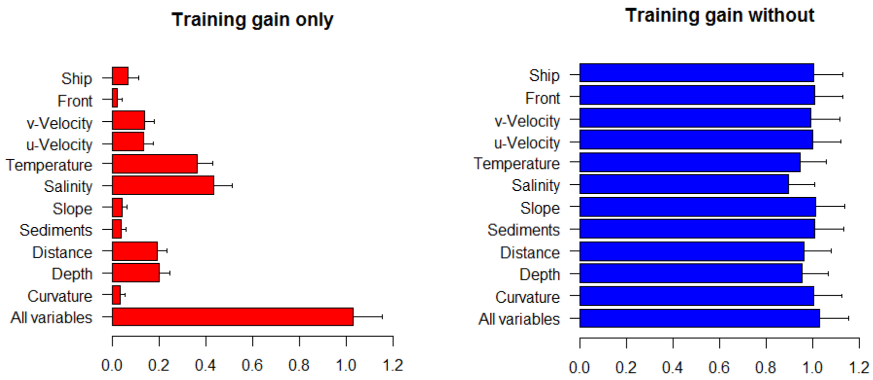



*Figure 38: June-August. Results of the jack-knife test of variable importance measured by the gain of the variables. Left: The variable used in isolation. Right: The decrease in gain when omitted from the model. Error bars represent standard deviation.*

Figure 38 shows response curves for the four most important variables (salinity, temperature, distance to land and depth. The response curve illustrates the relationship between probability of presence and environmental variables. The probability of presence increase sharply when the salinity reaches ca. 7‰. The temperature response curve shows high variability between the model runs up to about 15 degrees, where the probability appears to drop followed by an increase. This may be caused by the present of one or few low temperatures in the dataset and must be considered as an artefact. The distance to land curve is rather constant, but with a tendency of a parabolic shape. The probability of presence decreases more or less continuously with increasing depths.

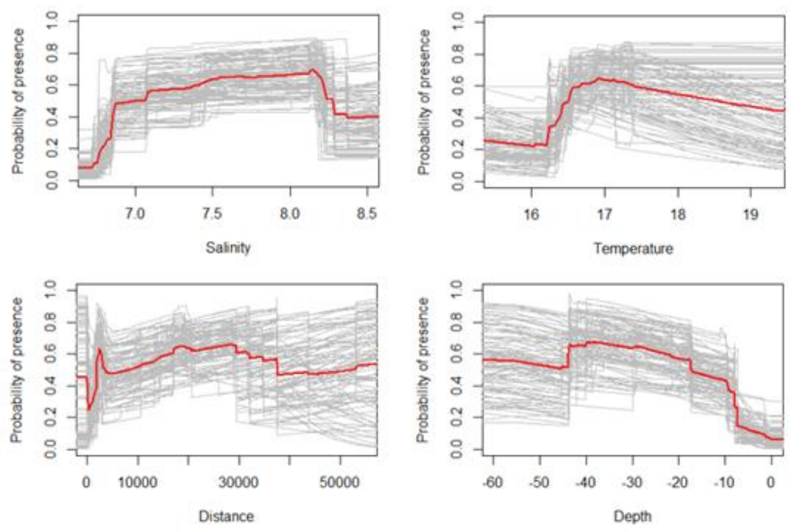



*Figure 39: Summer (Jun-Aug). Response curves. The curves show how the probability of occurrence changes as the variable is varied, keeping all other variables at their average sample value. Response curve for all 100 bootstrap models are shown with the mean curve in red.*

**Results, autumn (September-November)**

Figure 40 shows a map of suitable habitat areas in the Western Baltic during autumn (Sep-Nov) based on the results of 100 bootstrap models. The most important areas are in the south-western part of the study area, in the waters between Falster and Germany. The eastern part of the study area appears not to include suitable areas. In the studied area, there is a gradient of salinity with highest salinity in the western part and lowest in the eastern part (see Appendix 4). As most of the positions of harbour porpoise are from the western part, the MaxEnt model "catches" this and salinity comes out as the most important variable, which is also mirrored in the prediction of suitable habitats. The uncertainty of the model prediction is generally higher in the eastern part than in the western part of the studied area, which reflects the fewer observations here.

The Kriegers Flak area lies on the border between areas with relatively high suitability in the western part and low suitability in the eastern part.

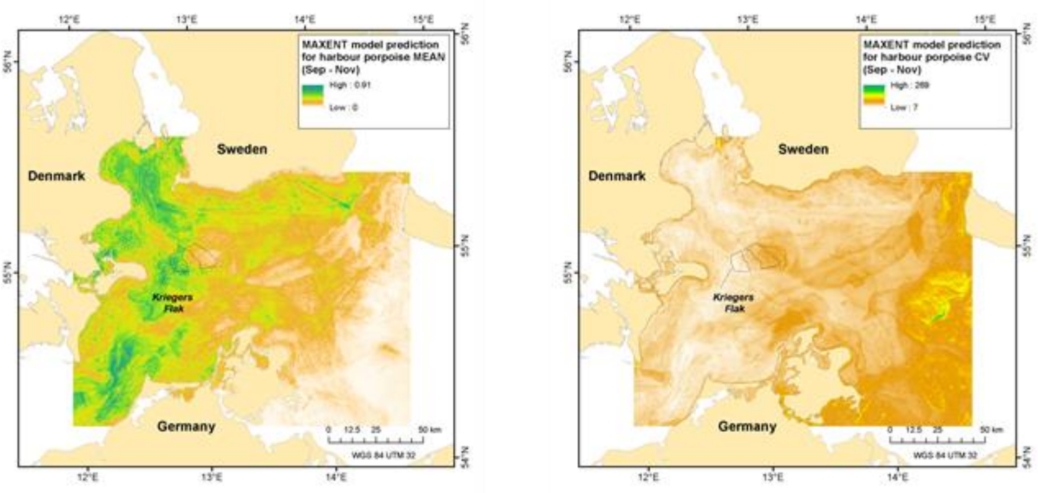



*Figure 40: September-November. Left: Mean prediction of the "probability of presence of harbour porpoise based on 100 bootstraps model. Right: The uncertainty of the prediction expressed by the coefficient of variations (CV). The construction area is outlined on the map as well as the three SAMBAH C-POD positions (black dots).*

The mean AUC value for the 100 bootstrap models was 0.893 (SD=0.011). This was a little lower than the AUC obtained for the summer (Jun-Aug) period but still at a satisfactory level.  In a previous study using MaxEnt and harbour porpoise satellite positions in inner Danish waters, AUCs ranged from 0.70 to 0.86 (Edrén, Wisz, Teilmann, Dietz, & Söderkvist, 2010).

The jack-knife test of variable importance shows that salinity is by far the most important variable both when evaluated by the gain when used as single variable and gain decrease when omitted from the model (Figure 41). Other variables with some importance are temperature, distance to land and v-velocity.

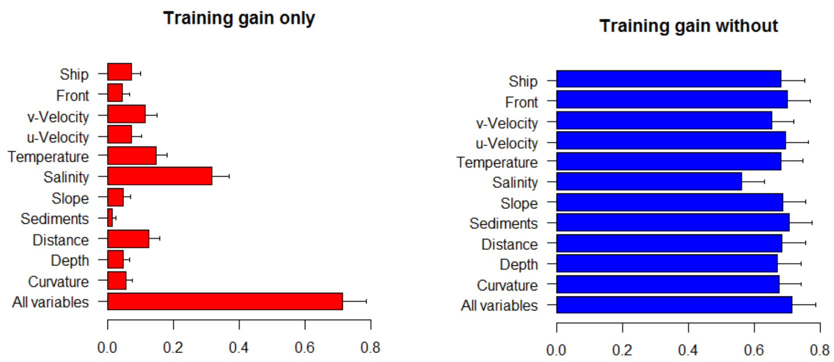



*Figure 41: September-November. Results of the jack-knife test of variable importance measured by the gain of the variables. Left: The variable used in isolation. Right: The decrease in gain when omitted from the model. Error bars represent standard deviation.*

Figure 42 shows the response curves for the four most important variables. The probability of presence increases from a salinity of approximately 7‰ up to the maximums at 9 and 11‰. The probability of presence appears to have a maximum just above 11 °C and decrease with higher temperatures. The distance to land curve is rather constant, except for an increase some distance from land and out to a distance of approximately 20 km. The response curve of v-Velocity shows a continuous increase from the lowest velocity to the highest.

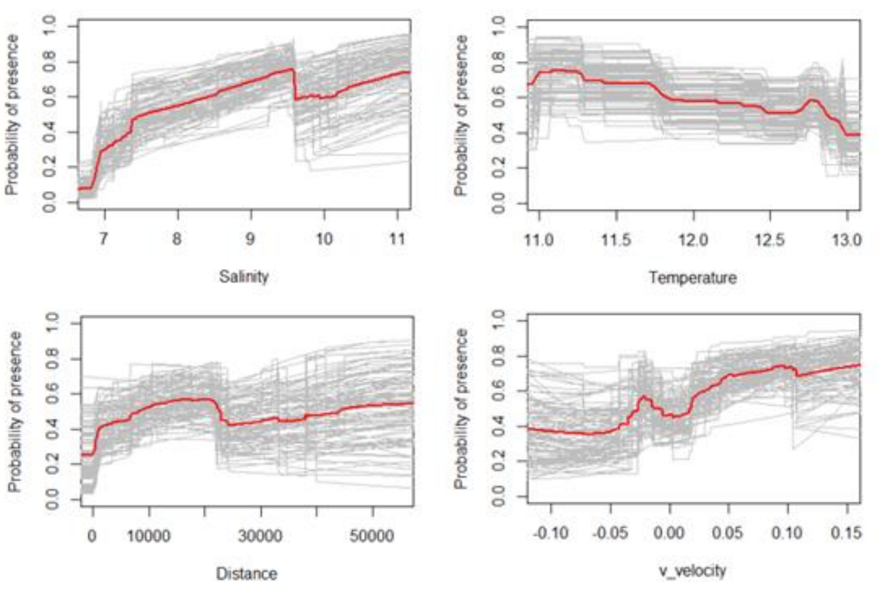



*Figure 42: September-November. Response curves. The curves show how the probability of occurrence changes as the variable is varied, keeping all other variables at their average sample value. Response curve for all 100 bootstrap models are shown by the mean curve in red.*

**MaxEnt results compared to SAMBAH acoustical data**

Both the MaxEnt results from summer (Jun–Aug) (Figure 37) and autumn (Sep–Nov) (Figure 40) seem to be in accordance with the SAMBAH C-POD results (Figure 31). The model predicts a higher probability of porpoise occurrence in the western part of the Kriegers Flak project area compared to the eastern part in both seasons. The C-POD results show much higher detections at the stations to the west, 8005 and 8007, than at the eastern station (1001) for the same months (Figure 31). This is also illustrated in Figure 43, where results from the MaxEnt model are plotted as a function of DPM per day. When looking at each season separately (Blue: summer (Jun-Aug), Red: autumn (Sep-Nov)), the results seem very coherent, station 1001 has the lowest score on both axes, station 8007 is intermediate and 8005 shows the highest value. The two variables are significantly correlated, which adds validation to the MaxEnt model. Also, the period of high detections of the C-PODs starts in June and ends in November/December (Figure 31), with hardly any detections in January – May, corresponding well with the satellite data which only show few observations of tagged animals in the period December – May (Table 9), hence modelling was not possible for this period.

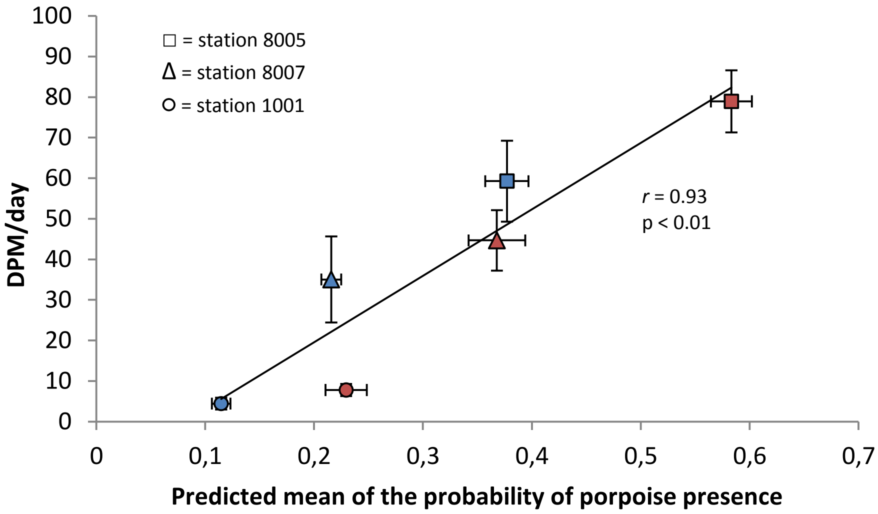



*Figure 43: The MaxEnt predicted mean of probability of presence of porpoises as a function of DPM per day (from C-PODs) with std. error bars. Blue: Results from summer (Jun-Aug), Red: Results from autumn (Sep-Nov). All points were included in calculation of the Pearson correlation coefficient.*

## 6.5 Biology of the harbour seal

**Reproduction**

In Danish waters, the female harbour seal gives birth to one pup every year in May-June (Olsen M. , et al., 2010). The pup suckles for about three to four weeks after which it is left to fend for itself. Like the birth, suckling mostly takes place on land. Harbour seal pups shed their embryonic fur (lanugo) before birth and are thus born with the adult fur. In contrast to most other true seals (e.g. grey and harp seals), the pups are thus able to swim and dive immediately after birth. In case the mother and pup are disturbed on land, they will flee together into the water, but they depend on getting back on land again for weaning/suckling. Disturbances in the breeding season in June and July can hence severely affect pup survival. During August, the adult seals change their fur, for which they also depend on longer, undisturbed periods on land, as the development of the new fur critically depends on a good blood perfusion to the outer layers of the skin. In order to reduce heat loss from the body, this increased perfusion can only occur on land, preferably with dry fur. Thus, the adult seals are more vulnerable to disturbances during the summer months.

Mating occurs immediately after end of suckling and takes place in the water i.e. primarily during July (Olsen M. , et al., 2010). Little is known on the exact circumstances surrounding the mating. Several studies from Norway, Scotland and California have suggested that males have an underwater display, which includes vocalisations (Bjørgesæter, Ugland, & Bjørge, 2004) and that females seek out the displaying males and decide whether to mate or not (Hanggi & Schusterman, 1994), (Hayes, et al., 2004), (Boness, Bowen, Buhleier, & Marshall, 2006). This mating structure is known as a lek-system and is well known and described in detail for several species of birds. The implications of such a system are that males do not form and defend a harem of females, as seen in many other seal species (e.g., sea lions and elephant seals). Neither do the males defend individual territories. Harbour seal males in California have been shown to return to the same territories for at least 2-4 subsequent years (Hayes et al. 2004).

The most important haul-out site for harbour seals close to Kriegers Flak is at Måkläppen at Falsterbo, Sweden, which is also a breeding site (see Figure 51 below). Whether there are display territories and mating sites close to the haul-out or in the waters surrounding Falsterbo, is unknown.

The harbour seals in the area moult their fur in July to September with the peak season in August. During this period, the seals spend a lot of time hauled out. During the present study, harbour seals spent less time hauled out during December and January than the other months, for which data were available (Figure 44).

The tagged harbour seals did not show any tendency towards a uniform pattern in the time spent hauled out (Figure 45)

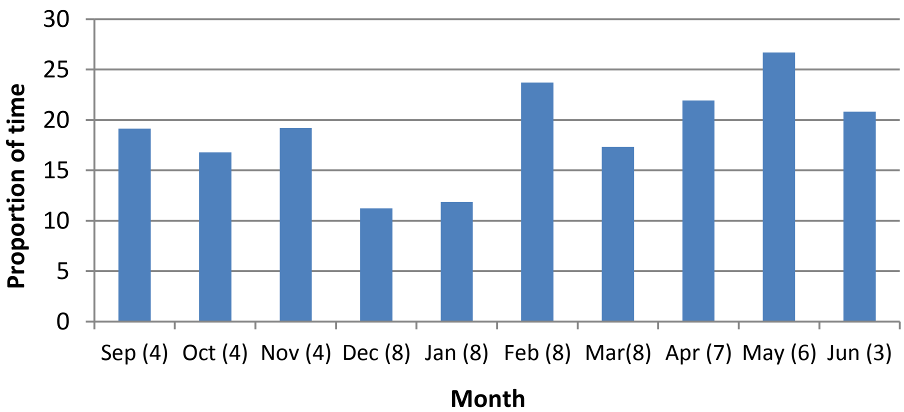



*Figure 44: The mean percentage of time spent hauled out of all harbour seals tagged during the present study (numbers in parentheses indicate the number of individuals available for each monthly mean).*

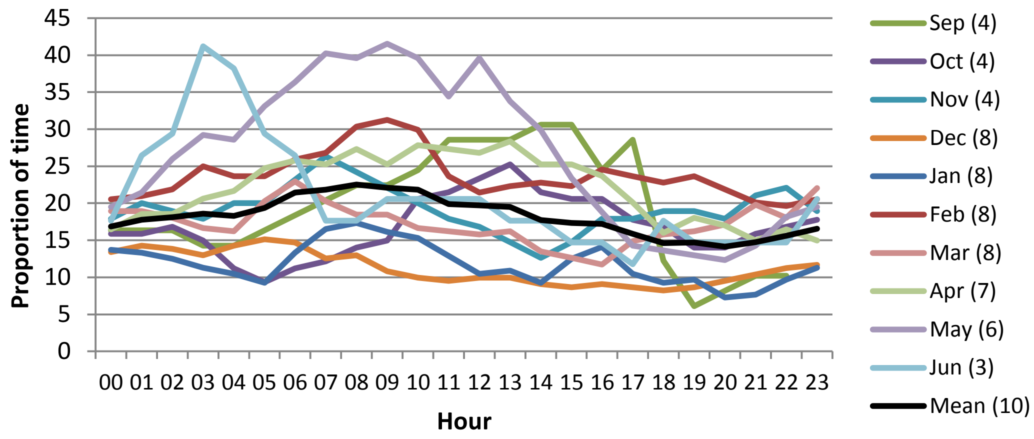



*Figure 45: The mean percentage of time spent hauled out per hour of the day on a monthly basis for all harbour seals tagged during the present study (numbers in parentheses indicate the number of individuals available for each monthly mean).*

**Foraging**

No diet data exist from the Kriegers Flak region, but from the Rødsand area diet was analysed from 30 harbour seals during 2001-2005 (Andersen, Teilmann, Harders, Hansen, & Hjøllund, 2007). In total 20 species of fish were identified, while the main prey was cod dominating both spring and autumn seal diet (42% and 43%, respectively, of the weight consumed). Cod were less common in summer (22%), when the fish species dab, flounder and plaice together made up 62% of the weight consumed. Also Atlantic herring and lesser sandeel contributed substantially to the seal's diet. In total, seven newly ingested garfish lacking their heads were recovered in two seal digestive tracts from Rødsand. Harbour seals have moderate ranges and usually feed rather close to their haul-outs (Frost, Simpkins, & Lowry, 2001), (Härkönen, 1987), (Härkönen & Hårding, 2001), (Dietz, Teilmann, Andersen, Rigét, & Olsen, 2012). Seals tagged at Rødsand, in the Danish Baltic generally stayed within 50 km of the haul-out (McConnell, Lonergan, & Dietz, 2012). Harbour seals generally forage in areas shallower than 100 m (Tollit, et al., 1998), (Lesage, Hammill, & Kovacs, 1999), (Eguchi & Harvey, 2005). In the south-western Baltic, around the Kriegers Flak area, water depths do not exceed 50 m. The harbour seals tagged during the present work had a fairly even distribution of dive depths over 10 m intervals from 0-10 m to 40-50 m (Figure 46).

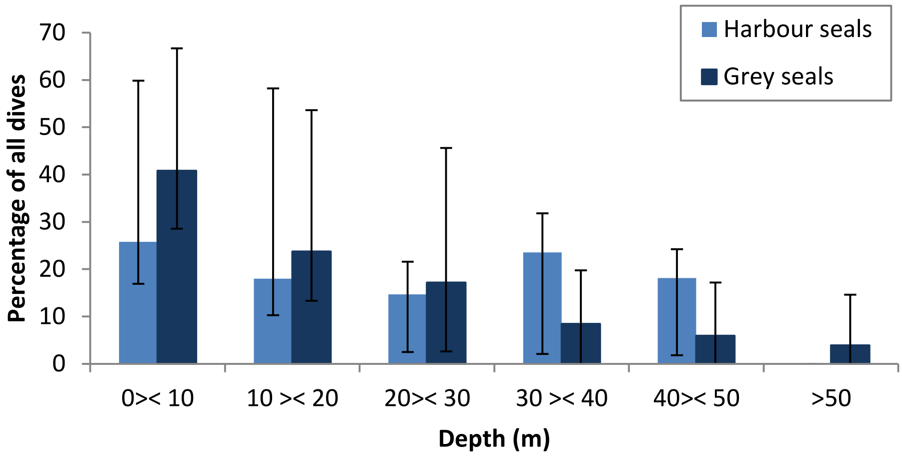



*Figure 46: Mean distribution of dives for grey and harbour seals during the present study. The error bars indicate the ranges of individual values.*

The mean dive duration varied around 2-3 min by month and species, only June showed substantial differences with longer dive duration in harbour seals. As the transmitters were lost prior to the moult (harbour seals), there are no data from July and August (Figure 47). The variations in dive duration may be explained by different prey items in different seasons.

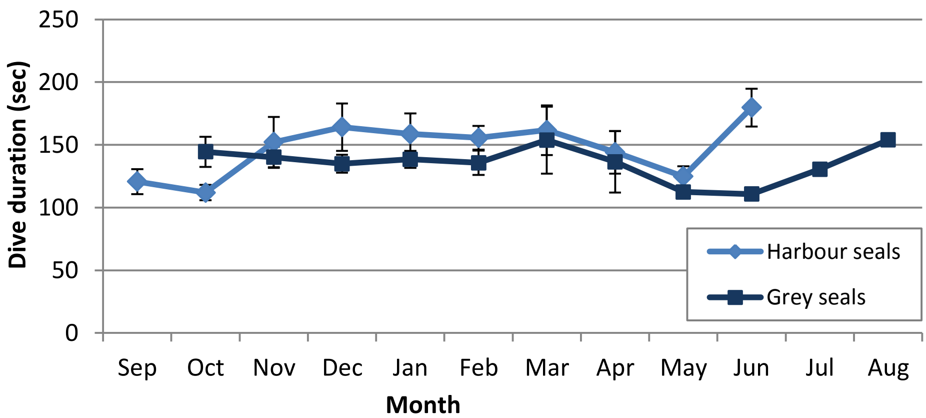



*Figure 47: Mean dive durations of grey and harbour seal presented by month during the present study. Error bars indicate standard errors.*

**Hearing**

Seals have hearing well adapted to an aquatic life. Adaptations to underwater hearing include a cavernous tissue in the middle ear which allows for balancing the increased pressure on the eardrum when the animal dives (Møhl, 1967), and a separate pathway for sound to the middle ear in water. The audiogram of harbour seals shows good underwater hearing in the range from a few hundred Hz to about 50 kHz (Figure 48, left). The critical bandwidth of harbour seal hearing decreases with frequency, at least in the range 2.5 kHz to 30 kHz where it has been measured (Figure 48, right). The critical bandwidth is (among other things) a measure of the sensitivity to masking by noise. Noise which falls within the critical bandwidth around a given tone stimulus of constant frequency can mask the tone (i.e. cause an elevation of the detection threshold) whereas noise that falls outside the critical band has no or only little effect on the detection of the tone. Small critical bandwidths thus indicate little sensitivity to noise interference, whereas broader critical bands indicate greater sensitivity to noise.

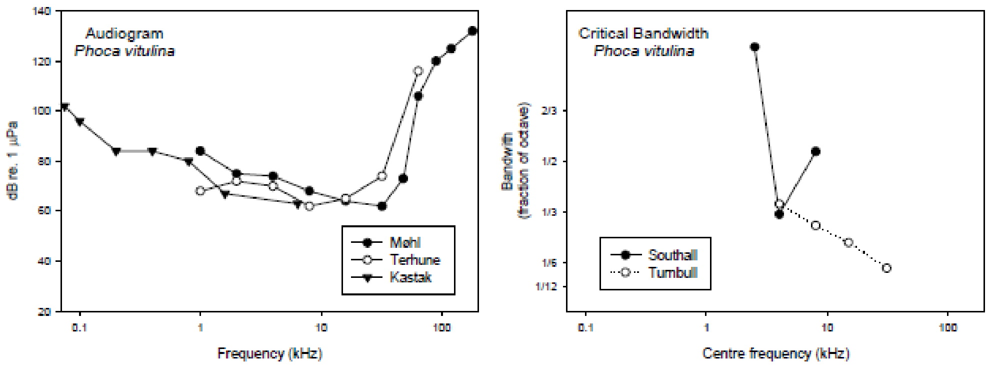



*Figure 48: Left: audiograms of three harbour seals, showing threshold of hearing under quiet conditions at frequencies in the range from 80 Hz to 150 kHz. (Møhl, 1968); (Terhune & Turnbull, Variation in the psychometric functions and hearing thresholds of a harbour seal. In: Sensory systems of aquatic mammals, 1995); (Kastak & Schusterman, Low-frequency amphibious hearing in pinnipeds: Methods, measurements, noise, and ecology, 1998). Note that thresholds are measured in dB re. 1 µPa and thus cannot be compared with tabdB SPL of human audiology, which is referenced to 20 µPa. Right: critical bandwidth of harbour seals, expressed as fraction of an octave. Data from (Southall, Schusterman, & Kastak, Masking in three pinnipeds: underwater, low-frequency critical ratios, 2001) and (Turnbull, 1990).*

#### Vision

Seals have good vision, both in air and water, with variation from species to species in terms of the degree to which the eyes are adapted to water. The lens is adapted to underwater vision and focusing in air is believed to be possible due to the slit-formed pupil (when contracted), which results in a large depth of focus (Fobes & Smock, 1981), (Hanke & Dehnhardt, 2009).

As all other pinnipeds (and cetaceans) the harbour seal is considered to be functionally colour blind (Peich, Behrmann, & Kröger, 2001). They have very few cones in the retina and all of these are of the same (blue) type (Newman & Robinson, 2005).

The sensitivity of the eyes is high, enhanced by the presence of a tapetum lucidum behind the retina and seals are probably able to orient visually even at great depth (Levenson & Schusterman, 1999).

#### Touch/vibration

Seals have very well developed whiskers (vibrissae) and the follicles are highly vascularised and with a large number of attached sensory nerves (Dykes, 1975). Behavioural experiments have shown that the whiskers of seals are extraordinary sensitive to particle movement in the water (Denhardt, Mauck, & Bleckmann, 1998) and it is within practical possibilities that seals can detect the vortices and eddies left behind in the wake of a swimming fish, even several minutes after the fish has passed (Denhardt, Mauck, Hanke, & Bleckmann, 2001). It can thus be conjectured that the whiskers play as large a role as the eyes, if not larger, in terms of locating prey.

#### Electro- and magneto-reception

There is no evidence of electroreception or the ability to detect magnetic fields in seals. As for porpoises, the possibility of especially magneto-reception should not be dismissed, however.

### 6.6 Abundance of the harbour seal

The harbour seal is abundant throughout the Danish waters. Hunting was abolished in 1976, and at the same time, a number of protected areas were established, where seals could haul-out and breed undisturbed (Olsen M. , et al., 2010). This protection has resulted in a large increase of the populations, which now number a total of about 16,000 animals (counting in August 2012) and continue to increase. In 1988 and 2002 however, the entire population was reduced with about 50% and 25% respectively, by outbreaks of disease caused by phocine distemper virus (Härkönen, et al., 2006).

Based on molecular data and satellite telemetry, the harbour seals in Denmark and neighbouring areas have been split into four management units or sub-populations, among which there is at least partial reproductive isolation: the Wadden Sea, the Limfjord, Kattegat and the Western Baltic (Olsen M. , Andersen, Dietz, Teilmann, & Härkönen, 2014). The seals occurring around the Kriegers Flak area will almost exclusively come from the latter unit and there is evidence both in movements and genetics of harbour seals within the Western Baltic that the area east of Gedser show population differences compared to west of Gedser. A small isolated inner Baltic population is resident in the Kalmar Sound area on the Swedish west coast (Härkönen & Isakson, 2010), but given the distance from Kriegers Flak, stray animals from this population is not likely to occur here.

Haul-out sites of the Western Baltic sub-population are well known and long records of counts from airplanes, which provide reliable records on population development and distribution across haul-out sites in the region (Figure 49, Figure 51). The Western Baltic population (possibly divided into two subunits) is limited in distribution to the southern part of the Sound and the waters around Lolland, Falster and Møn. No breeding sites are found west of Fehmarn Belt and the Great Belt, and harbour seals are only rarely observed in the waters south of Funen.

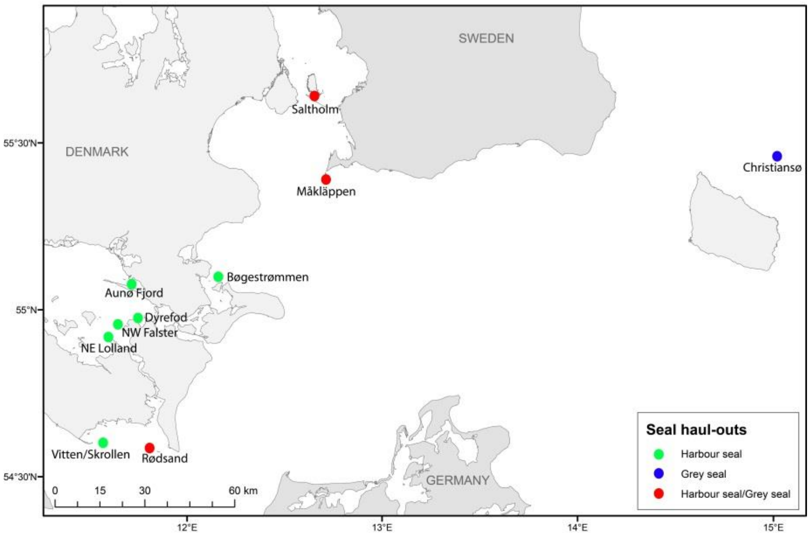



*Figure 49: Seal haul-out sites in the Western Baltic Sea.*

**Aerial counts**

Seals in Denmark and the neighbouring countries are counted internationally coordinated by aerial surveys of the haul-outs during the moulting seasons, during which the highest numbers of seals are hauled out. For harbour seals in the inner Danish waters, the peak of the moulting season is in the latter part of August. In 1988, the estimated number of harbour seals in the Western Baltic only amounted to a few hundred individuals. Despite a dip in the population increase in connection with the distemper epidemic in 2002, the sub-population has grown to an estimated 1,300 individuals in 2012 (Figure 50). This population hence, represents less than 10% of the entire Danish–Swedish population of harbour seals.

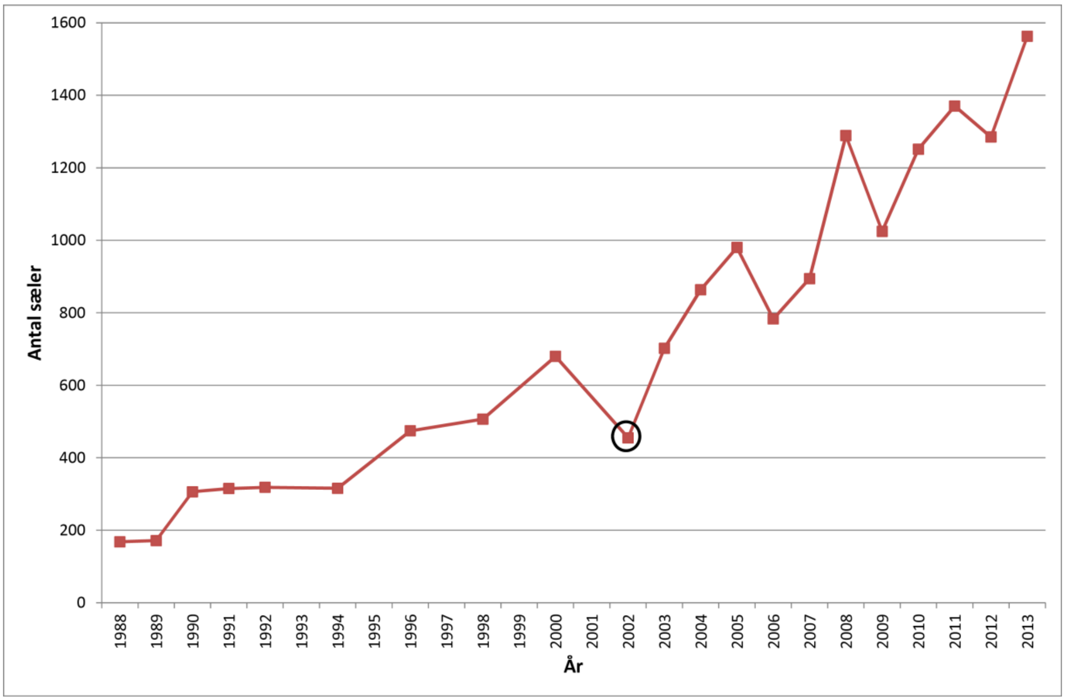



*Figure 50: Development in the corrected number of harbour seals in the Western Baltic between 1988 and 2012. The number of seals is estimated by taking the average of the two highest counts out of three surveys. A correction factor is applied to make up for the 43% of seals which are presumed to be at sea during the survey.*

A number of haul-out sites are used by the Western Baltic harbour seal management unit and the grey seals occurring in the area (Figure 50) of which Rødsand, Falsterbo and Aunø Fjord have traditionally been the most important. In recent years, an increasing number of seals have also hauled out at Saltholm and Vitten/Skrollen (Figure 51).

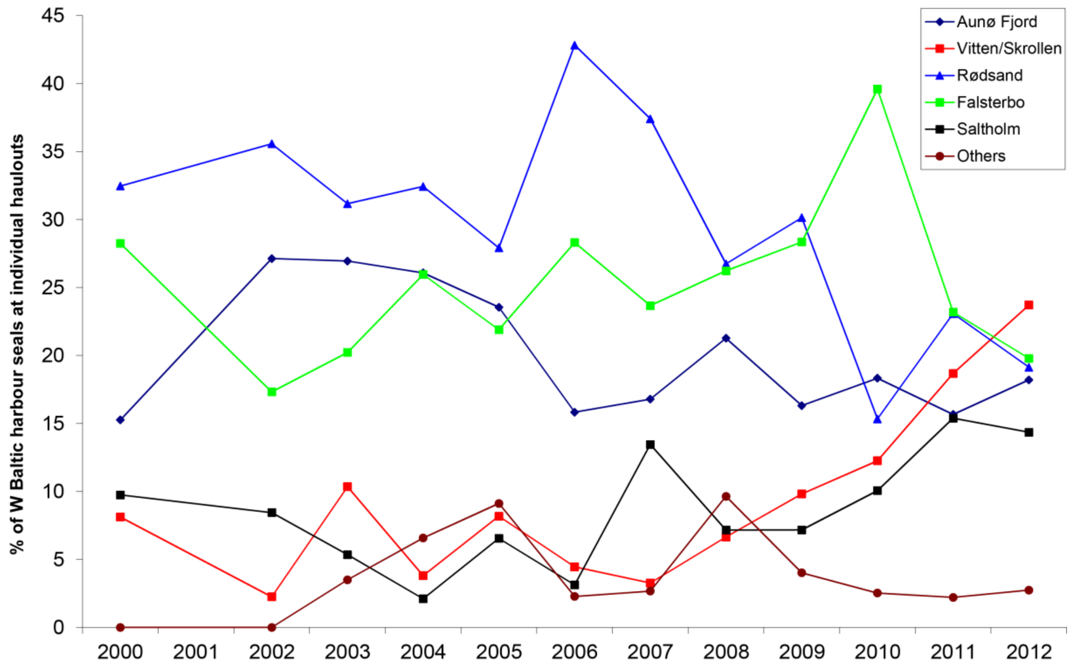



*Figure 51: Annual mean percentage distribution of harbour seals at the most important haul-outs in the Western Baltic.*

There is a marked variation in number of harbour seals hauled out, with most animals in the moulting and breeding season in June-September. Falsterbo is the haul-out closest to the Kriegers Flak area. The fraction of seals at Falsterbo has ranged between 17% and 40% of the total counted seals between 2000 and 2012, making Falsterbo the second most important haul-out on average for the harbour seals in the area

## 6.7 Biology of the grey seal

The grey seal is a large sized seal (weight up to 300 and 180 kg for males and females, respectively), endemic to the North Atlantic. The grey seal is found along the temperate region of the North American east coast, around the British Isles, Iceland, and the Faeroes, along the Norwegian coast from Trondheim to Finmark, in Brittany, the Wadden Sea and the Baltic Sea. The grey seals occurring in the Kriegers Flak area belong to the Baltic Sea population, in which more than 28,000 individuals where counted during the 2012 moult census (HELCOM Seal, 2012).

**Reproduction and annual cycle**

In March the white grey seal pups are born. Grey seal pups are born with their foetal fur (lanugo, the white and thick fur previously sought after by the fur industry). This fur is not waterproof and until the pup sheds it and attains the adult fur, it is unable to enter the water. Thus, for a period of several weeks in mid-winter, they rely on a completely undisturbed area above the high water line, where the pup can suckle and remain when the mother leaves on foraging trips. After 14 days their mother stops nursing them and they have then gained in weight from approx. 10 kg to almost 50 kg.

Baltic grey seals moult their fur in May and June. During this period, the seals spend a lot of time hauled out. During the present studies, grey seals spent considerably less time hauled than harbour seals. The shortest time spent at haul-outs was during October (Figure 52). During and after the moult in May, data were only obtained from one individual.

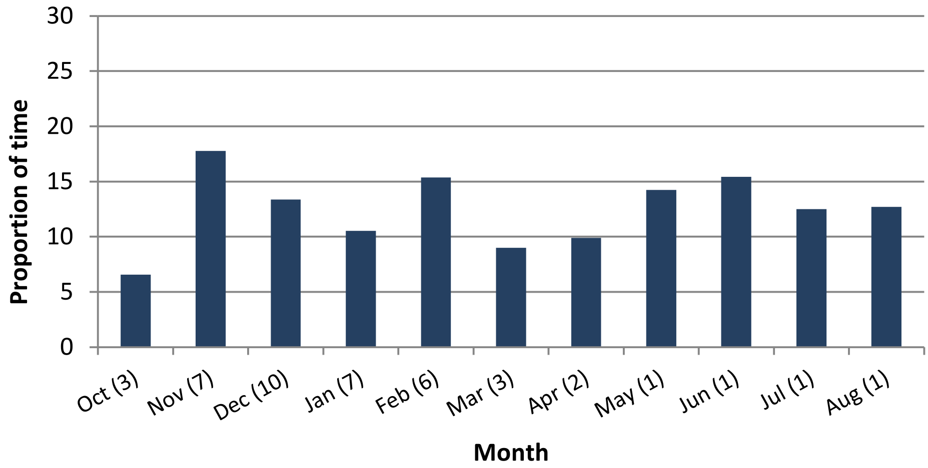



*Figure 52: Average percentage of time hauled out by month of grey seals tagged during the present study (numbers in parentheses indicate the number of individuals available for each monthly estimate).*

The tagged grey seals showed a clear preference for spending the time hauled out during night (Figure 53). Similar results have been obtained for Baltic grey seals previously (Sjöberg, Fedak, & McConnell, 1995) (Sjöberg, 1999).

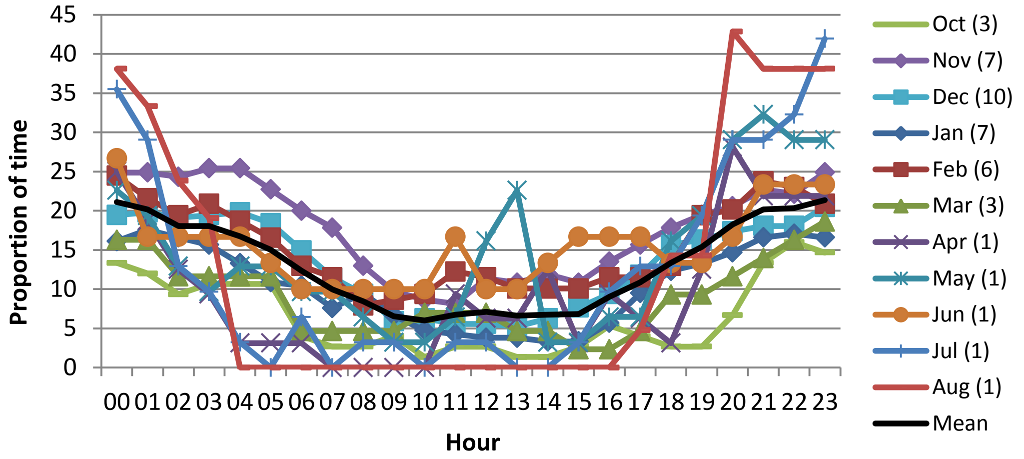



*Figure 53: The percentage of time spent hauled out during the day for all grey seals tagged during the present study (numbers in parentheses indicate the number of individuals available for each monthly estimate).*

**Foraging**

No studies of the grey seals' diet in Danish waters have been carried out. A study in the Baltic Sea revealed herring, sprat and common whitefish to be the most important prey species (Lundström, Hjerne, Alexandersson, & Karlsson, 2007). Grey seals are able to eat larger fish than harbour seals because of their larger size as well as their ability to bring large fish to the surface and tear it to smaller bits with the aid of the flippers. This behaviour is rarely observed in harbour seals, which probably generally swallow their prey whole. Grey seals have very wide ranges. In the North Sea, travels up to 2,100 km have been recorded. Grey seals tagged at Rødsand in the Danish Baltic have moved up to 850 km eastwards, into the Baltic (Dietz, Teilmann, Henriksen, & Laidre, 2003) (McConnell, Lonergan, & Dietz, 2012). In the North Sea, grey seals have been observed to alternate long foraging trips with local, repeated trips and forage at depths between 50 and 90 m (McConnell, Fedak, Lovell, & Hammond, 1999). In the present study dive depths were mostly shallower than 30 m, although, some dives deeper than 50 m were recorded (Figure 46). There were only slight variations in grey seal dive durations with season (Figure 47).

**Senses**

Very limited information is available on the sensory capabilities of grey seals. Due to their comparable anatomy and close taxonomic relation to harbour seals (Arnason, Bodin, Gullberg, Ledje, & Mouchaty, 1995), (Mouchaty, Cook, & Shields, 1995) it is reasonable to expect that also their senses are comparable. Results from electrophysiological studies (ABR) of grey seal hearing in air indicate that their hearing between 3-20 kHz is very similar to harbour seals (Ruser, et al., 2014). However, as the hearing and grey seals has never been studied under water it is still uncertain whether their hearing is comparable with harbour seals at all frequencies. Thus, data from harbour seals are used to cover both species in the following.

### 6.8 Abundance of the grey seal

Historically, the grey seal has been the most common seal species in Denmark. In contrast to the very few remains of harbour seals, grey seal remains are much more numerous in mittens and remains from Stone Age settlements (Søndergaard, Joensen, & Hansen, 1976). This is probably to some extent explained by the grey seal being more easily accessible to hunters. The grey seal's historical distribution extends throughout the inner Danish waters (Søndergaard et al. 1976). From 1889 to 1927 (and again from 1941 to 1977, but the grey seal was very rare in this period) bounties were paid for seals killed in Denmark. Similar actions were taken in Sweden and Finland, and during this time the Baltic population of grey seals suffered a dramatic decline from almost 100,000 individuals to around 20,000 (Harding & Harkonen, 1999). A second decline during the 1960s to 80s was caused by reduced fertility brought about by organochlorine contamination of the Baltic Sea (Harding & Harkonen, 1999). During this time, the grey seal population was further reduced to approximately 4,000 individuals (Harding & Harkonen, 1999). At this time, the grey seal only occurred in the central Baltic, in the area between Sweden, Finland and Estonia. Since then, the grey seal has been protected and levels of organochlorines in the Baltic have decreased and the grey seal population has recovered (Roos, Bäcklin, Helander, Rigét, & Eriksson, 2012). During the Baltic-wide coordinated moulting survey in 2012, 28,000 grey seals were counted. A correction factor for Baltic grey seals has not been estimated, so this number does not include an unknown number of seals that have been at sea during the survey. However, the HELCOM seal expert group (2013) has recommend using a correction factor where 20-40% of the population is in the water during surveys. Taking the mean value (30%) this implies that 40,179 grey seals live in the Baltic Sea.

In the South-western Baltic, the grey seal breeding colonies disappeared around 1900 in Denmark and Sweden and around 1910 in Poland and Germany, as a result of the bounty campaigns (Søndergaard, Joensen, & Hansen, 1976), (Harding & Harkonen, 1999). Sightings at the traditional grey seal localities in Denmark were only sporadic between 1940 and 1975, except for Læsø and Rødsand, where a few individuals were regularly observed (Søndergaard, Joensen, & Hansen, 1976). During the recovery of the population, the range of the grey seals in the Baltic has expanded, and the numbers of grey seals in the South-western Baltic (Blekinge and Skåne in Sweden and the Danish Baltic have risen from the very few individuals to a total count of 1,000 individuals during the moulting survey in 2012 (HELCOM Seal, 2012).

For grey seals, Falsterbo is by far the most important haul-out in terms of the numbers of seals. Up to 576 (in 2011) grey seals have been recorded here, while at the second-most important haul-out at Rødsand the highest number recorded is 67 in 2008 (Unpublished data, Department of Bioscience, DCE, Aarhus University).

## 6.9 GPS tracking of seals

**Overall distribution pattern of harbour seals**

As seen from Figure 54, the different tagged seals show quite different movement patterns according to their preferred feeding areas as well as their age and the season (se details below). The Kriegers Flak concession area lies within the 95% kernel home range of the harbour seals, which means that the offshore wind farm will be placed in an area where the seals feed and migrate through. The overall 95% kernel home range of the harbour seals had a size of (5 234 $km^2$) of which the Kriegers Flak concession area (183 $km^2$) constitutes only 3.5%. However, the Kriegers Flak concession area is not equally important during all seasons or for all age groups, and not all seals are using the concession area, as can be seen from the sections on home range variability with age and season, provided below as well as the maps of the individual seal preferences (see Appendix 5).

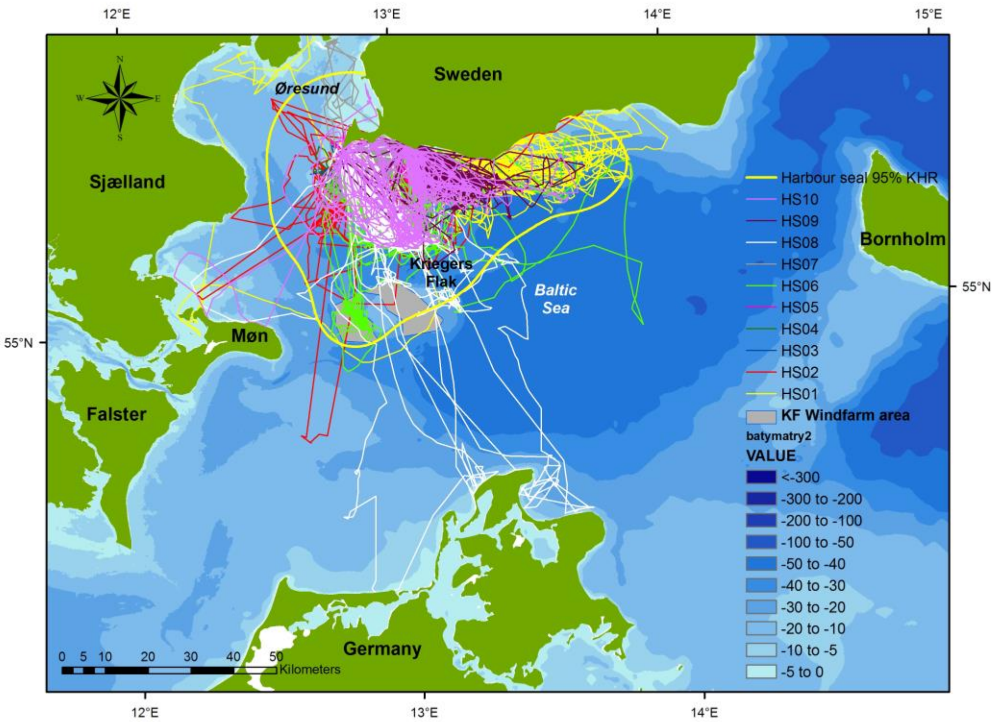



*Figure 54: Map showing the migration routes and the 95% kernel home ranges (yellow polygon) for 10 harbour seals tagged during the autumn 2012 at Måkläppen, Falsterbo.*

**Age-related differences**

As seen from Figure 55, there are age related differences in the distribution of the harbour seal. The 95% kernel home range of the yearling harbour seals is overlapping both the eastern and west parts of the concession areas. As seen from one of the tagged seals (HS08) subadult seals may move as far south as the northern coast of Germany. Based on the few adult animals tagged (n=2), the adult harbour seals stay closer to the haul-out sites as found in other studies as well and a larger percentage (50%) use the Sound region entering as far north as Saltholm compared to the yearlings (20%) and subadults (0%) (see Appendix 5). The daily mean distance (daily means was used to reduce the enormous dataset) to the haul-out site for three age groups and four seasons were analysed by a linear mixed effect model with individual seals as random (nested) variable. The model showed a significant interaction between age group and season ($p<0.001$), showing that the seals in different age groups were behaving differently during the individual seasons. No general conclusion could therefore be drawn regarding differences between age groups and between seasons.

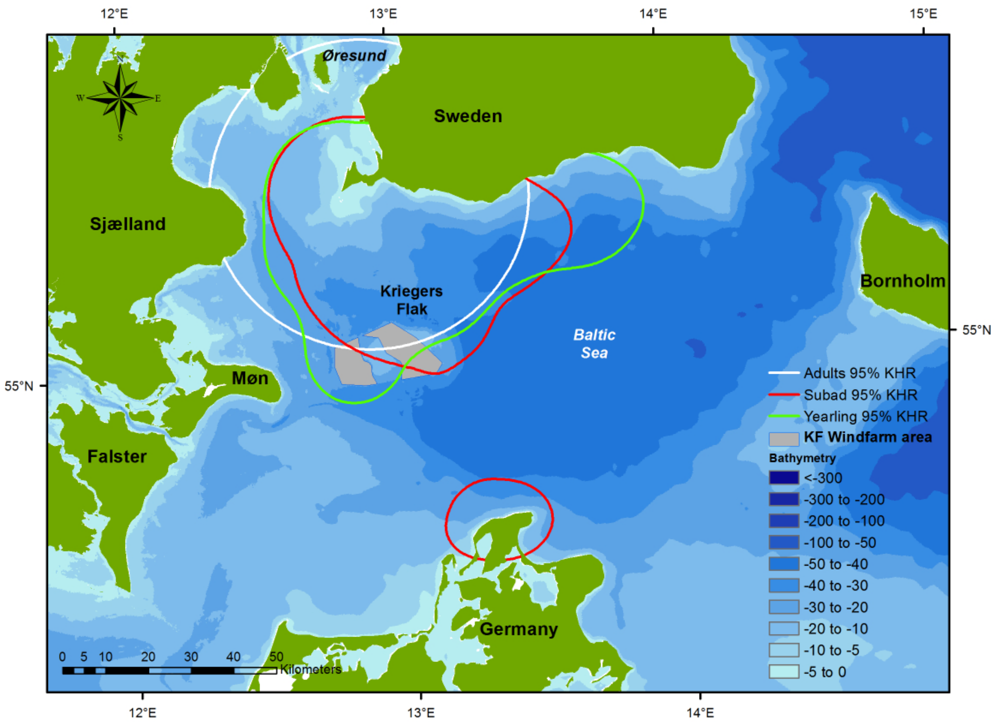



*Figure 55: Map showing the 95% kernel home ranges for the three age groups of the 10 harbour seals tagged during the autumn 2012 at Måkläppen, Falsterbo.*

**Seasonal distribution**

Seals were more stationary during summer and showed quite extensive movements during winter and spring. During spring, one harbour seal (HS08) moved as far south as the German north coast. The mixed effect modelling of the daily mean to the haul-out site for the four seasons proved to be highly significant (p<0.0001). The Kriegers Flak concession area was used during both winter and spring, whereas only few visits in the northern part of the Kriegers Flak area were recorded during autumn, and the area was not of importance at all during the summer.

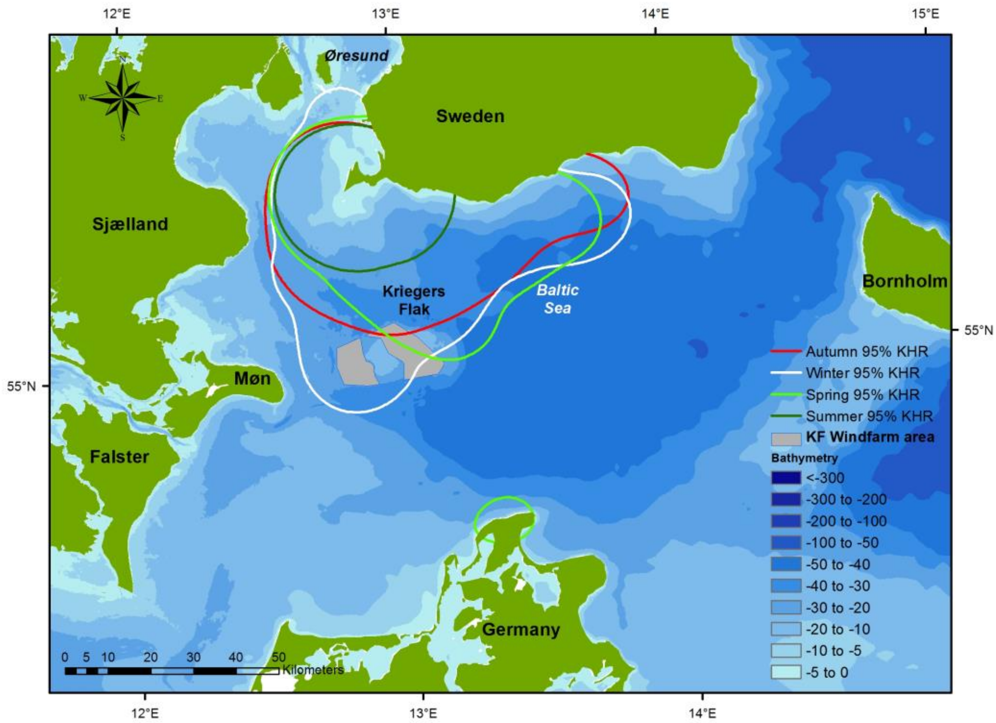



*Figure 56: Map showing the 95% kernel home ranges for four seasons (summer, autumn, winter and spring) of the 10 harbour seals tagged during the autumn 2012 at Måkläppen, Falsterbo.*

The travelled difference to the Falsterbo haul-out site used in the mixed effect modelling is depictured in Figure 57. In winter and spring all 3 age groups of harbour seals travel longer distances.

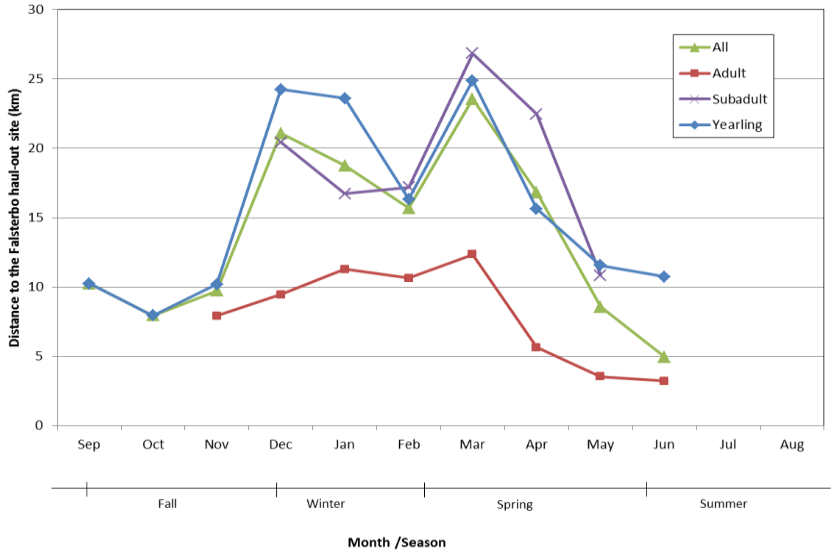



*Figure 57: Travelled distances from the Falsterbo haul-out site for harbour seals tagged for the Kriegers Flak EIA. With seasonal indications.*

**Harbour seals in the Kriegers Flak wind farm area**

Four out of the ten tracked harbour seals entered the Kriegers Flak wind farm area, namely HS01, HS02, HS06 and HS08 (Figure 58). Three of these were yearling seals and one was a subadult. None of the adult harbour seals (n=2) entered the area.

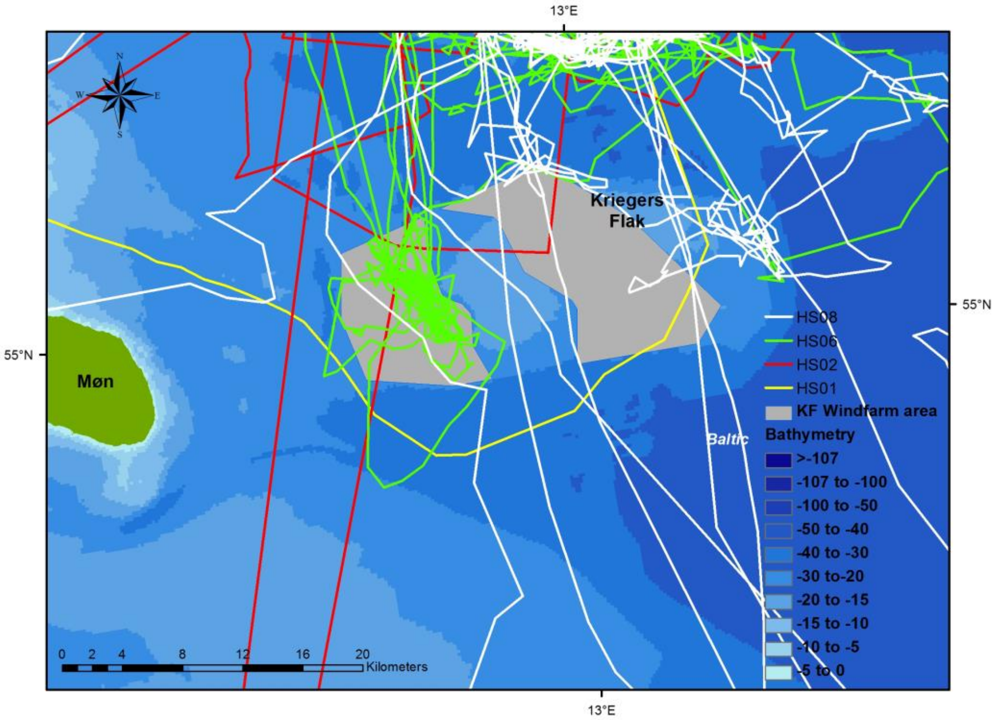



*Figure 58: Close op of the 4 harbour seals entering the Kriegers Flak wind farm concession.*

**Overall distribution pattern of grey seals**

As seen from Figure 59 the grey seals moved over considerable distances within the Baltic (see single tracks in Appendix 6). Like the harbour seals, the individual grey seals exhibited very different movement patterns. The overall 95% kernel home range of the grey seals included the Kriegers Flak area, but the concession area was rather small (183 $km^2$) compared to the 95% kernel home area (70 727 $km^2$) and hence of limited importance to the grey seals.

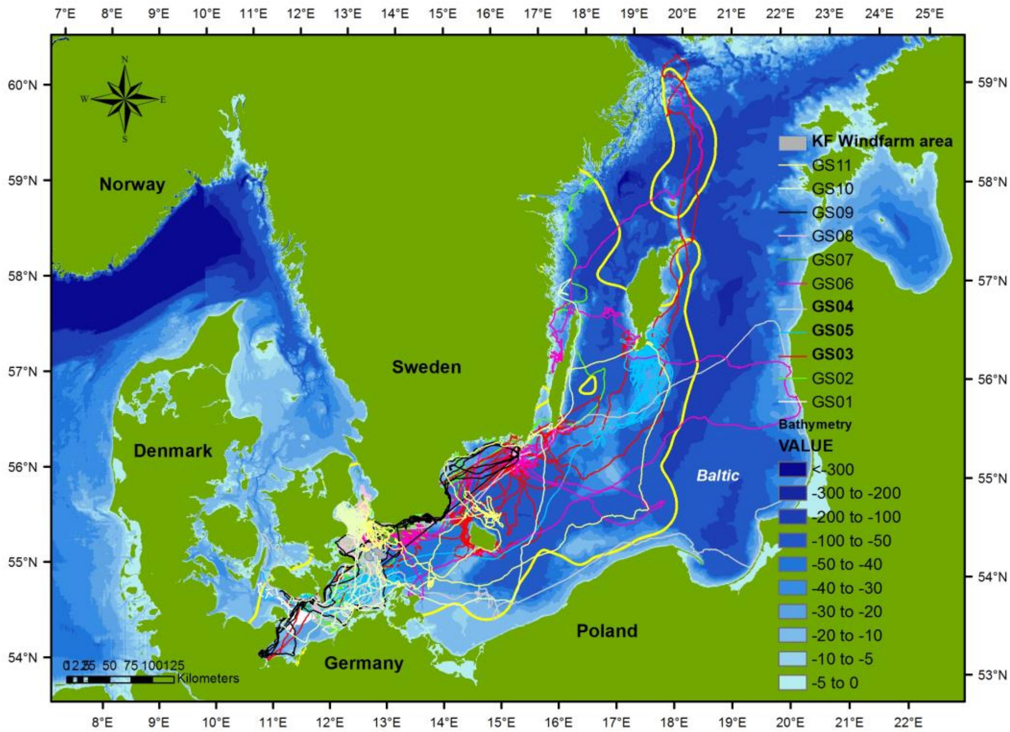



*Figure 59: Map showing the migration routes and the 95% kernel home ranges (yellow polygon) for 11 grey seals tagged between 2009 and 2012 at Flasterbo (n=5), Rødsand (n=5) and at Ålandsøerne (n=1).*

**Age-related differences**

Although the 95% kernel home range of the yearling grey seals was different from the subadult seals, no significant difference could be detected from the mixed effect modelling of the daily mean distance to the Falsterbo haul-out for the age groups (p=0.7936) (Figure 60). Given this information, as well as the very large home ranges covering the majority of the southern Baltic, the Kriegers Flak concession area is not likely to have detectable different effects on the different age groups throughout the year (however, see also section on seasonal distribution below). As no tracking data were available from adult grey seals, the importance of the concession area cannot be evaluated for adult grey seals.

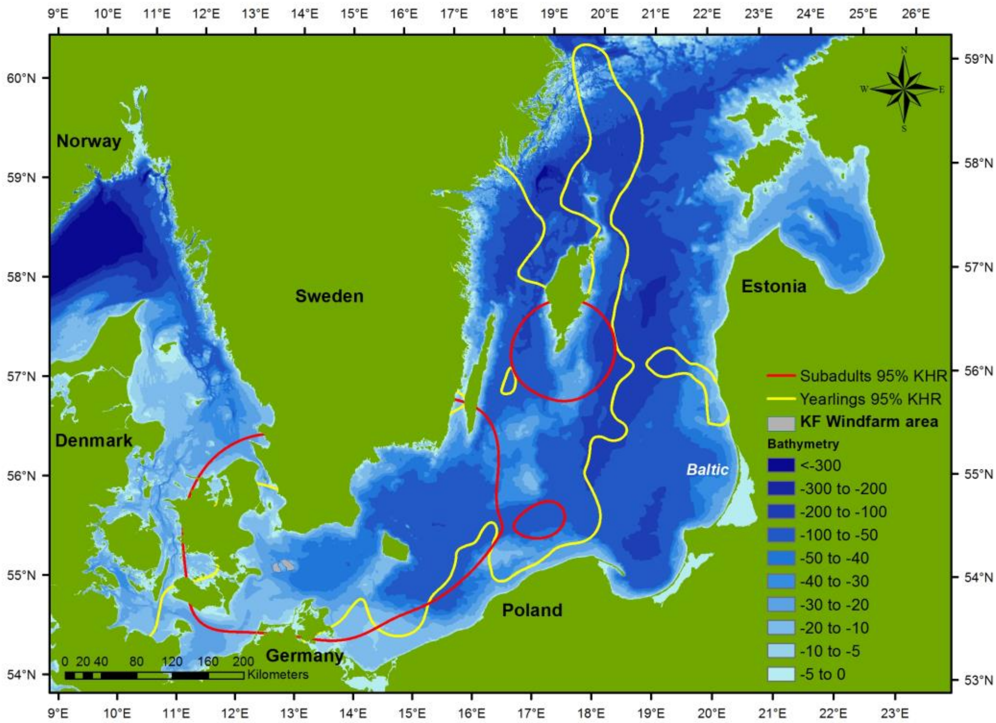



*Figure 60: Map showing the 95% kernel home ranges for the two age groups (Yellow: yearlings; Red: subadults) of the 11 grey seals tagged between 2009 and 2012.*

**Seasonal distribution**

In the mixed effect modelling of the daily mean of the distance to the haul-out site at Falsterbo, the four seasons proved to be significantly different ($p<0.0001$). Likewise, we found a significant effect ($p<0.0001$) of the interaction of age group and season, showing that the different age groups were behaving differently during different seasons. The Kriegers Flak concession area was used by the grey seals during all four seasons, but due to the large 95% kernel home ranges at all these seasons, the Kriegers Flak area made up a relatively small percentage of the entire range of the grey seals (Figure 61). The significant seasonal effect as well as the interaction between season and age is in concordance with the results of the harbour seals from Falsterbo and Anholt, although the ranges of the harbour seals are significantly smaller (Dietz, Teilmann, Andersen, Rigét, & Olsen (2012); this study).

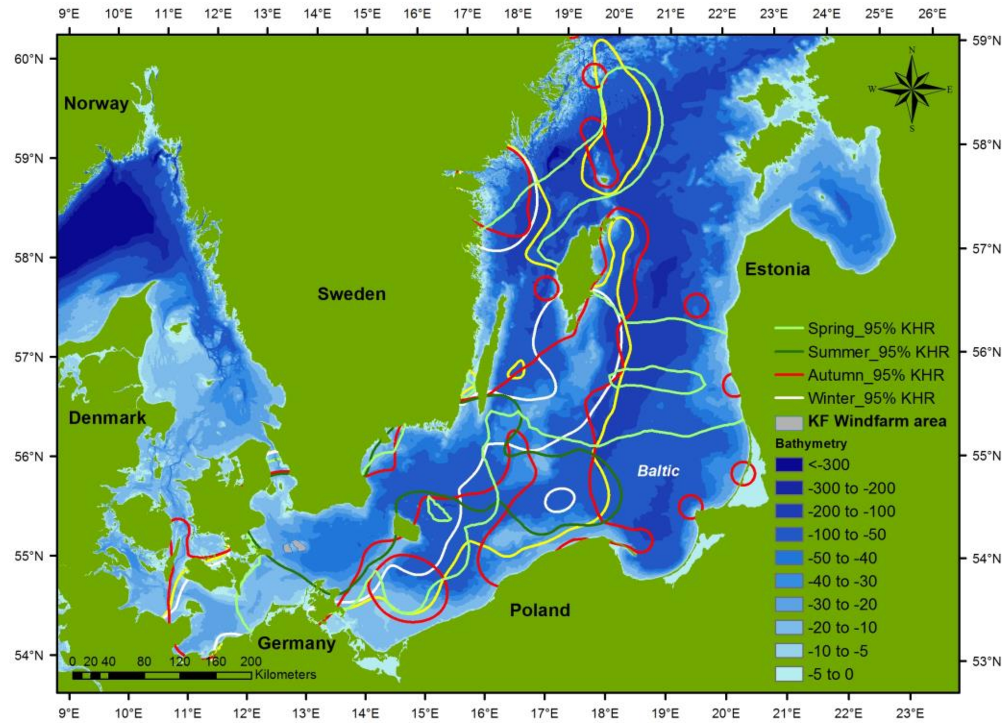



*Figure 61: Map showing the 95% kernel home ranges for four seasons (summer, autumn, winter and spring) of the 11 grey seals tagged between 2009 and 2012.*

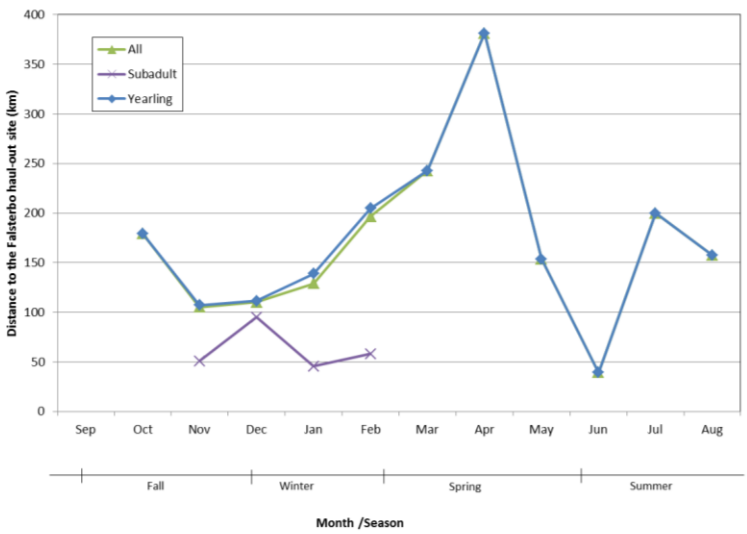



*Figure 62: Seasonal distances to the Falsterbo haul-out site for the tagged grey seals used in the present EIA.*

The grey seals were furthest away from the Falsterbo haul-out site and the Kriegers Flak during late winter and early spring (March and April). During this season, a previous study have documented that the grey seals tagged in Danish waters breed in Estonian waters (Dietz, Teilmann, Andersen, Rigét, & Olsen, 2012).

### Grey seals in the Kriegers Flak wind farm area

Sixty-four percent of the tracked grey seals actually entered the Kriegers Flak wind farm area, namely GS02, GS04, GS05, GS06, GS09, GS10 and GS11 (Figure 63). Six of these were yearling seals and one was a subadult, while no information was available from adult grey seals.

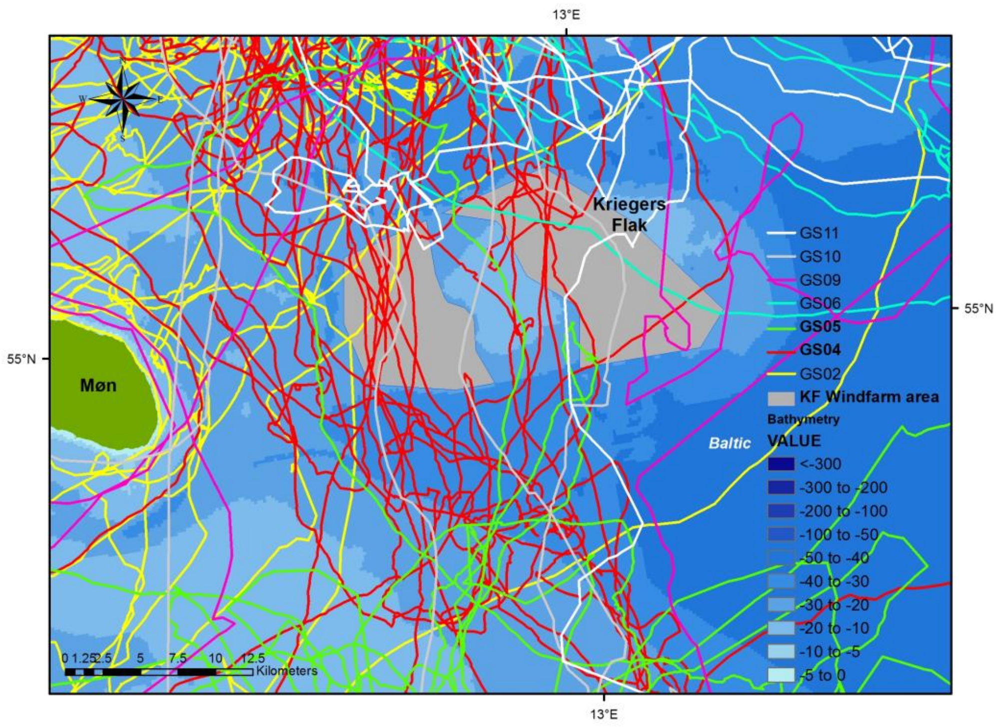



*Figure 63: Close up of the 7 grey seals (64%) entering Kriegers Flak wind farm concession area.*

**Harbour seal vs. grey seal distribution**

As documented by e.g. Dietz, Teilmann, Henriksen, & Laidre (2003), the harbour seal has a much more local distribution compared to the grey seal in the Baltic (Figure 64). In comparison, the 95% kernel home range of harbour seals (5,234 $km^2$) made up only 7.4% of the grey seal home range (70,727 $km^2$). This is also evident from the seasonal plot over the average monthly distances from the Falsterbo haul-out site extrapolated from the tracking data of the two seal species (Figure 65). A mixed effect modelling of the daily mean distance to the Falsterbo haul-out site of the grey seals proved to be significantly ($p<0.0001$) larger (mean range: 50-400 km) than that of the harbour seals (means ranges < 25 km). The grey seals range between most regions of the Baltic and are hence less susceptible to local disturbances than the harbour seals. Thus grey seals have alternatives to foraging sites, haul-outs and mating grounds, to a much higher extent than the harbour seal.

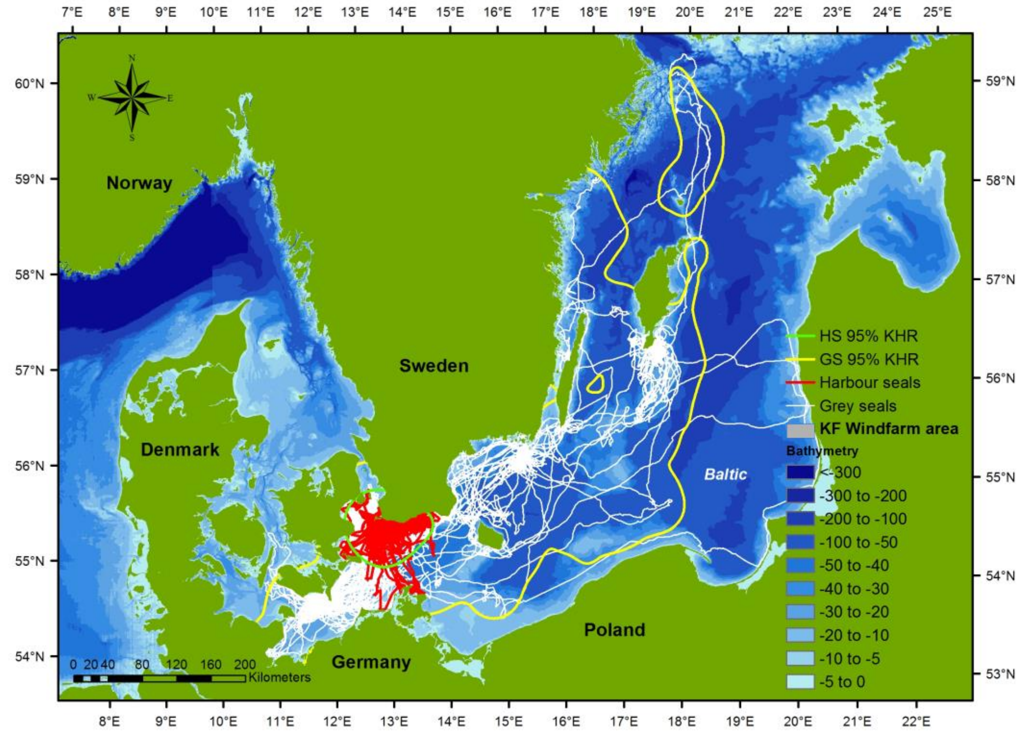



*Figure 64: Migration routes and the 95% kernel home ranges for the 10 harbour seals tagged during the autumn 2012 and 11 grey seals tagged between 2009 and 2012.*

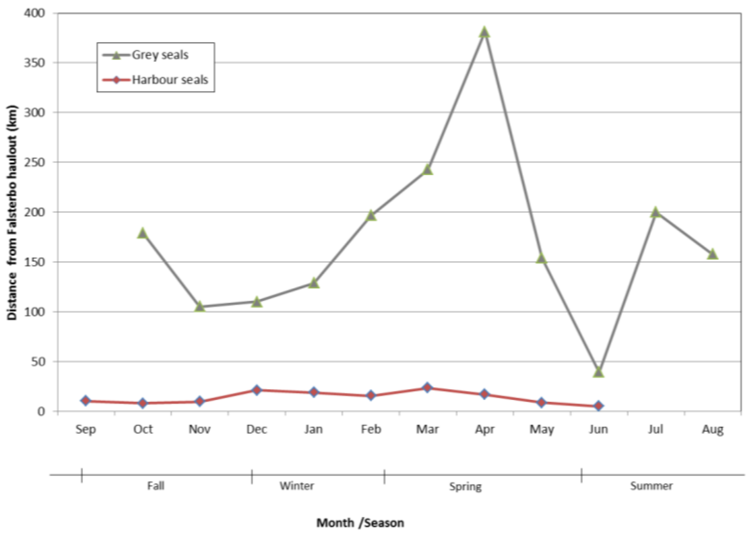



*Figure 65: Monthly mean distances to the Falsterbo haul-out site for harbour and grey seal.*

## 6.10 Modelling the distribution and habitat use of seals

### Selection of area-restricted search scale

The spatial scale at which seals focused their search effort varied among individuals. Only some spent a large part of their time within areas of a particular size. These animals usually stayed within one or a few relatively well-confined areas of the same size. When the area used for calculating residence time was increased to cover larger areas, it did not cause the residence time estimates to increase further (e.g. approx. 6 000 m for pv46-07-12; Figure 66). Other seals spent their time moving between different haul-out sites and foraging grounds and searched for food at varying spatial scales. The seals that mostly spent time within areas of a fixed size stayed within areas with a radius of 7 000 m, and circles with this radius were therefore used for calculating residence times throughout.

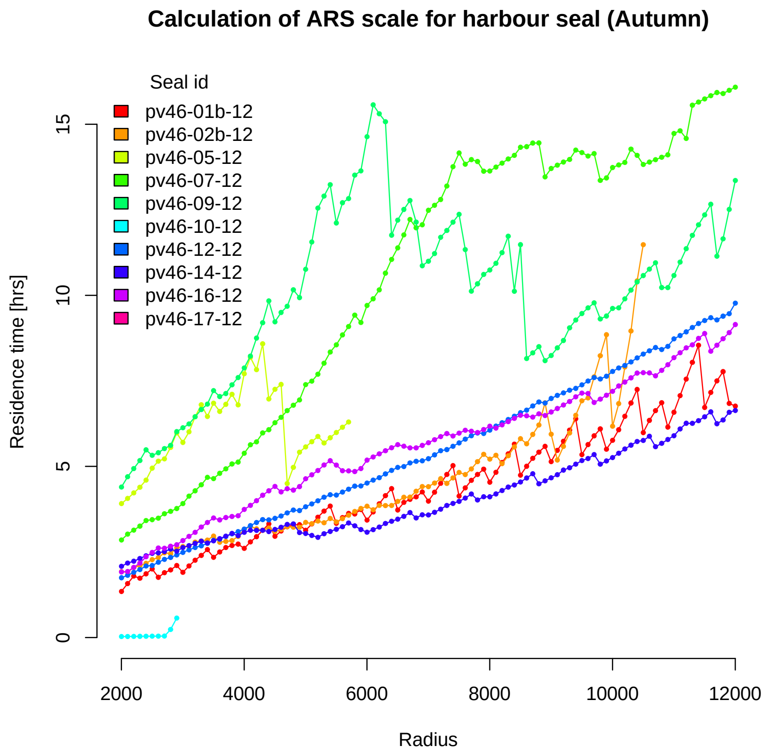



*Figure 66: Selection of the radius used for calculating residence times (the Area Restricted Search scale; ARS scale) as the radius where the residence times ceased to increase.*

**Characterization of areas with high search effort/residence time**

Both harbour seals and grey seals focused their search effort in areas with particular environmental conditions. For harbour seal, models fitted best in the autumn where tracks with residence time estimates covered most parts of the area between Sweden and Germany ($R^2$=0.31 for the full model). During winter and spring, tracks with high residence time were found only in the vicinity of the Swedish coast (Figure 68). During summer, the harbour seal model was fitted based on only seven interpolated positions from a single track, and the results therefore only have very little general value. For grey seal the environmental variables included in the generalized additive models explained up to 33% of the variation in residence time (Table 12; $R^2$=0.33 for the full model in the spring), and the models fitted well for all seasons.

The models that included all variables were always the most parsimonious (Table 12, full models had lowest AIC). Models that only included fixed, visible characteristics of the habitats or only included hydrodynamic variables fitted more poorly, even when taking into account that the full model included more parameters. For grey seals, the correlation between the predicted and observed residence times varied between 0.47–0.59 during autumn, winter and spring, but dropped to 0.12 in the summer (Pearson correlations; predictions from full GAM models). For harbour seals the corresponding correlations varied between 0.14 (in winter) and 0.34 (in the spring).

*Table 12: Selection of generalized additive model for prediction of seal residence times based on the Akaike Information Criterion (AIC). Five different models were compared for each species and season (see text for details). The full model was the most parsimonious in all cases and was therefore used throughout. The results for harbour seal during summer should be excluded due to insufficient data.*

| | Autumn | | | | Winter | | | | Spring | | | | Summer | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Harbour seal** | | | | | | | | | | | | | | | | |
| **Model name** | **AIC** | **Delta i** | **$w_i$** | **$R^2$** | **AIC** | **Delta i** | **$w_i$** | **$R^2$** | **AIC** | **Delta i** | **$w_i$** | **$R^2$** | **AIC** | **Delta i** | **$w_i$** | **$R^2$** |
| Full model | 8140 | 0 | 1.00 | 0.31 | 19329 | 0 | 1.00 | 0.11 | 17316 | 0 | 1.00 | 0.11 | 17316 | 17324 | 0.00 | 0.11 |
| Bathy only | 8476 | 336 | 0.00 | 0.00 | 19599 | 270 | 0.00 | 0.00 | 17496 | 180 | 0.00 | 0.02 | 30 | 38 | 0.00 | 0.63 |
| Bathy, hauldist and AIS | 8380 | 240 | 0.00 | 0.10 | 19583 | 254 | 0.00 | 0.01 | 17422 | 106 | 0.00 | 0.06 | 25 | 34 | 0.00 | 0.81 |
| All static vars | 8260 | 120 | 0.00 | 0.20 | 19555 | 226 | 0.00 | 0.02 | 17401 | 85 | 0.00 | 0.07 | -9 | 0 | 1.00 | 1.00 |
| All dynamic only | 8217 | 77 | 0.00 | 0.24 | 19399 | 70 | 0.00 | 0.08 | 17370 | 54 | 0.00 | 0.08 | 17370 | 17378 | 0.00 | 0.08 |
| **Grey seal** | | | | | | | | | | | | | | | | |
| **Model name** | **AIC** | **Delta i** | **$w_i$** | **$R^2$** | **AIC** | **Delta i** | **$w_i$** | **$R^2$** | **AIC** | **Delta i** | **$w_i$** | **$R^2$** | **AIC** | **Delta i** | **$w_i$** | **$R^2$** |
| Full model | 80463 | 0 | 1.00 | 0.32 | 171497 | 0 | 1.00 | 0.30 | 32215 | 0 | 1.00 | 0.33 | 11968 | 0 | 1.00 | 0.30 |
| Bathy only | 82856 | 2393 | 0.00 | 0.11 | 175260 | 3763 | 0.00 | 0.11 | 33840 | 1626 | 0.00 | 0.05 | 12311 | 343 | 0.00 | 0.06 |
| Bathy, hauldist and AIS | 82537 | 2074 | 0.00 | 0.15 | 173971 | 2474 | 0.00 | 0.18 | 33764 | 1549 | 0.00 | 0.08 | 12258 | 290 | 0.00 | 0.10 |
| All static vars | 82345 | 1882 | 0.00 | 0.17 | 173788 | 2291 | 0.00 | 0.19 | 33484 | 1270 | 0.00 | 0.14 | 12114 | 146 | 0.00 | 0.20 |
| All dynamic only | 81505 | 1042 | 0.00 | 0.23 | 173228 | 1731 | 0.00 | 0.21 | 32471 | 257 | 0.00 | 0.27 | 12208 | 240 | 0.00 | 0.14 |

The relationship between residence time and the individual environmental parameters was complex (Figure 67). Harbour seals tended to focus their search effort in the relatively deep waters close to their haul-out sites and in areas with a low surface temperature, at least during autumn at which time the model fitted well. The grey seals tended to focus their search effort in areas relatively close to the coast in the spring, but during all other seasons their search effort was particularly high in areas with low salinity (top and bottom), particularly close to their haul-out sites. The spatial distribution of areas with low salinity varied among seasons.

The GAM models were tested using separate Pearson correlation tests for each species and season. Correlation coefficients varied between 0.12 (for grey seals during summer) and 0.59 (for grey seals in autumn), with the all but two of the correlation coefficients being ≥0.26.

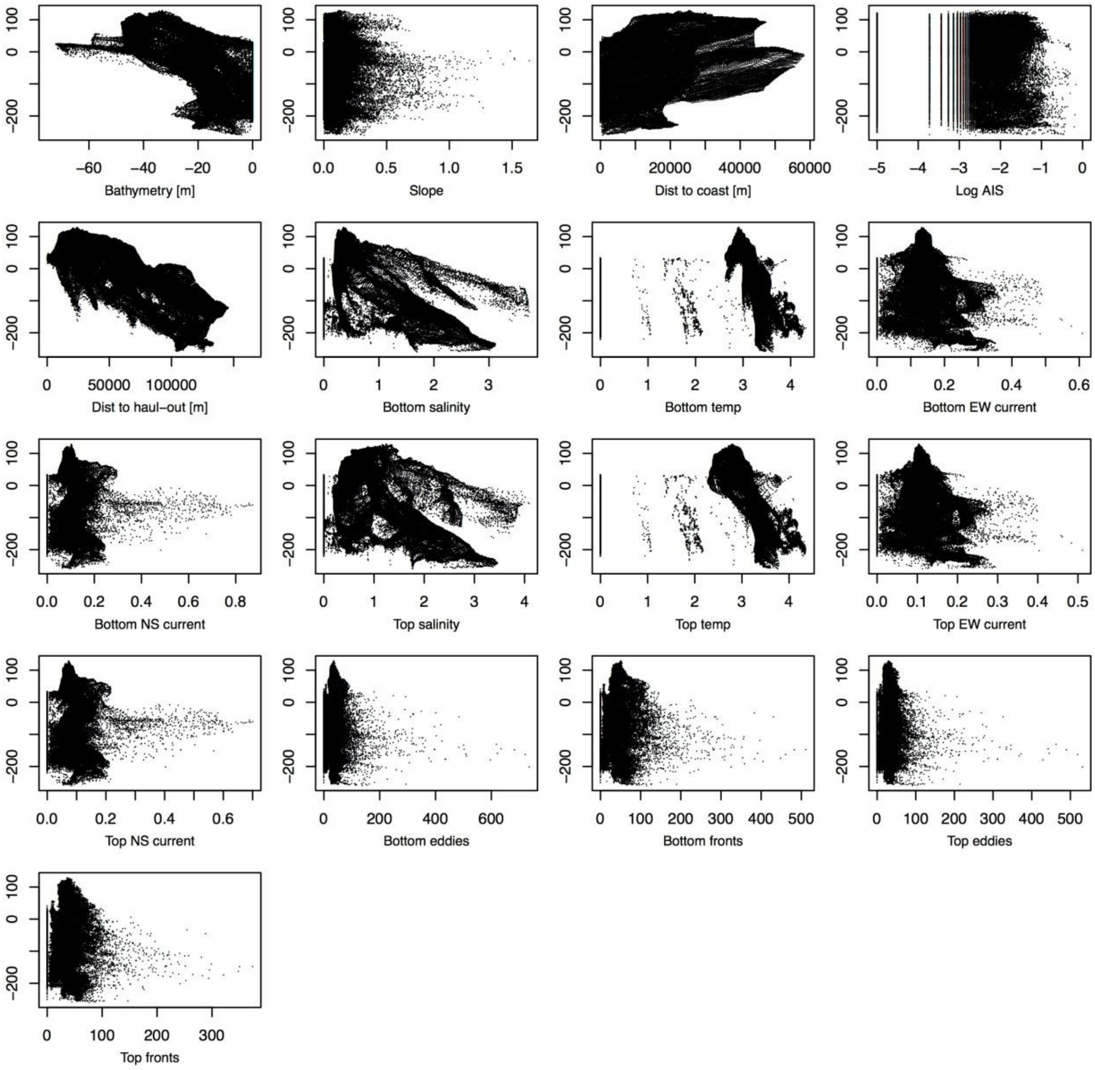



*Figure 67: Relationship between predicted residence times (in hours) and each of the environmental variables in the full GAM model (on the x-axes) based on model for harbour seals in the autumn. Model predictions are shown for the entire research area (cf. Figure 18), i.e. extrapolated beyond the area where seals occur. Seals are only predicted to occur in areas with residence times >0 hrs.*

**Predicting areas with high value for seals**

For harbour seals, the most intensively used areas were located north of the Kriegers construction site during autumn and somewhat more to the east during winter (Figure 68). In the spring, the most intensely used areas were located close to the coast. The distribution of the harbour seals was more limited than that of the grey seals, and residence times were therefore only predicted close to the Swedish coast during autumn and winter.

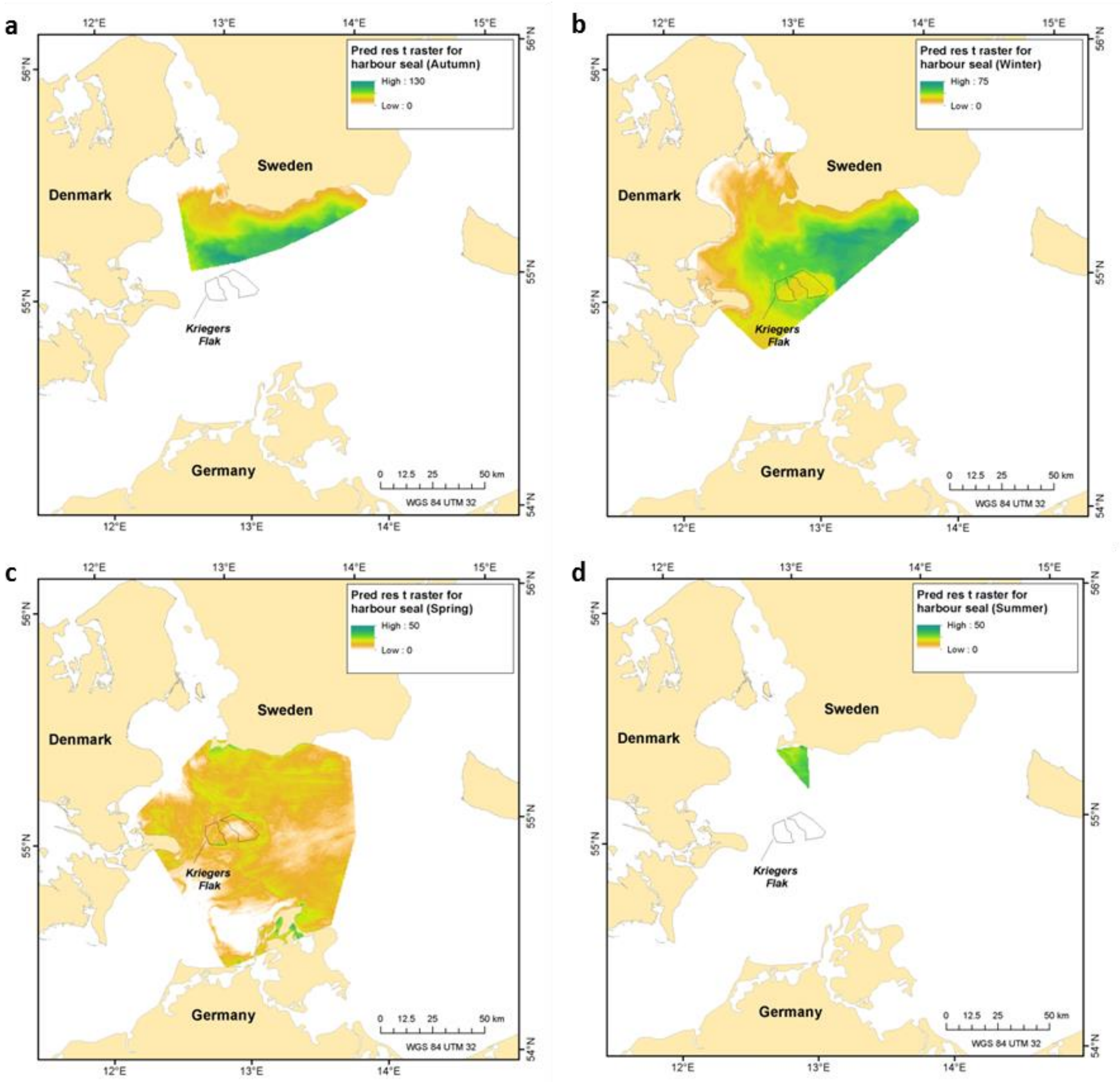



*Figure 68: Predicted residence times for harbour seals (a: autumn, b: winter, c: spring, d: summer). All predictions are based on the full generalized additive models. The one for summer is based on very few observed positions.*

For the grey seals, the areas that were predicted to be intensely used were mostly located along the coasts of Sweden and Germany, but also in the relatively shallow waters in the northern part of the Kriegers construction site and just north and east of the site (Figure 69). As the grey seals moved over most of the studied area between Sweden, Germany and Denmark, predicted values could be produced for most of the area for most seasons without extending the predictions outside the area used for parameterizing the model. Their movements were, however, restricted to the area closest to Sweden during summer causing the area with predicted residence times to be smaller during this season.

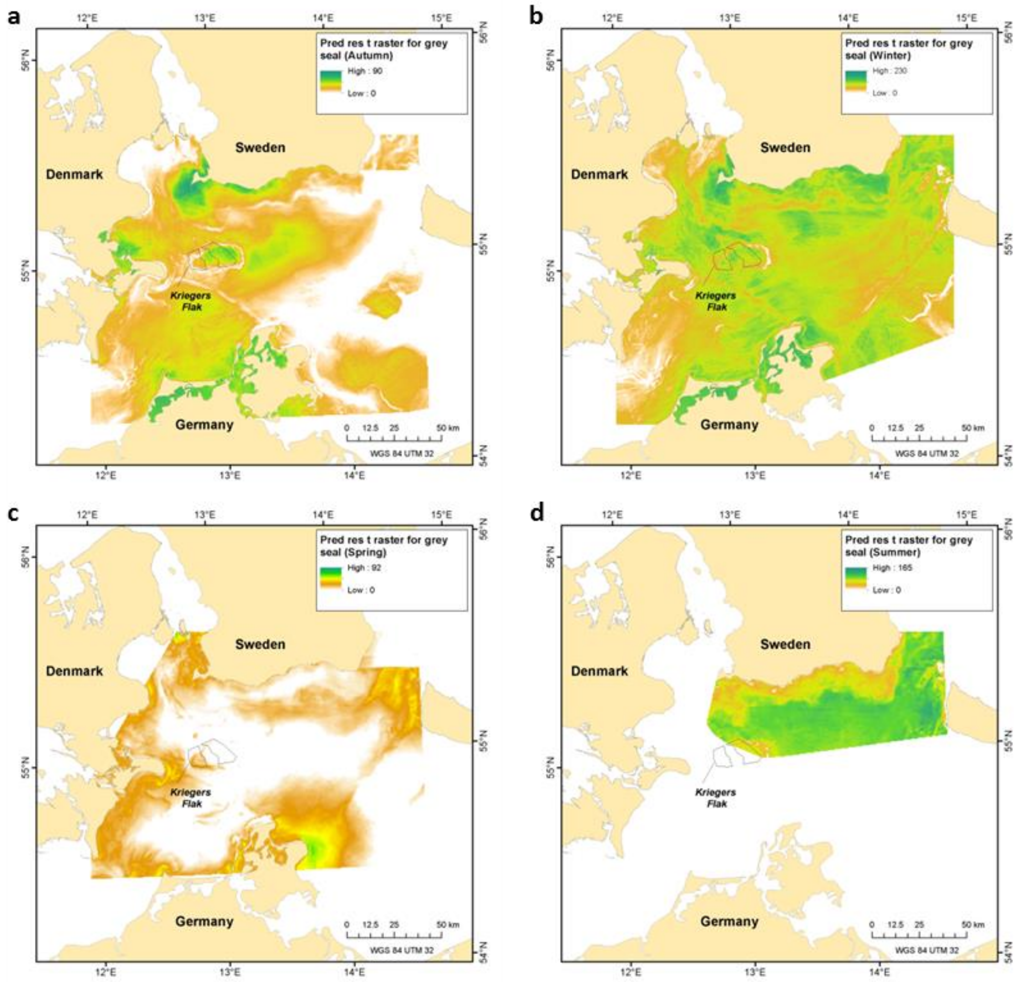



*Figure 69: Predicted residence times for grey seal (A: autumn, B: winter, C: spring, D: summer). All predictions are based on the full generalized additive models.*

## 6.11 Population sizes relevant for the impact assessment

**Harbour porpoises**

Genetics, morphometrics and tagging information show that there is a population within the Kattegat, Belt Seas and Western Baltic limited somewhere in Kattegat and probably just east of Kriegers Flak (Wiemann, et al., 2010), (Galatius, Kinze, & Teilmann, 2011), (Sveegaard, et al., 2011). Based on the MiniSCANS ship survey described above, Viquerat, et al. (2013) estimated the absolute porpoise abundance within this area to be 40,475 animals (95 % CI 25,614–65,041, CV = 0.235). Although there is some debate regarding the population borders, this estimate will be used as the reference population for the Kriegers Flak area.

The population of porpoises in the Baltic Sea proper has diminished over the past decade for unknown reasons (Benke, et al., 2014). No abundance estimate and spatial distribution of this population is available. The SAMBAH EU LIFE+ project (ends in 2015) will provide information on this population. Until then, an unknown proportion of the Baltic proper porpoise population will be affected by the Kriegers Flak wind farm.

**Grey seals**

It is known that the grey seals in the North Sea belong to a different population that breeds during a different time of year and probably never enters the Baltic Sea (Härkönen, Brasseur, Teilmann, & Vincent, 2007). Therefore, only the Baltic Sea grey seal population should be considered a part of the Kriegers Flak area. At the same time there is no detailed genetic information on population structure within the Baltic Sea (Fietz, Graves, & Olsen, 2013), but the tagged grey seals in Bothnian Bay have never moved to the southern Baltic Sea and none of the tagged seals in the southern Baltic have moved to the Bothnian Bay. So for this assessment, we will use both the number for the southern Baltic Sea for a precautionary approach (until Ålandsøerne, N=29 633 grey seals) and the entire Baltic Sea (N=42 179 grey seals). These numbers include a best guess of the proportion of animals in the water during the surveys counting seals on land of 30% (HELCOM Seal 2013).

**Harbour seals**

Harbour seals in the Western Baltic Sea are considered a separate population and the total abundance estimate was 1 563 in 2013 ( (Olsen M. , et al., 2010), DCE unpubl. results). Harbour seals are extremely conservative where they feed and breed and seldom move more than 50-100 km from where they were born (Dietz et al. 2012). According to new genetic information (Olsen M. , Andersen, Dietz, Teilmann, & Härkönen, 2014) and the fact that there was no mixing of the tagged harbour seals east and west of Gedser, it is reasonable to believe that the harbour seals in the waters around Kriegers Flak constitute a discrete unit. We therefore also include the total estimated abundance for this area (N=460) as a precautionary approach. All abundance estimates are corrected for seals in the water during the survey time (43%) according to (Harkonen, 1999).

# 7 Assessment of effects in the construction period

In order to assess the effect of construction on harbour porpoises, harbour seals and grey seals, studies of other wind farms will be taken into account. The impact studies conducted in connection to construction of Nysted Offshore Wind Farm, Rødsand 2 Offshore Wind Farm and Horns Rev I and II Offshore Wind Farms will be reviewed as well as studies from wind farms in the Belgian North Sea. The impact ranges will then be determined, based on results of the noise modelling conducted as part of the EIA (NIRAS, 2014) and the recommendations of exposure limit values made by the Working Group (2015) based on studies of behavioural changes and physical injury. These recommendations were assessed for Kriegers Flak in DCE, DHI, & NIRAS (2015). After agreement with Energinet.dk only the worst case scenario will be assessed in depth. The worst case was judged to be pile driving of 10 MW wind turbine foundation.

## 7.1 Likely effects of construction on harbour porpoises

**Gravitational foundations**

The Nysted Offshore Wind Farm was constructed in June 2002 – Nov 2003 and consists of 72 turbines placed on gravitational foundations with a sheet pile wall vibrated in to the seabed to support one foundation. During construction, the presence of porpoises and effect of construction and operation were quantified by T-PODs deployed inside the wind farm area and in a nearby reference area (Figure 70) (Carstensen, Henriksen, & Teilmann, 2006).

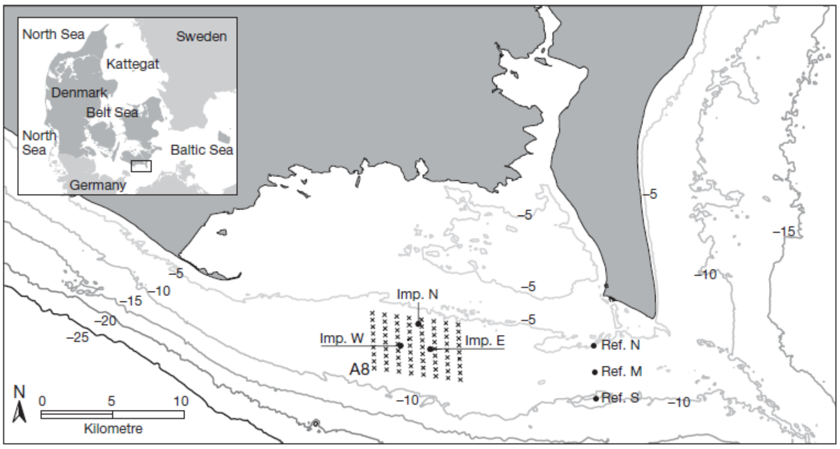



*Figure 70: Layout of T-POD measuring stations within Nysted Offshore Wind Farm and reference area (Carstensen, Henriksen, & Teilmann, 2006).*

The T-PODs recorded and stored the time and duration of echolocation clicks from harbour porpoises and provided semi-continuous records of porpoise abundance from a period before construction began and through the construction period. Relative differences between the wind farm and a reference area were tested by comparing the baseline activity with activity recorded during construction and operation (see also chapter 8). Two statistical indicators related to porpoise abundance were extracted: PPM (Porpoise Positive Minutes, the number of minutes per day where porpoise clicks was detected, equal to DPM – detection positive minutes); Waiting time (time between groups of associated echolocation clicks, this measure indicates how often porpoises enter the area. During the baseline period, there was no difference in waiting time and number of porpoise positive minutes between the reference and impact area (Figure 78).

During construction, waiting time increased and porpoise positive minutes decreased considerably in the wind farm area (Figure 71), indicating that fewer porpoises were present in the wind farm area during these periods. During baseline, porpoises were encountered at the T-PODs inside the wind farm area on average more than twice per day before construction, which decreased to less than once every second day during construction, i.e. a fourfold decrease in abundance, if waiting time is used as proxy for animal density. Measured on porpoise positive minutes, there was a more than 10-fold decrease in acoustic activity during construction, as compared to baseline conditions.

A smaller, yet still significant increase in waiting time and decrease in porpoise positive minutes was also observed in the reference area, possibly signifying a general effect of the wind farm construction on porpoises at least 10 km away from the Nysted Offshore Wind Farm (Figure 78). It is unclear what factor was responsible for deterring porpoises from the wind farm site during construction, although noise is likely a significantly contributing factor. As pointed out by Carstensen, Henriksen, & Teilmann (2006), the seabed at one of the turbines had to be stabilised with steel sheet piles that were driven into the sediments using a pile driver and a barge-mounted vibrator. This activity occurred intermittently during the construction period and may have caused the adverse effects.

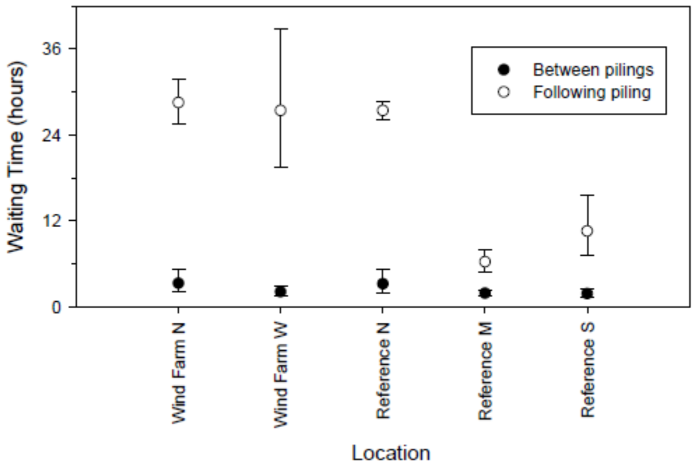



*Figure 71: Waiting time between acoustic encounters of porpoises recorded at two stations inside Nysted Offshore Wind Farm and at three stations in a reference area 15 km east of the wind farm (Tougaard & Teilmann, 2007).*

**Steel driven monopiles**

A significant impact is predicted if steel monopiles are selected as foundations for the turbines. Pile driving of steel monopiles represents a significant source of high intensity underwater noise (see Figure 9). Although it is difficult to extrapolate sound levels out to greater distances, the high levels and the presence of significant energy at high frequencies would predict the sounds to be clearly audible to porpoises and seals and thus, also potentially able to interfere with their behaviour at distances of tens of kilometres and possibly more.

The Horns Reef II Offshore Wind Farm was constructed in 2008 northwest of the Horns Reef I Offshore Wind Farm (Figure 72). The wind farm consists of 92 2.3 MW wind turbines supported by monopile foundations. The piles had a diameter of 3.9 m, were 30 to 40 m long, had a wall thickness of 25 to 88 mm, weighed 170 to 210 t, and were driven into the seabed to depths of 20 to 25 m.

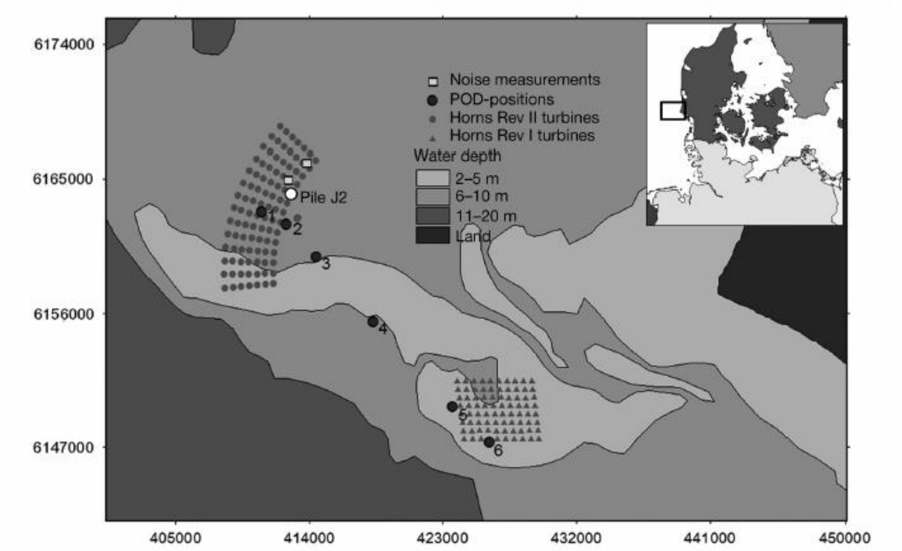



*Figure 72: Shows the positions of the wind turbines of the wind farm Horns Reef II to the NW, and the position of the wind farm Horns Reef I to the SE that was already installed. Black dots indicate positions of the T-PODs (1-6). White squares indicate the positions where noise measurements were conducted during pile driving of monopile J2 (Brandt, Diederich, Betke, & Nels, 2011).*

Brandt, Diederich, Betke, & Nels (2011) measured porpoise activity as PPM/h (Porpoise Positive Minutes per hour, which gives the number of minutes per hour where a porpoise was detected) at several distances from the pile driving (see Figure 72 and Table 13). They found a negative response to the pile driving out to a distance of 18 km. Porpoise activity decreased significantly during the construction period (19 May – 7 Sept 2008) as compared to the baseline period (8 Apr – 18 May 2008) at POD positions 1, 2 and 3, but not at positions 5 and 6 (Table 13). No baseline data were available at position 4 due to equipment loss. The duration of the effect of pile driving lasted between 17 and 72 hours at the first five positions (Table 13). They found no negative affect at the POD station 21.2 km away from the pile driving. This might indicate that porpoises exhibit no behavioural response at this distance or that porpoises from the nearer locations were displaced to this position.

*Table 13: Distances of POD position and the duration of pile driving effect on PPM/h (porpoise positive minutes per hour) as found in their GAM model. (Brandt, Diederich, Betke, & Nels, 2011)*

| POD position | Mean distance (km) | Duration of pile driving effect on PPM/h (h) |
|---|---|---|
| 1 | 2.5 | 24 – 72 |
| 2 | 3.2 | 18 – 40 |
| 3 | 4.8 | 17 – 42 |
| 4 | 10.1 | 9 – 21 |
| 5 | 17.8 | 10 – 23 |
| 6 | 21.2 | 0 |

At Horns Reef I Offshore Wind Farm, located next to Horns Reef II (see Figure 72), a similar study with T-PODs was conducted to examine the effects of construction here (Tougaard, Carstensen, Teilmann, Skov, & Rasmussen, 2009). Animals returned within 4-5 hours following piling at Horns Reef I compared to average between 17 and 72 hours at Horns Reef II. However, porpoises at the reference station furthest away from the pile driving (21 km west of the wind farm) were affected to the same degree as porpoises inside the construction site. This implies that monopile pile drivings can affect porpoise behaviour and probably deter the animals from a very large area surrounding the pile driving site. In general, animals returned much faster to the Horns Reef wind farms compared to Nysted Offshore Wind Farm. This is probably related to the generally higher density of animals in the Horns Reef area also a considerably more dynamic distribution of the animals.

**Jacket foundations**

The piling work required for installation of jacket foundation involves piling of three or four pinpiles. The dimensions of these pinpiles are smaller than a single monopile and hence the generated sound source level should necessarily be lower (see Figure 10). Norro, Rumes, & Degraer (2013) made a comparative study of the underwater construction noise of steel monopiles and jackets foundations requiring four steel pinpiles. Both have been applied at wind farms in the Belgian part of the North Sea, i.e. at the Blighbank and the Thorntonbank wind farms. The dimensions of the two types of piling activities can be seen in Table 14. The jacket pinpiles have a smaller diameter, are generally shorter and therefore less energy per stroke is needed, however, the number of strokes required per foundation is much higher since four legs are needed and thus the sound emission period is much longer.

*Table 14: Summary statistics of the piling activities of monopile A02 and B10 and jacket foundations G3 and B6, as well as the averages and total (where appropriate) for the 56 monopiles installed at the Blighbank and the 49 jacket installed on the Thorntonbank (Norro, Rumes, & Degraer, 2013).*

| | Monopile piling activities (pile diameter = 5 m) | | | | | Jacket piling activities (pinepile diameter = 1.8 m) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Unit | A02 | B10 | Average | Total | Unit | G3 | B6 | Average | Total |
| Pile length | m | 55 | 63 | 54 | | m | 48 | 21 | 37 | — |
| Mass | t | 401 | 453 | 375 | | t | 96 | 46 | 77 | — |
| Number of strokes required | | 2114 | 3848 | 2982 | 168550 | | 13321 | 4288 | 9476 | 464328 |
| Average energy per stroke | kJ | 642 | 839 | 706 | | kJ | 436 | 321 | 412 | |
| Duration of piling | min | 64 | 163 | 120 | 6779 | min | 405 | 162 | 319 | 15646 |
| Net piling frequency | Number of strokes/minute | 42 | 39 | 40 | | Number of strokes/minute | About 40 | About 40 | | |
| Total energy | MJ | 1356 | 3224 | 2084 | 118909 | MJ | 5805 | 1376 | 3909 | 191531 |

The underwater noise from the constructions was measured at various distances (250–14000 m) from the pile driving locations with a hydrophone at 10 m depth. The highest normalised $L_{z-p}$ (zero to peak sound pressure level, normalised or back calculated from recordings made from various distances) of 194 dB re 1 $\mu$Pa was observed at 750 m distance for the piling of the B10 monopile at the Blighbank, while for the piling of the jacket pinpiles a maximum of 189 dB re 1 $\mu$Pa at 750m was observed (G3) at the Thorntonbank (Table 14). For both types of piling, the highest noise levels were emitted between 60 to 2000Hz, well into the hearing range of both porpoises (Figure 20) and seals (Figure 48). Normalized mean SEL values at 750 m was found to be similar from the two types, whereas the max SEL found was from the jacket G3, this was at most 12 dB higher compared to the monopiles. On average, the jackets required three times more blows than monopiles, equivalent to 58% more blows per MW (Table 15, Right). Also, the average pile time was 2.5 times longer per foundation and the resulting energy used for the 49 jacket foundations was just above 0.19 TJ compared to 0.12 TJ for the 56 monopile foundations. More energy was produced and transmitted to the environment with the jacket foundations.

*Table 15: Left: Normalized @ 750m zero to peak sound pressure level ($L_{z-p}$) in dB re 1µPa. Normalized @ 750m mean and maximum sound exposure levels (SEL) in dB re 1 µPa2s. Right: Characterization of the monopile and jacket piling activities. Normalized maximum sound exposure level (norm. max. SEL @ 750 m) (Norro, Rumes, & Degraer, 2013).*

| | Record | Norm. $L_{z-p}$ @ 750 m | Norm. mean SEL @ 750 m | Norm. max. SEL @ 750 m |
|---|---|---|---|---|
| Monopile A02 | 1 | 186 | 161 | 164 |
| | 2 | 189 | 164 | 166 |
| | 3 | 180 | 160 | 164 |
| Monopile B10 | 1 | 194 | 162 | 166 |
| | 2 | 190 | 168 | 162 |
| | 3 | 179 | 163 | 166 |
| Jacket CG3 | 1 | 185 | 168 | 174 |
| | 2 | 189 | 168 | 178 |
| | 3 | 186 | 168 | 175 |
| Jacket CB6 | 1 | 180 | 155 | 159 |
| | 2 | 172 | 145 | 151 |
| | 3 | 176 | 150 | 152 |
| | 4 | 180 | 152 | 157 |

| Foundation type | Monopile (3 MW) | Jacket (6 MW) |
|---|---|---|
| Average no. of blow/foundation | 3010 | 9476 |
| Average no. of blow/MW installed | 1021 | 1612 |
| Average energy (MJ)/blow | 0.7 | 0.4 |
| Average energy (MJ)/foundation | 2123 | 3909 |
| Average energy (MJ)/MW installed | 721 | 665 |
| Norm. max. SEL @750 m (dB re 1 $\mu Pa^2 s$) | 166 | 178 |
| Average duration of piling (min)/foundation | 120 | 319 |
| Average duration of piling (min)/MW installed | 41 | 55 |
| Average piling frequency (blow/min) | 25 | 30 |

**Power cable to land**

The proposed cable connecting Kriegers Flak Offshore Wind Farm to land as indicated on Figure 1 is passing through some important areas for harbour porpoises and for the seals in some seasons, still, compared to the impact from pile driving the disturbances from laying the cable is considered to be much smaller.

**Increased boat traffic**

Small fast ships such as barges and supply ships produce noise with energy content primarily below 1 kHz (Richardson W. J., Greene, Malme, & Thomson, 1995). However, as there may still be considerable energy at frequencies above 1 kHz, and harbour porpoise hearing is more acute at higher frequencies, the high-frequency components of the vessel noise could potentially pose a problem for the animals. The severity of such disturbances depends on the kind and number of boats, i.e. on the extent of required maintenance. The effect of boat noise on porpoises must be put into the perspective that some of the most heavily trafficked areas in Danish waters are also areas with a very high abundance of harbour porpoises (Sveegaard, et al., 2011), and therefore any displacements of animals is not likely to be permanent.

There is also a risk of increased noise from boats causing TTS. A study by Popov et al., (2011) has investigated TTS for the Yangtze finless porpoise. When exposed to prolonged noise (30 min) between 32 and 128 kHz, they found TTS to occur at sound pressure levels as low as 140 dB re 1 µPa. In a recent study, Kastelein, Gransier, Hoek, & Olthuis (2012) also induced TTS in a harbour porpoise using low levels of octave band noise centred around 4 kHz in longer duration exposures. TTS could be elicited at relatively low sound levels (124- 136 and 148 dB re 1 µPa), depending on exposure time.

**Impact criteria for porpoises**

Substantial uncertainty is connected to the question of how, the fact that animals do not hear equally well at all frequencies, should be handled when assessing risk for inflicting temporary and permanent threshold shift (TTS and PTS). Based on the recommendations made by the Working Group (2015), unweighted levels are used for the impact criteria assessment (see also 6.1 Echolocation and hearing).

A number of experiments have been conducted on noise induced physical impacts in porpoises and seals as summarized in Table 16 and Table 22. The relevant unit for expressing thresholds has been debated intensively and resulted in setting the double criteria presented by Southall et al., (2007) (Working Group, 2015). Thresholds are expressed both as maximum instantaneous pressure (peak pressure) and cumulated acoustic energy (sound exposure level, SEL dB re. 1 $\mu Pa^2 s$.). The difference between the two thresholds is pronounced, as the SEL takes into account the duration of the noise exposure whereas peak pressure ignores duration. It now seems that there is general consensus on SEL as a better predictor of TTS/PTS than peak pressure (Tougaard, Wright, & Madsen, 2015) and only SEL is considered here.

The value for PTS has not been empirically proven for the harbour porpoise or other cetaceans. Southall et al., (2007) proposed a threshold for inducing PTS in high-frequency cetaceans, including harbour porpoises (Table 16). However, this threshold is based solely on experimental data from mid-frequency cetaceans (bottlenose dolphins and beluga) and is no longer considered representative. Only one study is directly relevant to PTS and this was performed on a sister species to the harbour porpoise, the finless porpoise. Popov, Supin, Wang, Wang, Dong, & Wang (2011) were able to induce very high levels of TTS (45 dB) by presenting octaveband noise centred on 45 kHz. The energy in this noise was at considerably higher frequency than the main energy of pile driving noise. As the hearing of porpoises at 45 kHz is much better than at frequencies below a few kHz where the pile driving noise energy is present, it is likely that this proposed threshold underestimates the threshold for inducing PTS by pile driving noise, i.e. the threshold for PTS for pile driving noise is likely to be higher than 183 dB re. 1 $\mu Pa^2 s$. How much higher is not possible to say at present, so the threshold of 183 dB re. 1 $\mu Pa^2 s$ is retained as a precautionary measure (Working Group, 2015).

Several studies on TTS in harbour porpoises have been conducted (Table 16). Lucke, Siebert, Lepper, & Blanchet (2009) measured TTS induced by exposure to a single sound pulse from an airgun array. The TTS limit was at 164 dB re 1 $\mu Pa^2 s$ SEL (unweighted sound; TTS = 6 dB, recovery of hearing after >4 h). TTS of 6 dB will half the distance over which an animal can detect a sounds source depending on the frequency. It is important to consider that in harbour porpoise, TTS happens close to the main frequency of the impact sounds both for continuous tones (Kastelein R. , Gransier, Hoek, & Rambags, 2013) and impulsive low frequency sounds (Lucke, Siebert, Lepper, & Blanchet, 2009). The other studies that measured TTS (Table 16) used other stimuli of longer duration and thus considered less representative for pile driving noise. As the threshold of Lucke, Siebert, Lepper, & Blanchet (2009) furthermore is the lowest of all the thresholds measured, the Working Group (2015) recommend to retain this for precautionary reasons (Table 18).

After the Working Group finished its work, new results on TTS induced in a harbour porpoise by exposure to pile driving noise became available (Kastelein R. A., Gransier, Marijt, & Hoek, 2015). A harbour porpoise in captivity was subjected to long exposures (1 hour) of pile driving noise played back at reduced levels.

Cumulated sound exposure levels of 180 dB re. 1 µPa$^2$s (unweighted) resulted in TTS at 4 and 8 kHz but not at 2 kHz or higher than 8 kHz. This threshold level is 16 dB higher than the threshold reported by Lucke, Siebert, Lepper, & Blanchet (2009) and only 3 dB lower than the tentative PTS threshold provided by the Working Group. It is difficult to say whether the 16 dB discrepancy betweem the two studies is due to differences in the stimulus paradigm (one very powerful airgun pulse vs. 1 hour of repeated weak pile driving pulses), reflects differences in sensitivity between the two animals tested, or whether there may be experimental errors in one or the other study. Still, in the light of these new results, it is possible that the TTS threshold set by the Working Group (2015) is over-estimated.

*Table 16: Experiments where TTS and PTS thresholds for harbour porpoises were measured or could be inferred.*

| Harbour porpoises | Reference | Level | Stimulus | Comments |
|---|---|---|---|---|
| PTS | (Southall, et al., 2007) | 198 dB SEL M-weighted | General | Extrapolated from TTS-thresholds on bottlenose dolphin and beluga |
| | (Popov, Supin, Wang, Wang, Dong, & Wang, 2011) | 183 dB SEL unweighted | 45 kHz octaveband noise | Level that induced severe TTS (45 dB) in a finless porpoise, at the brink of PTS |
| TTS | (Lucke, Siebert, Lepper, & Blanchet, 2009) | 164 dB SEL unweighted | Single airgun pulse | TTS-threshold measured on a harbour porpoise |
| | (Kastelein R. , Gransier, Hoek, Macleod, & Terhune, 2012) | 163-172 dB SEL unweighted | Continuous octave-band noise 4 kHz | TTS-thresholds measured on a harbour porpoise |
| | (Kastelein , Hoek, Gransier, Rambags, & Claeys, 2014) | 189-197 dB SEL unweighted | Continuous pure tone 1.5 kHz | TTS-thresholds measured on a harbour porpoise |
| | (Popov, Supin, Wang, Wang, Dong, & Wang, 2011) | <163 dB SEL unweighted | 45 kHz octaveband noise | Extrapolated threshold for TTS in a finless porpoise |
| | (Kastelein R. A., Gransier, Marijt, & Hoek, 2015) | 180 dB SEL unweighted | Playback of broad-band pile driving sounds | TTS-thresholds measured on a harbour porpoise |

When it comes to determining thresholds for behavioural reactions to noise there is also considerable disagreement among authors on the best noise measure to use. Sound exposure level (SEL) is generally supported as being a better overall predictor for reactions than for example sound energy cumulated over long periods (such as across all pile driving pulses within a complete piling operation). As was the case for TTS and PTS thresholds, there is also not agreement on how to perform frequency weighting when computing sound levels. However, with respect to pile driving noise, the individual pile driving pulses are very similar to each other and the different parameters such as peak level, rms-average and single stroke SEL are highly correlated (Working Group, 2015).

Several studies have studied behavioural reactions of porpoises to pile driving noise (summarised in Table 17). Lucke, Siebert, Lepper, & Blanchet (2009) found that captive harbour porpoises exposed to an airgun sound showed avoidance behaviour at received sound exposure levels ~145 dB re. 1 µPa$^2$s. Studies looking at the behavioural impacts of pile driving in wild harbour porpoises have confirmed these findings and in some cases even indicate lower reaction thresholds at approx. 140 dB re. 1 µPa$^2$s (Brandt, Diederich, Betke, & Nels, 2011) (Dähne, et al., 2013). Of these, Dähne et al. (2013) is considered the most reliable, as it is based on a large and well-balanced dataset and a threshold for reactions could be established. This leads to a tentative threshold for pile driving noise causing fleeing in porpoises of 140 dB re. 1 µPa$^2$s single pulse SEL, unweighted.

*Table 17: Field studies where porpoise reactions to pile driving has been investigated. Units in the three middel studies are in rms-average sound pressure level (unweighted) otherwise in single pulse SEL, Values are thus not directly comparable.*

| Reference | Level | Stimulus | Comments |
|---|---|---|---|
| (Lucke, Siebert, Lepper, & Blanchet, 2009) | 145 dB re. 1 µPa$^2$s SEL | Play back | Not a real pile driving |
| (Tougaard, Carstensen, Teilmann, Skov, & Rasmussen, 2009) | 130 dB re. 1 µPa rms | Pile driving Horns Reef I | A threshold was not established |
| (Brandt, Diederich, Betke, & Nels, 2011) | 149 dB re. 1 µPa rms | Pile driving Horns Reef II | Likely overestimated, as excess attenuation of reef was not included |
| (Tougaard, Kyhn, Amundin, Wennerberg, & Bordin, 2013) | 130 dB re. 1 µPa rms | Play back | Not a real pile driving |
| (Dähne, et al., 2013) | 140 dB re. 1 µPa$^2$s SEL | Pile driving at Alpha Ventus | Supported by aerial surveys |

Table 18 summarizes the criteria used for evaluating noise effects on harbour porpoises as recommended by Working Group (2015).

*Table 18: Response criteria for harbour porpoises based on the recommendations by the working Group (2015)(SEL = sound exposure level, unwe = unweighted).*

| Harbour porpoises | PTS | TTS | Behaviour |
|---|---|---|---|
| Threshold | 183 dB re. 1µPa$^2$s cumulative SEL (unwe) | 164 dB re. 1µPa$^2$s cumulative SEL (unwe) | 140 dB re. 1µPa$^2$s single strike SEL (unwe) |

**Assessment of the worst case scenario for harbour porpoises**

Using the criteria for injury, noise induced threshold shifts and avoidance behaviour described above impact ranges have been modelled using noise levels estimated for a 10 MW and 10 m diameter pile as the worst case scenario. The noise levels for the injury criteria were unweighted based on the recommendations by the Working Group (2015). Modelling of the underwater noise is described in more detail in the accompanying noise modelling report (NIRAS, 2014) and Working Group (2015) and updated with respect to this report in DCE, DHI, NIRAS (2015). The noise propagation model considers cumulating noise regarding PTS and TTS and a single strike regarding behavioural effects.

The impact range results of the modelling for harbour porpoises are shown in Table 19, and the spatial dimensions of ranges for the different impacts are shown in Figure 73. It is clear from the acoustic model that permanent physical impacts (PTS) can happen within a large area (approx. 17km). Temporary noise induced threshold shifts (TTS) are modelled to occur at even more considerable distances (approx. 49km) from the noise source. Behavioural responses in harbour porpoises can occur at ranges 43 km from the source of a single pile strike. This range is shorter than the range causing TTS, which intuitively may seem contradictory. The behavioural reaction is based on a single pile strike and the cumulated effect may exceed this range. But as noted above, it may also be that the TTS threshold is over-estimated.

*Table 19: Ranges of impact on harbour porpoises for cumulative pile strikes for a 10 MW and 10 m diameter monopile (see detailed results in the updated noise report (DCE, DHI, & NIRAS, 2015).*

| Effect | Maximum range to threshold |
|---|---|
| PTS (183 dB SEL) | 16 900 m |
| TTS (164 dB SEL) | 48 700 m |
| Avoidance behaviour (140 dB SEL) | 43 200 m |

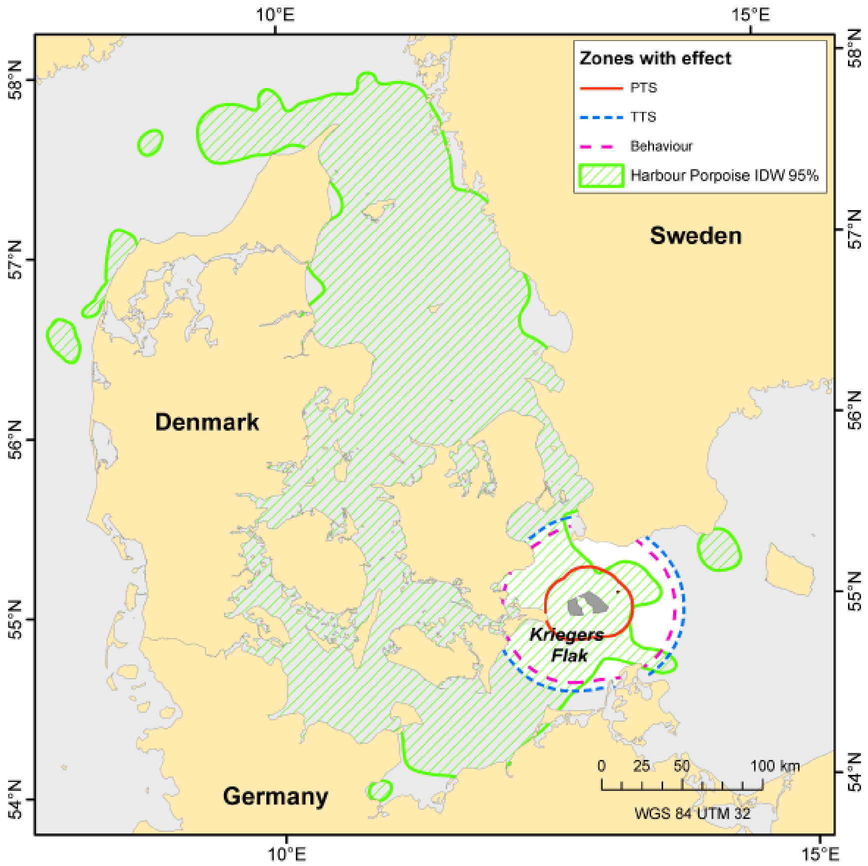



*Figure 73: 95% kernel home ranges for Argos satellite tagged harbour porpoises for the whole year (green shaded area). The Kriegers Flak wind farm area is indicated as the dark grey area. Zones of cumulated noise exposure impact on hearing thresholds (PTS/TTS) are also indicated as well as the single strike behavioural avoidance zone.*

**Proportion of animals affected**

The MaxEnt modelling results for the modelling area including Kriegers Flak (see chapter 6) in conjunction with the impact ranges for cumulative noise exposure regarding PTS and TTS and a single pile strike regarding behavioural reactions as presented above, were used to estimate the proportion of animals affected inside the modelling area during summer (June-August; Figure 74a) and autumn (September-November, Figure 74b). Winter and spring seasons were excluded, as the MaxEnt modelling results for these seasons were too uncertain due to very few locations from the tagged animals (see sections 5.4 and 6.4). The impact in proportion to the entire population was estimated based on the 95 % kernel home range covering the whole year (Figure 73; see chapter 6). Estimates of the number of individuals affected in the range of the population were based on a new total abundance estimate by Viquerat et al. (2013).

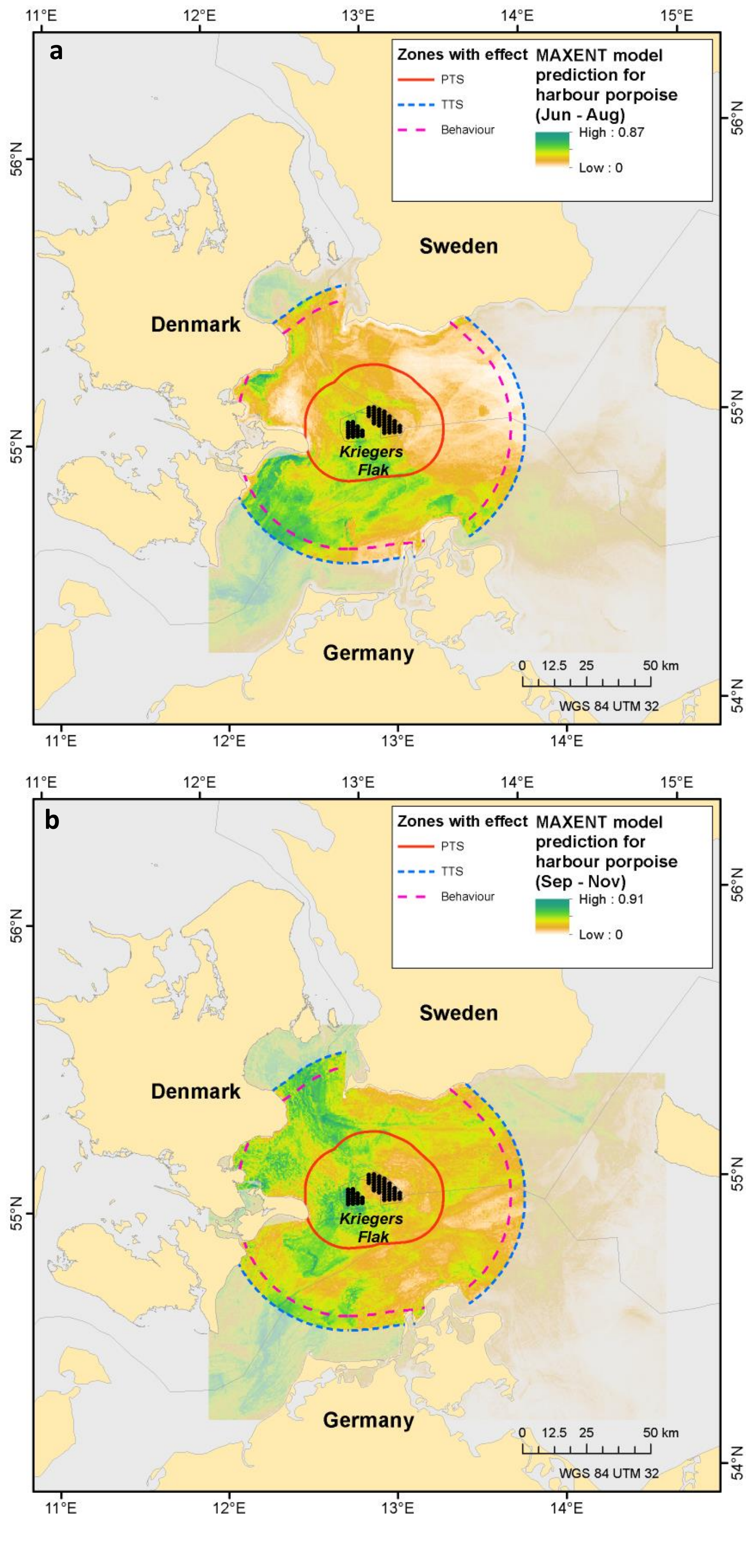



*Figure 74. Predicted probability of presence of harbour porpoise in the modelling area, based on the MaxEnt model. (a) Prediction during summer months (Jun-Aug), (b) prediction during autumn months (Sep-Nov). Zones of impact are indicated.*

Table 20 shows the maximal proportion of animals affected seasonally on a local scale as well as annually on a regional scale. It is evident from the table that severe effects are found for cumulated noise induced threshold shifts. PTS is likely to occur to a significant proportion of individuals in the modelled area during summer and autumn (12.9 %/12.5 %). The proportion of Individuals affected within the entire population range is less severe (3.62 %; 1 465 individual). PTS is a permanent reduction in hearing, and the effect will thus be long-term for the affected individuals. The proportion of animals that will experience a temporary hearing reduction will be fairly high (11.73 %; 4 748 individuals) on a population scale, but particularly high when looking at the seasonal scale. Almost half of the individuals occurring in the model area in summer and autumn will experience TTS. There is also substantial impact on harbour porpoises when looking at behavioural effects. A single pile strike will potentially induce avoidance behaviour in approx. 47 % of the porpoise in the modelled area during both summer and autumn, possibly causing a displacement of half of all individuals from this area (Table 20). On the scale of the population, 10.65 % (4 311 individuals) will be displaced from their home range. The short-term effect is therefore quite severe. The displaced animals may be forced to forage in areas that are already occupied by other animals, so the impact of extended periods of displacement may be severe on the population level due to increased competition for food for large parts of the population.

*Table 20: Percent of harbour porpoises affected within the modelling area during the different seasons and within the 95% kernel home range for the whole year. Corresponding estimates of the number of individuals affected based on estimated numbers of individuals in the genetically distinct population in the Kattegat, Belt Seas and Western Baltic. No reliable data exists from the Baltic Sea porpoise population and thus it is not included in this table.*

| Effect | Percent of individuals affected within modelling area | | Percent of Individuals affected within population range (95 % kernel) | Number of individuals in genetic population | Number of animals affected in genetic population |
|---|---|---|---|---|---|
| Season | Summer | Autumn | Year | | |
| PTS | 12.9 | 12.5 | 3.62 | 40 475 | 1 465 |
| TTS | 46.5 | 54.5 | 11.73 | 40 475 | 4 748 |
| Avoidance behaviour | 46.5 | 47.1 | 10.65 | 40 475 | 4 311 |

**Comparison to scenario with implemented mitigation**

As the impacts described above are quit severe, modelling of an alternative scenario was undertaken. In the alternative scenario, mitigation methods were implemented to reduce the source level. The Working Group (2015) suggested the use of a pingers and seal scarers and a reduction of the source level, which could be accomplished by using bubble curtains, such as those used in the construction of Alpha Ventus and Borkum West II Offshore Wind Farms (see chapter 12.1 and the noise modelling report, NIRAS (2014) and DCE, DHI, & NIRAS (2015) for a more detailed description). Based on the experiments with seal scarers (Brandt, et al., 2012) (Olesuik, Nichol, Sowden, & Ford, 2002), where the majority of harbour porpoises flee to a distance of >1 km, it was calculated that if pingers and seal scarers are implemented prior to pile-driving, with the resulting starting distance of 1 or 2 km from the pile for harbour porpoises, it would be necessary to reduce the noise source level by 14-16 dB for 2 and 1 km deterrence distances respectively to avoid causing PTS based on the site specific sound propagation and animal fleeing speed (DCE, DHI, & NIRAS, 2015).

Table 19 shows the impact ranges based on the two new scenarios. Even after reducing the noise level there are still a considerable number of animals experiencing TTS inducing noise levels and noise levels high enough to cause behavioural reactions. Again, the effect on behaviour is only modelled for a single pile strike.

*Table 21. Impact ranges for harbour porpoises when pingers and seal scarers are employed and when source levels have been reduced by 16 dB for 1 km deterring range and by 14 dB for 2 km deterring range to alleviate the risk of PTS (DCE, DHI, & NIRAS, 2015).*

| Effect | Maximum range to threshold (deterrence 1 km and 16 dB noise attenuation) | Individuals affected | Maximum range to threshold (deterrence 2 km and 14 dB noise attenuation) | Individuals affected |
|---|---|---|---|---|
| PTS (183 dB SEL) | 1 000 m | - | 2 000 m | - |
| TTS (164 dB SEL) | 22 000 m | 2 012 | 25 300 m | 2 388 |
| Avoidance behaviour | 19 100 m | 1 696 | 22 000 m | 2 012 |

## 7.2 Likely effect of construction on seals

The impact of pile driving on seals, if relevant (as monopile foundations, jacket foundations or sheet pile walls), is similar in nature to the impacts on porpoises (Sections 7 and 7.1 above), except that little is known regarding reaction distances.

As for porpoises, there are two types of impact from pile driving: actual impairments of the hearing systems (temporal or permanent) and behavioural effects (avoidance). Southall et al. (2007) estimated TTS and PTS thresholds for seals in general, but these estimates were based on data from bottlenose dolphins, beluga and a single California sea lion (Table 22). However, since 2007 actual measurements from harbour seals have become available. Kastak, Mulsow, Ghoul, & Reichmuth (2008) induced PTS in a harbour seal due to an experimental error. This means that an actual measurement is available. Also, a second experiment (in a different facility and on a different animal) produced a very strong TTS (44 dB) by accident, which is considered to have been very close to inducing PTS. By combining the two experiments a threshold for PTS in harbour seals is tentatively set to 200 dB re. 1 µPa$^2$s (Working Group, 2015).

In two experiments TTS have been induced in harbour seals with octave band noise centred on 2.5 kHz and 4 kHz, respectively. Simply taking the mean of the thresholds produces an estimated threshold for TTS of 176 dB re. 1 µPa$^2$s.

*Table 22: Experiments where TTS and PTS thresholds for harbour seals were measured or could be inferred.*

| Seals | Reference | Level | Stimulus | Comments |
|---|---|---|---|---|
| PTS | (Southall, et al., 2007) | 186 dB SEL M-weighted | General | Extrapolated PTS-threshold based on TTS-measurements from California sea lion, bottlenose dolphin and beluga |
| | (Kastak, Mulsow, Ghoul, & Reichmuth, 2008) | 202 dB SEL unweighted | 4.1 kHz pure tone | Level that induced small PTS in a harbour seal by an experimental error |
| | (Kastelein, Gransier, & Hoek, 2013) | 199 dB SEL unweighted | 4 kHz octave band noise | Level that induced severe TTS (44 dB) in a harbour seal, at the brink of PTS |
| TTS | (Southall, et al., 2007) | 171 dB SEL M-weighted | General | Extrapolated from TTS-thresholds on bottle-nose dolphin and beluga |
| | (Kastelein R. , Gransier, Hoek, Macleod, & Terhune, 2012) | 169-176 dB SEL unweighted | 4 kHz octave band noise | TTS-thresholds measured on a harbour seal |
| | (Kastak, Southall, Schusterman, & Kastak, 2005) | 182 dB SEL unweighted | 2.5 kHz octave band noise | TTS-threshold measured on a harbour seal |

It is at present not possible to provide a behavioural reaction threshold for seals as only very limited information is available on the reactions of seals to pile driving. A single study on ringed seals in the Arctic (Blackwell, Lawson, & Williams, 2004) studied reactions (or more correctly the absence of reactions) of ringed seals to conductor tube piling on an artificial island. However, these settings are very different from offshore wind turbine installation and are not considered applicable (Working Group, 2015). Still, this is in line with observations that seals do not react to construction noise at haul-out sites and are generally known to habituate fast, even to relatively loud sound levels (Edrén, et al., 2010), (Fjälling, Wahlberg, & Westerberg, 2006), (Blackwell, Lawson, & Williams, 2004).,

As for harbour seals, no studies have observed behavioural changes corresponding to strong avoidance in grey seals (Southall, et al., 2007), (Edrén, et al., 2010). PTS and TTS have not been investigated in the grey seals either. The criteria used for the harbour seals (Table 23) will therefore also be adopted for the grey seals.

Table 23 summarizes the criteria used for evaluating noise effects on seals.

*Table 23: Response criteria for harbour seals based on the recommendations by the Working Group (2015)(SEL = sound exposure level, unwe = unweighted).*

| Harbour seal | PTS | TTS |
|---|---|---|
| Threshold | 200 dB re. 1µPa$^2$s cumulative SEL (unwe) | 176 dB re. 1µPa$^2$s cumulative SEL (unwe) |

**Assessment of the worst case scenario for harbour seals and grey seals**

Based on the criteria for injury and noise induced threshold shifts described above, impact ranges have been modelled using noise levels estimated for a 10 MW, 10 m diameter single pile as the worst case scenario. The noise levels for the injury criteria were unweighted based on the recommendations by the Working Group (2015). Modelling of the underwater noise is described in more detail in the accompanying noise modelling report (NIRAS 2013) and updated in DCE, DHI, & NIRAS (2015).

The impact range results of the modelling for harbour seals and grey seals are shown in Table 24. The spatial dimensions of the different ranges of cumulative noise impact are shown in Figure 75 for harbour seals and grey seals in relation to 95 % home ranges.

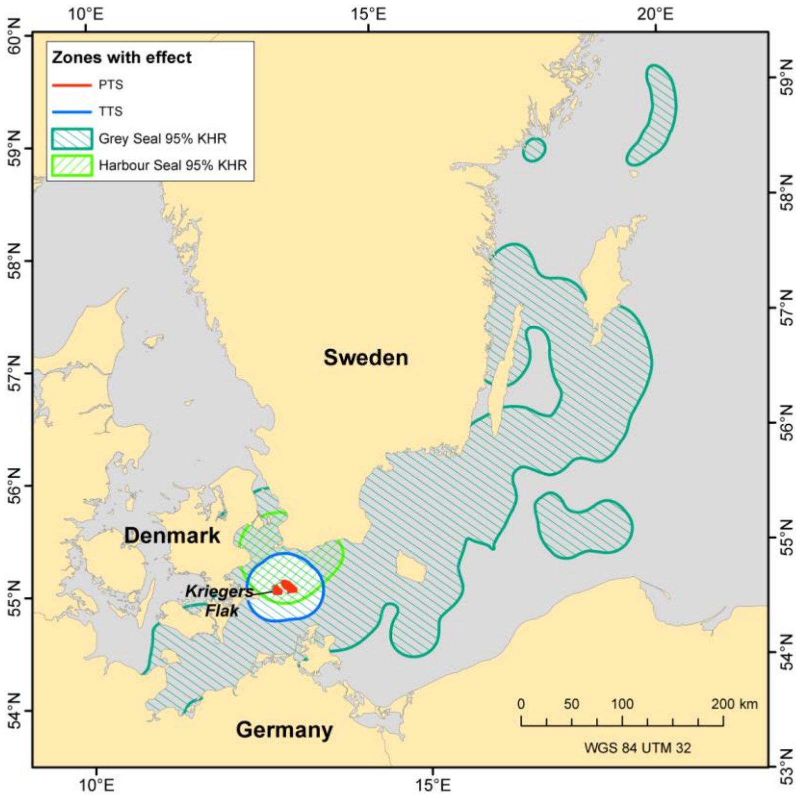



*Figure 75: 95% kernel home ranges for GPS tagged harbour seals (green shaded area), and for GPS tagged grey seals (blue shaded area) for the whole year.  The Krieger's flak wind farm area is indicated as the grey area. Zones of impact are also indicated.*

The impact ranges for multiple pile strikes are smaller for harbour seals and grey seals than for harbour porpoises. Physical impact (PTS) due to the cumulated noise exposure (200 dB SEL) is restricted to a relatively close range of the source (590 m) for both species. However, temporary threshold shifts (TTS) can occur at considerable distances, approx. 28 km from the noise source.

As no information exists regarding behavioural changes of seals in response to noise, an impact range for behavioural changes is therefore not included in the assessment.

*Table 24: Ranges of impact on harbour seals and grey seals for cumulative pile strikes for a 10 MW, 10 m diameter monopile (see detailed results in in DCE, DHI, & NIRAS (2015).*

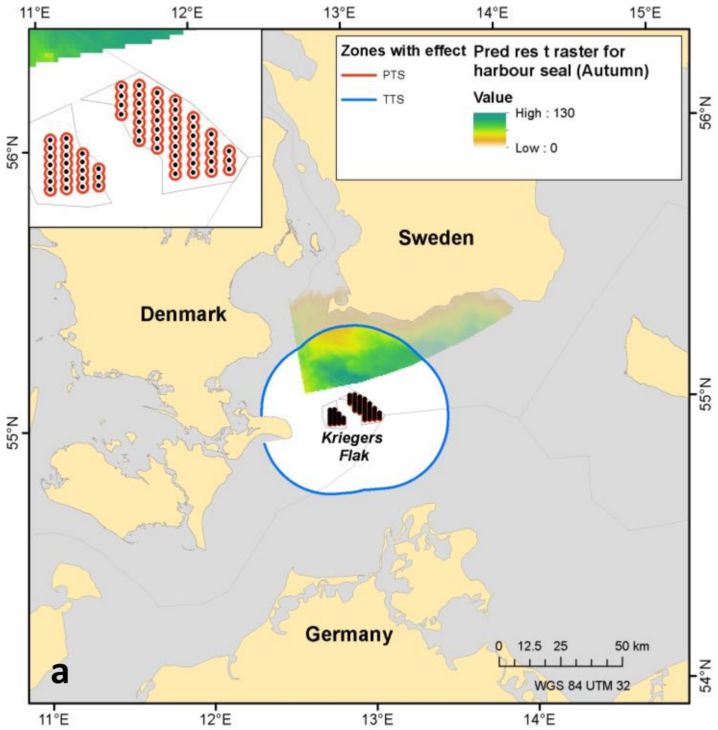
| Effect | Maximum range to threshold |
|---|---|
| PTS (200 dB SEL) | 590 m |
| TTS (176 dB SEL) | 27 800 m |

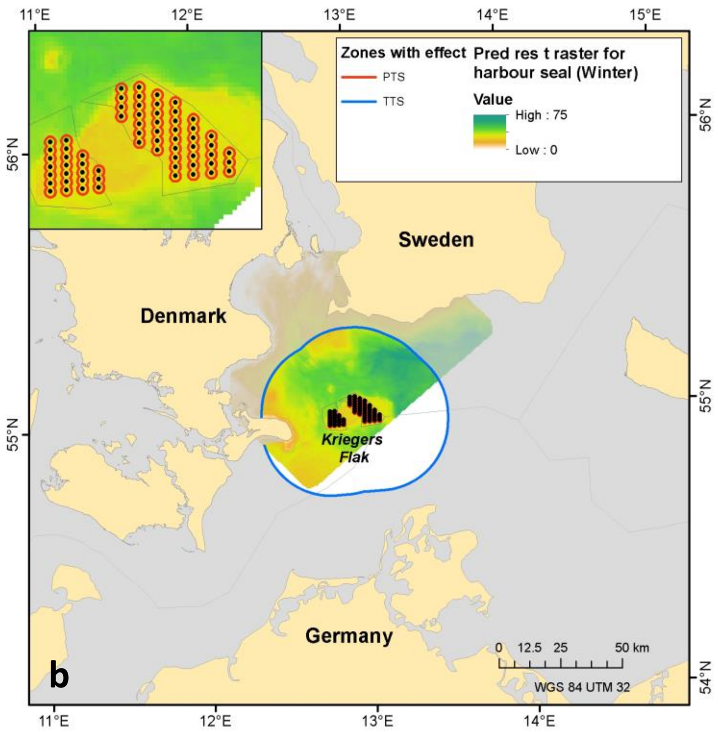
**Proportion of animals affected**

Results of distribution and habitat use for the modelling area including Kriegers Flak along with the impact ranges for cumulative noise exposure presented above, were used to estimate the proportion of the areas that were intensely used by seals (indicated by high residence times) that were affected by wind farm construction noise in different seasons (harbour seal, Figure 76; Grey seals, Figure 77). Areas were characterized as intensely used if their environmental conditions corresponded to those in areas where seals had highly convoluted movement tracks. Such tracks generally indicate that animals are foraging. For most seasons only an extremely small part of the intensely used areas (as predicted with the full GAM models) coincided with areas that could induce PTS. Grey seals occurred in areas with the risk of PTS in all seasons (Figure 77a), but it constituted only a very small part of the possible foraging area. None of the studied harbour seals approached the PTS area in the autumn or summer, and the potential suitability of this area as foraging ground for harbour seal could therefore not be calculated (Figure 76a and d). The situation was different for the TTS area calculated for multiple strikes. For harbour seals, a large part of the area they use intensely in winter and spring coincides with this area (Figure 76b and c. See also Table 25). Pile driving may therefore have a considerable effect on the harbour seals's ability to forage in the Kriegers Flak area during these seasons, and if they retain the current foraging areas during pile driving their hearing is likely to be permanently reduced. For grey seals, the TTS zone is predicted to be of intermediate importance as foraging area in autumn, winter and partly in summer (Figure 77a, b, and d and Table 26), but due to the large home ranges of the grey seals, the TTS area constitutes only a minor part of the predicted important foraging areas for this species.

For harbour seals, the impacts in proportion to the entire genetic population covering the haul-out sites Falsterbo, Saltholm and Bøgestrømmen (Olsen M. , Andersen, Dietz, Teilmann, & Härkönen, 2014), were estimated based on the whole year 95 % kernel home range of 10 tagged individuals as well as on population size estimates from the Danish national NOVANA monitoring program the for harbour seals in this area (Figure 75 ; see chapter 6). For grey seals the 95% kernel home range for the whole year is based on taggings of 11 individuals from the Falsterbo haul-out area (Figure 75 ; see chapter 6). The genetic structure of the grey seals population in the Baltic is not known, but it seems that animals from the Bothnian

Sea do not move to the southern Baltic Sea and seals in the southern Baltic do not go into Bothnian Sea (HELCOM Seal). Therefore two population size estimates were used. One was the population size estimate covering animals from Western Estonia, Central & Southern Swedish Baltic waters, and can be considered a precautionary size. The other estimate is from new unpublished results covering the population from the entire Baltic Sea (HELCOM Seal Group, Anders Galatius, pers. comm.).


Zones with effect
PTS
TTS
Pred res t raster for harbour seal (Autumn)
Value
High : 130
Low : 0
Sweden
Denmark
Kriegers Flak
Germany
0 12.5 25 50 km
WGS 84 UTM 32
a
11°E
12°E
13°E
14°E
15°E
54°N
55°N
56°N


Zones with effect
PTS
TTS
Pred res t raster for harbour seal (Winter)
Value
High : 75
Low : 0
Sweden
Denmark
Kriegers Flak
Germany
0 12.5 25 50 km
WGS 84 UTM 32
b
11°E
12°E
13°E
14°E
15°E
54°N
55°N
56°N

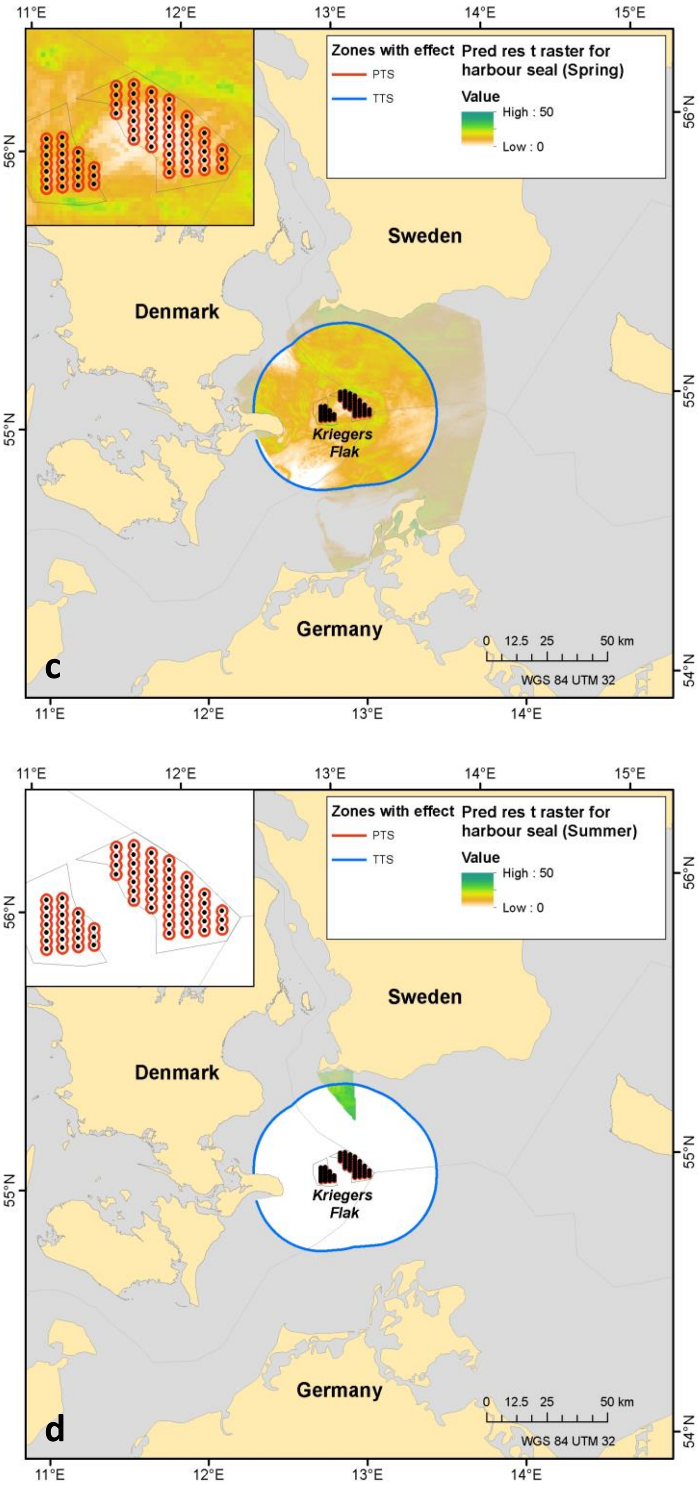
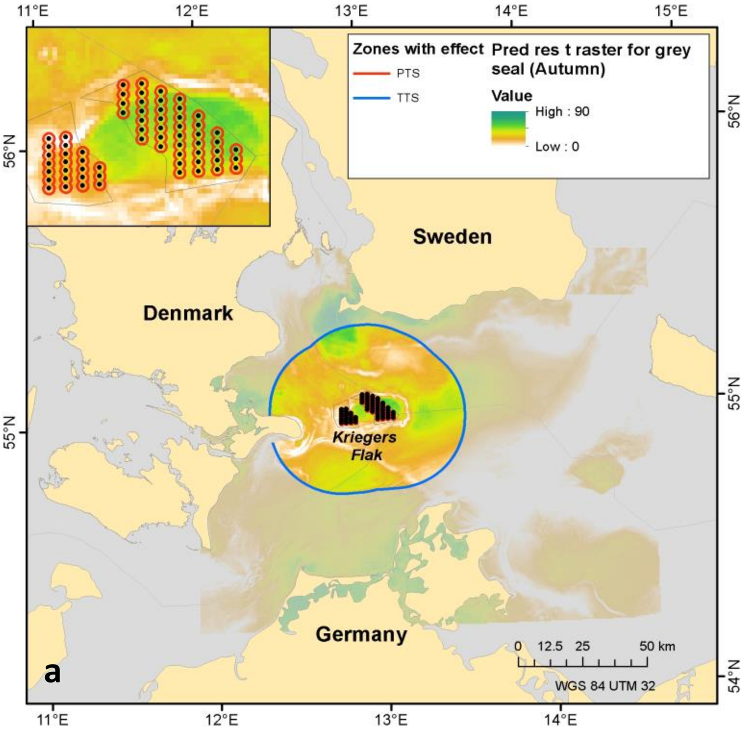
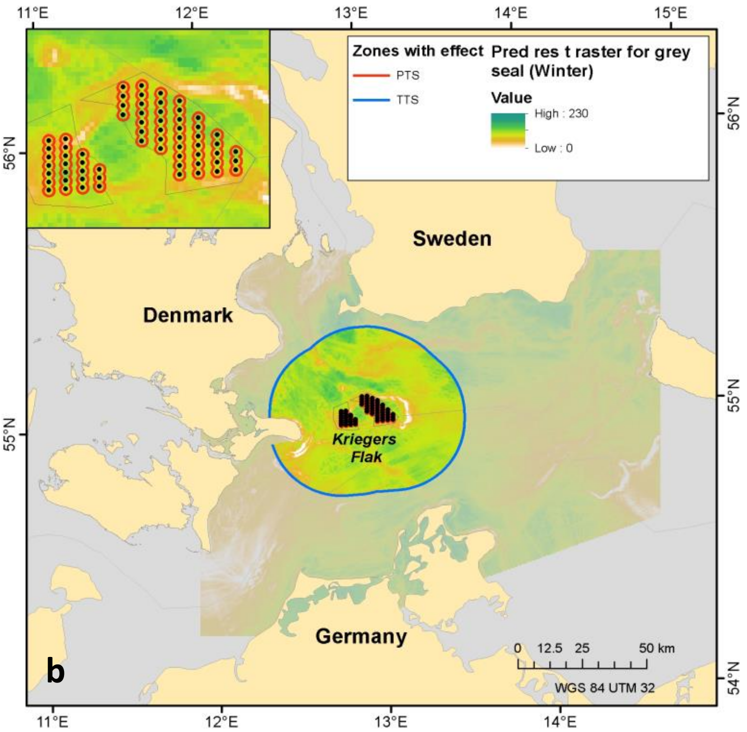
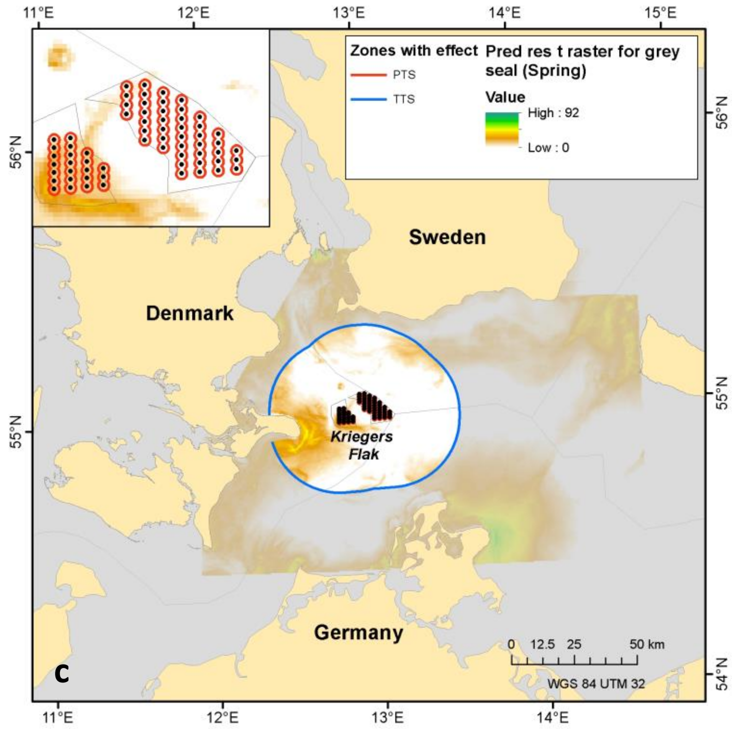



*Figure 76: Predicted residence times of harbour seals in the modelling area during autumn (a), winter (b), spring (c) and summer (d). Areas with high residence times are intensely used by the seals. Zones of impact are indicated, PTS zones of impact are within the red shapes, TTS zones are within the blue circle.*


Zones with effect
PTS
TTS
Pred res t raster for grey seal (Autumn)
Value
High : 90
Low : 0
Sweden
Denmark
Kriegers Flak
Germany
0 12.5 25 50 km
WGS 84 UTM 32
a


Zones with effect
PTS
TTS
Pred res t raster for grey seal (Winter)
Value
High : 230
Low : 0
Sweden
Denmark
Kriegers Flak
Germany
0 12.5 25 50 km
WGS 84 UTM 32
b



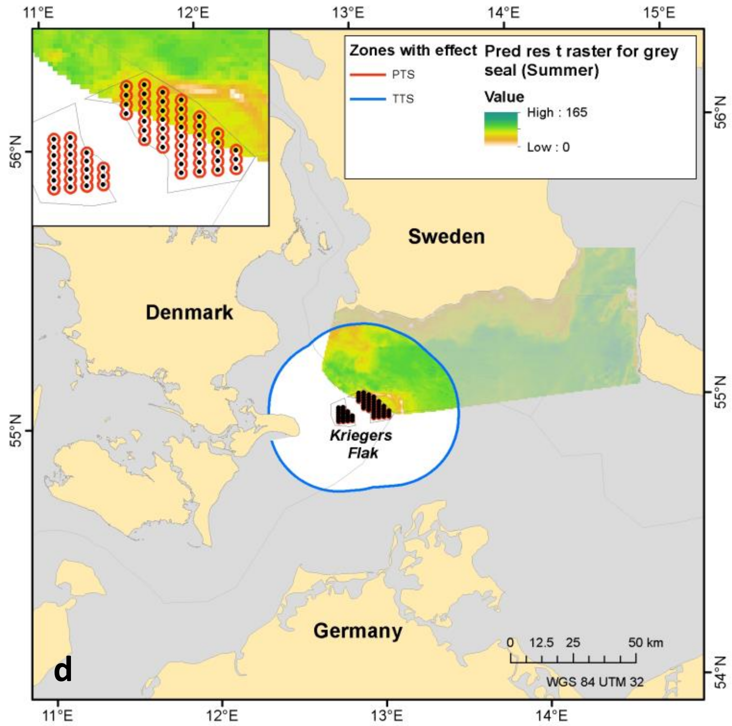




*Figure 77: Predicted residence of grey seals in the modelling area during autumn (a), winter (b), spring (c) and summer (d). Zones of impact are indicated. PTS zones of impact are within the red shape, TTS zones are within the blue circle.*

Table 25 shows the maximal proportion of harbour seals affected seasonally on a local scale as well as annually on a regional scale. It is clear that permanent noise induced threshold shifts (PTS) are unlikely to affect a significant number of individuals. However, a substantial part of the animals in the modelled area are likely to be exposed to a temporary threshold shift. During the winter, 64 % of the local population is at high risk of developing TTS from cumulative strikes. On a yearly basis that constitutes 49 % of the local population or 15 % of the entire population, or 226 individuals. The impacts on the local population are very high. However, since TTS is a short-term effect, this risk of TTS will only be present while construction activities are ongoing.

*Table 25: Percent of harbour seals affected within the modelling area during the different seasons and within the 95% kernel home range for the whole year. Corresponding estimates of the number of individuals affected based on estimated numbers of individuals in the genetically distinct population.*

| Effect | Percent of animals affected within modelling area | | | | Percent of the area used by the local/entire population (95 % kernel) | Population size/entire genetic population | Number of affected animals |
|---|---|---|---|---|---|---|---|
| Season | Autumn | Winter | Spring | Summer | Year | | |
| PTS | 0.0 | 1.2 | 0.7 | 0.0 | 1.2/0.4 | 460/1 563 | 6 |
| TTS | 56.2 | 63.9 | 53.1 | 62.0 | 49.2/14.7 | 460/1 563 | 226 |

Table 26 shows the maximal proportion of grey seals affected seasonally on a local scale as well as annually on a regional scale. As for harbour seals the most severe effects are found from cumulated noise induced temporary threshold shifts. Only a tiny proportion of the total population would be at risk of developing PTS (0.1 % or 27 individuals). However in autumn, cumulative strikes could potentially induce TTS in up to 27 % of the individuals in the modelling area. This proportion of animals is similar for the other seasons, apart from spring (10 %). Annually, the effect on the population is somewhat smaller (5.6 %), but can still possibly affect 1 644 individuals. The impacts on the individuals in the modelling area are therefore quite severe. For the total genetic population, this risk is somewhat lower, but still substantial.

*Table 26: Percent of grey seals affected within the modelling area during the different seasons and within the 95% kernel home range for the whole year. Corresponding estimates of the number of individuals affected based on estimated numbers of individuals in the genetically distinct population.*

| Effect | Percent of animals affected within modelling area | | | | Percent of animals affected within local/entire population range (95 % kernel) | Population size/entire genetic population | Number of animals affected |
|---|---|---|---|---|---|---|---|
| **Season** | **Autumn** | **Winter** | **Spring** | **Summer** | **Year** | | |
| PTS | 0.7 | 0.4 | 0.1 | 0.3 | 0.1/0.1 | 29 633/42 179 | 27 |
| TTS | 26.4 | 23.0 | 10.3 | 24.9 | 5.6/3.9 | 29 633/42 179 | 1 644 |

**Comparison to scenario with implemented mitigation**

The impacts described above have substantial impact on the local populations of seals. As described earlier for harbour porpoises an alternative scenario with a reduced source levels were modelled with respect to avoiding PTS in harbour porpoises (Table 21) (Working Group, 2015). This involve the use of a pingers and seal scarers to deter porpoises approx. 1 km away and a 16 dB reduction of the source level, which could be accomplished by using bubble curtains (see details in (DCE, DHI, & NIRAS, 2015)). Attenuation of the source level with 16 dB would lead to a considerable reduction in the impact ranges for seals as their PTS/TTS threshold levels are higher than for porpoises. Table 27 shows the impact ranges and affected number of individuals, when permanent threshold shift should be avoided in seals. If a seal was 10 m away from the pile it would require an 8 dB reduction in source level to avoid PTS. This scenario would lead to a reduction of the range where TTS could occur approx. 28 km to around 6 km. If the seal started 100 m away from the pile, only a 4 dB reduction in the source level would be required, which would reduce the TTS impact range from approx. 28 km to 8.3 km. The corresponding numbers of affected individuals would drop equally. Hence, if the noise source level is reduced to the level recommended for preventing PTS in porpoises, no further action would be required for seals.

*Table 27: Ranges of impact on harbour seals and grey seals and number of individuals affected for cumulative pile strikes when source levels have been attenuated (see text and modelling details in DCE, DHI, & NIRAS (2015)).*

| Effect | Maximum range to threshold (10m starting distance) | Individuals affected (harbour/grey) | Maximum range to threshold (100m starting distance) | Individuals affected (harbour/grey) |
|---|---|---|---|---|
| PTS (200 dB SEL) | <2 m | - | <2 m | - |
| TTS (176 dB SEL) | 6 000 m | 50/237 | 8 300 m | 70/332 |

**Assessment of the severity of impacts during construction**

For the impact assessments, the methodology outlined by NIRAS was used (Table 28 and Table 29). Regarding the *degree of disturbance,* PTS is a permanent hearing damage the effect is therefore defined as high. TTS is also defined as high, though the effect on the hearing sensitivity is temporary. Behavioural responses will likely be a moderate impact, though depending on the number of animals affected, whether the effect is evaluated on a local or regional scale, and depending on the expected time of return of the displaced animals and the potential of alternative habitats, it may become a major impact. *Importance* of effects will be evaluated as effects that are estimated to be of interest either locally or regionally. The *likelihood* of an animal being affected is based on the proportion of animals expected to be affected and it ranges from low to high. The *duration* of effects will generally be defined as short-term as the effects of noise on marine mammals are directly coupled to the construction activities.

The results of the impact assessment are provided in Table 28 and in Table 29 mitigation measures are accounted for. As can be seen, the effects of noise on marine mammals are directly coupled to the activities. Effects of cumulative noise exposure may be substantial without mitigation as the number of individuals is fairly high. However, once construction activities subside, TTS effects should disappear within a few days. Behavioural effects could result in animals leaving the area for longer periods. The duration of this displacement, however, depends on a number of factors such as the area's importance for the species and overall habitat quality.

*Table 28: Overall effects of the construction activities on marine mammals when no mitigation measures are implemented.*

| Marine mammals – Construction phase – no mitigation | | | | | |
|---|---|---|---|---|---|
| **Source**<br>**Type**<br>**Receptor** | **Degree of disturbance** | **Importance** | **Likelihood** | **Duration** | **Extend of impact** |
| **Harbour porpoise/**<br>**PTS** | High | Regional interest | Medium | Short-term | Minor |
| **Argument** | Permanent hearing damage | Within 17km from pile driving for cumulative strikes | Proportion of the population affected is 3.6%, ~12% in summer/autumn | During pile driving period | |
| **Harbour porpoise/**<br>**TTS** | High | Regional interests | Medium | Short-term | Moderate/ major |
| **Argument** | Temporary hearing damages | Within 50km from pile driving for cumulative strikes | 11.7% of the population affected but approx. 50% in summer/autumn | During pile driving period | |
| **Harbour porpoise/**<br>**Behavioural reaction** | Moderate | Regional interests | Medium | Short-term | Moderate |
| **Argument** | Displacement of animals up to ~45 km for single strike; | Up to ~43 km from construction, but effect reversible after pile driving stops | Around 10% of the entire population affected but approx. 50% in seasons | During pile driving period | |
| **Harbour porpoise/**<br>**Increased boat traffic** | Medium | Local interests | Medium | Temporary | Minor |

| Marine mammals – Construction phase – no mitigation | | | | | |
|---|---|---|---|---|---|
| **Source**<br>**Type**<br>**Receptor** | **Degree of disturbance** | **Importance** | **Likelihood** | **Duration** | **Extend of impact** |
| **Argument** | Displacement of animals up to a few hundred meters | Within a few hundred of m from boats. Similar to other boat noise in the area. | Animals mainly in region autumn /winter | During construction period | |
| **Harbour seal/**<br>**PTS** | High | Local interest | Low | Short-term | Minor |
| **Argument** | Permanent hearing damage | Within 600 m from pile driving for cumulative strikes, | Less than 2 % of population | During pile driving period | |
| **Harbour seal/**<br>**TTS** | High | Regional interest | High | Short-term | Moderate/major |
| **Argument** | Temporary hearing damage | Within 28 km from pile driving for cumulative strikes | Large proportion of local polulation affected (50%). Up to 64% in winter | During pile driving period | |
| **Harbour seal/**<br>**Behavioural reaction** | No information | No information | No information | No information | No information |
| **Argument** | Displacement unknown | Can be heard ~ 100 km from construction; but reaction range is unclear | Almost the entire local population will be within the range of potential impact but reaction threshold is unclear | During pile driving period | |

| Marine mammals – Construction phase – no mitigation | | | | | |
|---|---|---|---|---|---|
| **Source**<br><br>**Type**<br><br>**Receptor** | **Degree of disturbance** | **Importance** | **Likelihood** | **Duration** | **Extend of impact** |
| **Grey seal/**<br><br>**PTS** | High | Local interest | Medium | Short-term | Minor |
| **Argument** | Permanent hearing damage | Within 600 m for cumulative strikes | Less than 1% of population affected (27 individuals). Uncertainty regarding grey seals | During pile driving period | |
| **Grey seal/**<br><br>**TTS** | High | Regional interest | High | Short-term | Moderate |
| **Argument** | Temporary hearing damage | Within 28 km for cumulative strikes | Minor proportion of the local population affected (6%), but up to 27% in autumn | During pile driving period | |
| **Grey Seals/**<br><br>**Behavioural reaction** | No information | No information | No information | No information | No information |
| **Argument** | Displacement unknown | Can be heard ~100 km from construction but reaction zone is unknown | Large proportion of local population will be within the range of potential impact, reaction zone is not known | During construction | |
| **Seals/**<br><br>**Increased boat traffic** | Medium | Local interests | Medium | Temporary | Minor |
| **Argument** | Displacement of animals up to a few hundred m | Within a few hundred m from boats | Animals occurring all year in construction area | During construction period | |

*Table 29: Overall effects of the construction activities on marine mammals when mitigation measures are implemented.*

| Marine mammals – Construction phase – mitigation implemented | | | | | |
|---|---|---|---|---|---|
| **Source**<br>**Type**<br>**Receptor** | **Degree of di-sturbance** | **Importance** | **Likelihood** | **Duration** | **Extend of impact** |
| **Harbour porpoise/**<br>**PTS** | High | Local interest | Low | Short-term | Minor |
| **Argument** | Permanent hearing da-mage | Within 1-2 km from pile driving for cumulative strikes | As most animals have been deterred to a dis-tance beyond 1-2 km, very few animals are likely to suffer PTS | During pile driving peri-od | |
| **Harbour porpoise/**<br>**TTS** | High | Local interests | Medium | Short-term | Minor |
| **Argument** | Temporary hearing da-mages | Up to ~25 km from construction | Approx. 5 % of the en-tire population affect-ed | During pile driving peri-od | |
| **Harbour porpoise/**<br>**Behavioural reaction** | Medium | Regional interests | High | Short-term | Moderate |
| **Argument** | Displacement of animals up to ~22 km; but reversible af-ter pile driving stops | Up to ~22 km from construction | Approx. 5 % of the en-tire population affect-ed | During pile driving peri-od | |
| **Harbour porpoise/**<br>**Increased boat traffic** | Medium | Local interests | Medium | Temporary | Minor |

| Marine mammals – Construction phase – mitigation implemented | | | | | |
|---|---|---|---|---|---|
| **Source**<br>**Type**<br>**Receptor** | **Degree of disturbance** | **Importance** | **Likelihood** | **Duration** | **Extend of impact** |
| **Argument** | Displacement of animals up to a few hundred meters | Within a few hundred of m from boats. Similar to other boat noise in the area. | Animals occur mainly in region autumn/winter | During construction period | |
| **Harbour seal/**<br>**PTS** | High | Local interest | Low | Short-term | Minor |
| **Argument** | Permanent hearing damage | Within a few meters from pile driving for cumulative strikes | PTS is only likely within a few meters of the pile | During pile driving period | |
| **Harbour seals/**<br>**TTS** | High | Regional interest | High | Short-term | Minor |
| **Argument** | Temporary hearing damage | Within 10 km from pile driving for cumulative strikes | Approx. 11 % of the population affected | During pile driving period | |
| **Harbour seals/**<br>**Behavioural reaction** | No information | No information | No information | No information | No information |
| **Argument** | Displacement unknown | Can be heard far from construction | Large proportion of local population will be within the potential range of impact; but impact zone is unknown | During pile driving period | |
| **Grey seals/**<br>**PTS** | High | Local interest | Low | Short-term | Negligible |

| Marine mammals – Construction phase – mitigation implemented | | | | | |
|---|---|---|---|---|---|
| **Source**<br><br>**Type**<br><br>**Receptor** | **Degree of disturbance** | **Importance** | **Likelihood** | **Duration** | **Extend of impact** |
| **Argument** | Permanent hearing damage | Within a few meters from pile driving for cumulative strikes | PTS is only likely within a few meters of the pile | During pile driving period | |
| **Grey seals/**<br><br>**TTS** | High | Regional interest | Low | Short-term | Minor |
| **Argument** | Temporary hearing damage | Within 10 km from pile driving for cumulative strikes | Only approx. 1 % of the entire population affected | During pile driving period | |
| **Grey Seals/**<br><br>**Behavioural reaction** | No information | No information | No information | No information | No information |
| **Argument** | Displacement unknown | Can be heard far from construction; reaction zone unknown | Almost the entire local population will be within the range of impact, but compared to the total population only approx. 20 %, reaction zone unknown | During construction | |
| **Seals/**<br><br>**Increased boat traffic** | Medium | Local interests | Medium | Temporary | Minor |
| **Argument** | Displacement of animals up to a few hundred m | Within a few hundred m from boats | Animals occurring all year | During construction period | |

# 8 Assessment of effects in the operation period

### 8.1 Likely effects of operation on porpoises

Several studies have looked at harbour porpoise activity in the operation period of wind farms and compared it to activity levels before construction (baseline). Three studies are shown here which illustrate that very different results have been obtained.

In the Nysted Offshore Wind Farm, porpoise abundance was followed for ten years into the normal operational period. The main conclusion from this study was that porpoises in both the wind farm area and the nearby reference area were affected during the first year after operation, seen as increased waiting times between porpoise encounters and a decrease in the recorded click activity (porpoise positive minutes, PPM) (Figure 78). By the second operation period, 2-3 years after the construction, echolocation activity had returned to baseline level for the reference area, but the acoustic activity had still not reached baseline levels in the wind farm and had still not returned ten years after the construction, although there has been a small increase since construction (Teilmann & Carstensen, 2012).

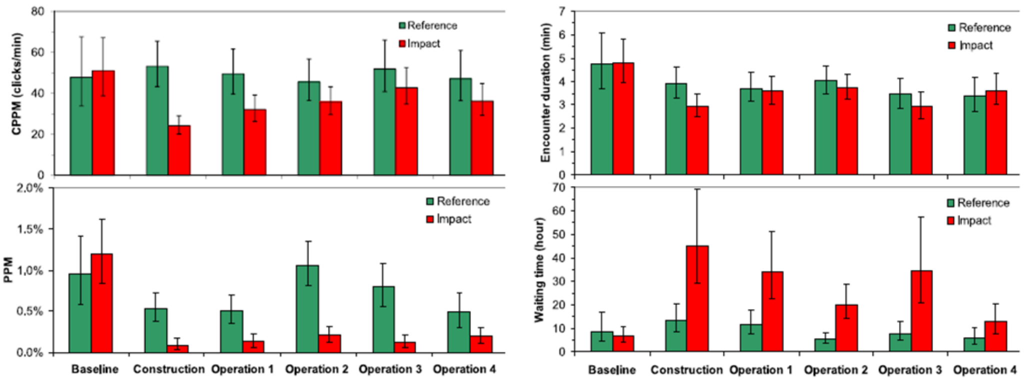



*Figure 78: Mean values for the four indicators back-transformed to the original scale for combinations of the two areas and the six periods (baseline: Nov 2001–Jun 2002, construction: Jul 2002–Nov 2003, operation 1: Dec 2003–Dec 2004, operation 2: Jan–Dec 2005, operation 3: Sep 2008–Feb 2009 and operation 4: Sep 2011–Mar 2012) in Nysted Offshore Wind Farm. Error bars indicate 95% confidence limits for the mean values. Variations caused by differences in months and T-POD versions have been accounted for by calculating marginal means (Teilmann & Carstensen, 2012).*

It has not been possible to pinpoint one or more factors responsible for the slow recovery at Nysted Offshore Wind Farm. The fact that significantly fewer porpoises are found in the wind farm ten years after completion strongly suggest that the effect is related to the operating wind farm and not a slow recovery from the impact of construction. A slow recovery would imply that the same animals that were disturbed during construction would still have memory of this and thus avoid the area, and at the same time that no other porpoises from the surrounding waters have entered the wind farm area and found conditions favourable. Given the large movements of individual animals, evidenced by the satellite telemetry data, this seems unlikely.

A newer study conducted at the Rødsand 2 Offshore Wind Farm, showed no overall effect on the porpoise activity from baseline to operation throughout the entire study area for any of the four indicators, Click PPM, PPM, Encounter duration (Encounters: groups of associated echolocation clicks) or Waiting time (between encounters) (Figure 79). Moreover, they observed no significant change in the echolocation activity in the impact area relative to the reference area, i.e. changes from baseline to operation were similar in the impact and reference areas (Teilmann & Tougaard, 2012).

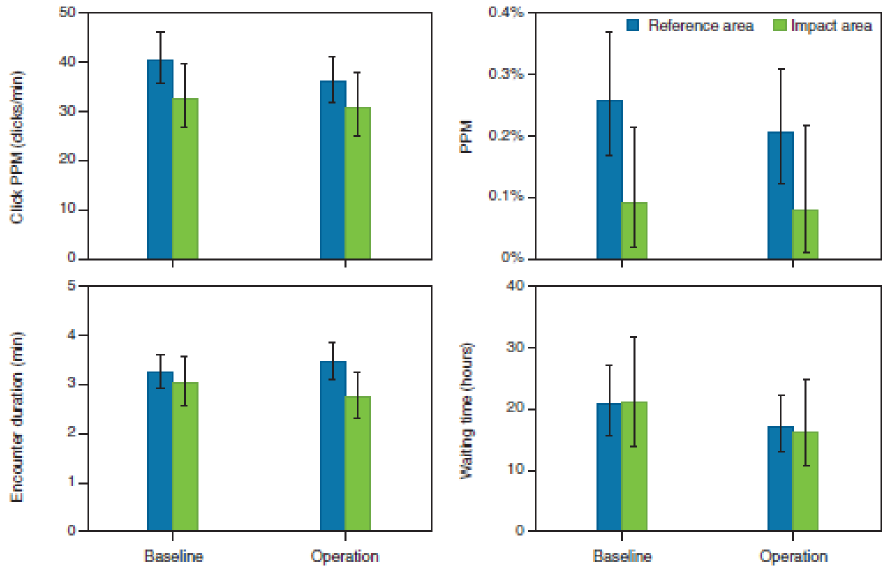



*Figure 79: Mean values for combinations of area and period back-transformed to the original scale for combinations of the two areas and the two periods, from Rødsand 2 Offshore Wind Farm. Error bars indicate 95% confidence limits for the mean values. Variations caused by differences in sub-areas and months have been accounted for by calculating marginal means (Teilmann & Tougaard, 2012).*

Scheidat, et al., (2011) demonstrated that after construction of the Egmond aan Zee offshore wind farm in Dutch waters, harbour porpoises returned to the operating wind farm in what appeared to be pre-construction numbers (Figure 80). They suggested that the wind farm area, where shipping is restricted, could potentially serve as a shelter in waters with otherwise heavy traffic, or could potentially mimic an artificial reef with increased foraging opportunities.

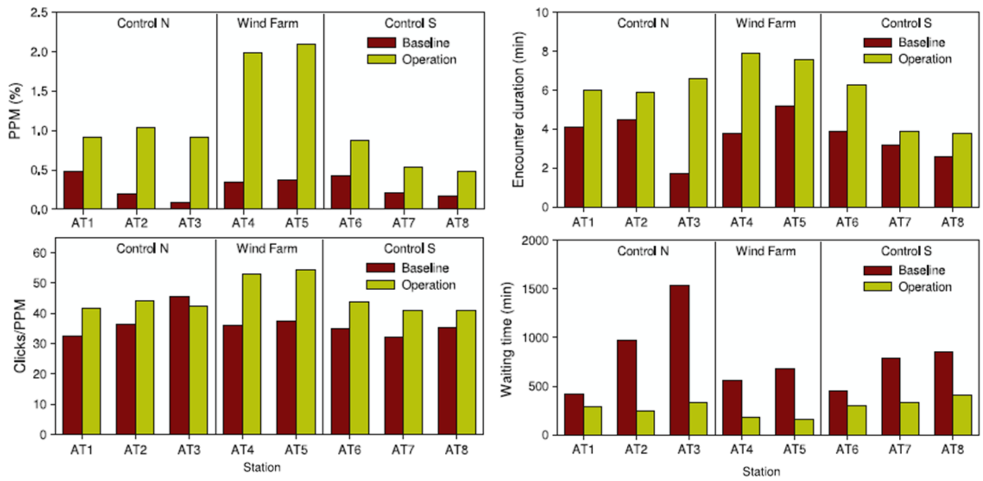



*Figure 80: Station-specific averages of the four indicators in Egmond aan Zee offshore wind farm. Stations within each area are ranked from west to east (Scheidat, et al., 2011).*

It is possible that the results from Nysted are exceptions from the rule. Porpoise activity – as measured with autonomous click detectors – did not differ from baseline levels into the operation period at Rødsand 2 Offshore Wind Farm. At Horns Rev I, porpoise activity returned to baseline levels during the first year of operation (Tougaard, et al., 2005). The results shown here from Egmont aan Zee also stand out from the rest (see also Murphy, et al., (2012) for a review).

**Noise from operating wind turbines**

At present, it is difficult to estimate the range at which lager turbines are audible to the porpoises. Wind turbines produce relatively low levels of noise with tonal components at frequencies below 1 kHz (Wahlberg & Westerberg, 2005) and combined with the relatively poor hearing abilities of porpoises at low frequencies this makes it, in principle, unlikely that they should be audible at large distances. Underwater noise recordings of operating turbines (max 2 MW), compared to harbour porpoise audiograms, also indicate that the zone of audibility is in the order of ~100 m (Madsen, Wahlberg, Tougaard, Lucke, & Tyack, 2006) (Tougaard, Henriksen, & Teilmann, 2009).

Besides being a disturbing factor in itself, noise has the potential to interfere with detection of other sounds, known as masking. This may occur when there is an overlap between the frequency ranges of the noise and the sound in question. The low frequency emphasis of the turbine noise makes it very unlikely that it will mask any sounds of importance to the porpoises under any conditions. The echolocation signals of porpoises contain virtually no energy below 100 kHz and are thus completely outside the frequency range of the turbine noise. There may be other sounds, such as from potential prey, which contain significant energy at lower frequencies and could thus potentially be masked by the turbine noise. However, it is well established that the audiogram of a particular animal reflects the frequency content of the sounds of importance to the particular animal. Porpoises have poor low frequency hearing, poorer than e.g. seals and considerably poorer than low frequency hearing specialists, such as fish. Thus, by this indirect inference, it seems unlikely that they listen for sounds below 1 kHz on a regular basis and any masking by the turbine noise in this frequency range is thus unlikely to be significant to harbour porpoises.

**Noise from service and maintenance activities**

As described in section 4.4, increased traffic with small fast boats that are known to be very noisy, especially at cruising speeds above 15 knots (Richardson W. J., Greene, Malme, & Thomson, 1995), (Erbe, 2002), could have a deterring effect on harbour porpoises. In contrast to the noise from the turbines, the boat noise is of intermittent nature and overall disturbance will depend on the duration of each visit and the intervals between visits. The effects of boat traffic on presence of harbour porpoises are poorly documented and while there is a general agreement that porpoises will evade individual fast motor vessels, there is no basis for concluding that high boat traffic levels generally correlate with low abundance of porpoises. Some of the highest densities of porpoises in inner Danish waters are in fact found in the most heavily trafficked areas, Great Belt and Little Belt (Sveegaard, et al., 2011).

**Changes in habitat**

The introduction of hard bottom substrates, in the form of foundations and scour protection on the sandy bottom will create changes to the habitat and may have a positive effect in the longer run as they may serve as artificial reefs or as sheltered areas with lower noise levels compared to heavily trafficked areas (Scheidat, et al., 2011), (Teilmann & Carstensen, 2012).

Mikkelsen et al., (2013) examined the effect of construction of an artificial stony reef on the presence of harbour porpoises. They found that echolocation activity increased significantly after the reconstruction, likely as a result of increased prey availability. Such reef structures are likely to attract fish, however, whether these fish species are important to porpoises and thus constitute an improvement of the quality of the area to porpoises, is difficult to conclude. As stony reefs are a natural type of habitat in the inner Danish waters and a habitat which was previously much more abundant than it is today (reefs were destroyed by extraction of stones and gravel, as well as damage from fishing gear), it is unlikely that the creation of this habitat could have a detrimental effect on porpoises. On the contrary, it remains a possibility that the net effect will be positive.

## 8.2 Likely effects of operation on seals

**Noise from operating wind turbines and service and maintenance activities**

Noise from the turbines could potentially disturb seals in the vicinity of the turbines, as may be the case with porpoises. Seals hear considerably better than porpoises at low frequencies and are thus probably able to hear the turbines at greater distances, perhaps up to several kilometres from the foundations (Madsen, Wahlberg, Tougaard, Lucke, & Tyack, 2006), (Thomsen, Lüdemann, Kafemann, & Piper, 2006). Common experience, combined with a few studies (e.g. Blackwell, Lawson, & Williams (2004)) however, suggests that seals are very tolerant to underwater noise. It is thus expected that the seals will habituate to the noise fairly quickly (Harris, Miller, & Richardson, 2001), (Southall, et al., 2007). In the same way it is expected that seals will habituate quickly to the increased service boat traffic in the wind farm area.

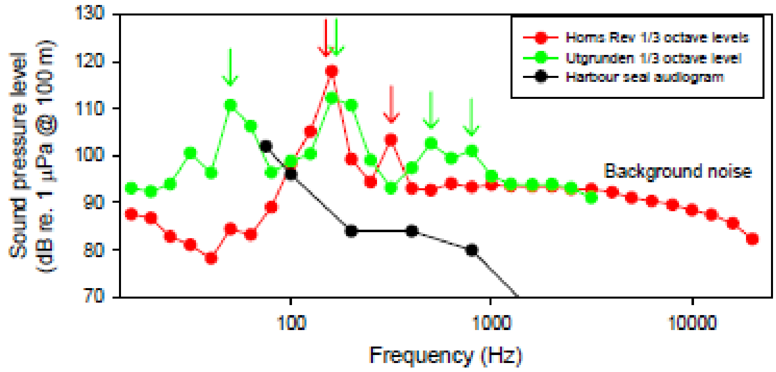



*Figure 81: Audiogram of harbour seal together with noise from two offshore wind turbines, expressed as 1/3-octave levels. Green and red arrows indicate peaks in the noise spectrum, which should be clearly audible to seals 100 m from the turbine and likely at considerably larger distances (Tougaard & Teilmann, 2007).*

Noise from the operation wind turbines could potentially cause masking of communication sounds in seals as there is significant frequency overlap in the lower frequencies between the sounds made by seals (Van Parijs, Hastie, & Thompson, 2000) and the sounds made by the wind farm. However, in the case of the harbour seal, the communication sounds contain significant energy above those of the wind turbine, and therefore complete masking of the signals is not likely to occur. This is also likely to be true for grey seals, even though their vocal repertoire is less well described.

**Likely effects of operation on seals based on tracking inside wind farms**

As seen from the tracking of the harbour seals from Falsterbo, the seals do not seem to avoid areas in The Sound, where offshore wind turbines have already been built. Of the harbour seals, 40% of the tracked seals entered The Sound area, namely HS01, HS02, HS07 and HS10 (Figure 82). However, these entrances were only single trips and only one of the seals (HS07) went through Lillgrund Wind Farm area and none through the Middelgrund Offshore Wind Farm area. The tracklines of HS07 did not indicate an effect of the Lillgrund Wind Farm. Another seal (HS01) went as far north as the Middelgrund Offshore Wind Farm area west of Saltholm, but this seals did not get closer than 3 km from the Middelgrund windturbines.

Based on the available data, it was therefore not possible to conduct a thorough analysis of the avoidance and behavioural changes inside the wind farm area.

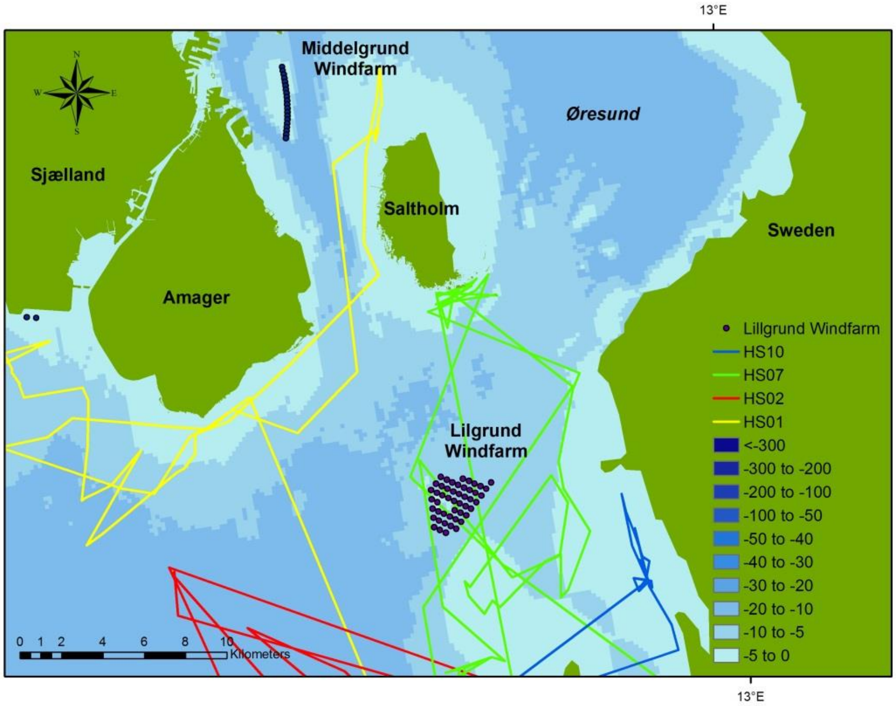



*Figure 82: Close op of the 4 harbour seals (40%) entering The Sound area where the Lillgrund and Middelgrund Windfarms are located.*

Of the grey seals, 64% of the tracked seals actually entered The Sound area, namely GS02, GS04, GS06, GS07, GS08, GS10 and GS11 (Figure 83). Six (not GS07) of these seven seals went through the Lillgrund Wind Farm area without any discernible behavioural change. However, only one seal (GS08) went as far north as the Middelgrund Offshore Wind Farm area east of Saltholm, but this seal did not get closer than 6 km from the Middelgrund wind turbines.

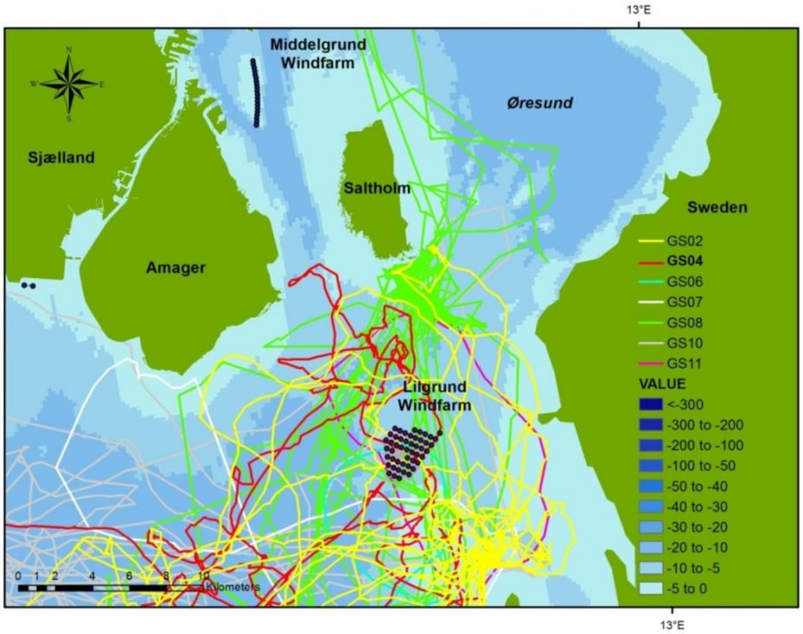



*Figure 83: Close op of the 7 grey seals (64%) entering The Sound area of which 6 also passed through the Lillgrund Wind Farm area.*

Recent studies have also been carried out on other populations of harbour seals from e.g. Rødsand in southern Denmark as well as from the Wash in Great Britain. In both cases, the harbour seals did not avoid the wind-farm areas (Figure 84; McConnell, Lonergan, & Dietz (2012).

McConnell, Lonergan, & Dietz (2012) concluded that both harbour and grey seals frequently transited from the two haul-out sites in the region through the two nearby wind farms (Nysted and Rødsand II). Visually, there is no obvious interruption of travel at the wind farms boundaries. Interaction was assessed using three analyses: 1. residence times within wind farm zones, 2. a comparison of path speed and tortuosity inside and outside the wind farms and 3. The proximity of individual locations to individual wind farm towers. All three analyses indicated no significant effect of the wind farms on seal behaviour. This is in accordance with another local study of haul-out counts (Edrén, et al., 2010) that concluded that the wind farms did not have a long term effect on the local seal population trends. However, McConnell, Lonergan, & Dietz (2012) also concluded that caution should be exercised in generalising the findings of that study to other potential sites of interaction. The type of wind farm foundation influences both the construction noise and also any subsequent reef effect. At other seal colonies, the different availability of alternative haul-out sites and foraging areas may affect their reaction to an altered seascape.

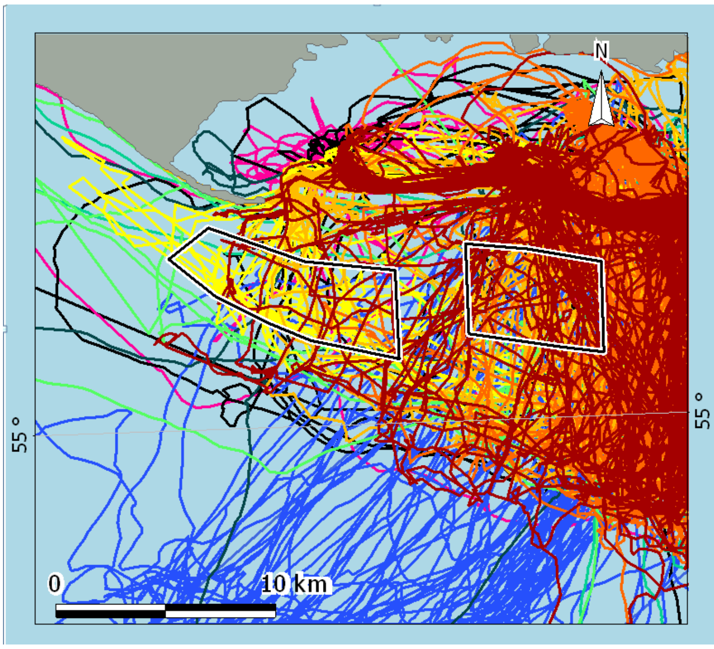



*Figure 84: Track lines of harbour and grey seals from Nysted I (square to the east) and Rødsand II (square to the west) Offshore Wind Farms showing that the seals do not avoid the wind farm areas (McConnell, Lonergan, & Dietz, 2012).*

**Assessment of the severity of impacts during operation**

The results of the impact assessment of the operational wind farm are assessed in Table 30. The effects on harbour porpoises and seals are generally thought to be minor during the operational phase, however, if the effect on porpoises will be similar to what was seen at Nysted the effect might be moderate. There may in some cases also be positive effects due to artificial reef effects that could increase foraging opportunities although we have no data to support this hypothesis.

*Table 30. Overall effect of the operating wind farm on marine mammals*

| **Marine mammals – Operation phase** | | | | | |
|---|---|---|---|---|---|
| **Source**<br>**Type**<br>**Receptor** | **Degree of disturbance** | **Importance** | **Likelihood** | **Duration** | **Extend of impact** |
| **Harbour porpoise/**<br>**Operating wind turbines** | Low | Local interests | Medium | Permanent | Minor |
| **Argument** | Displacement due to noise will only happen for few animals | Only very near or medium range of the turbines | Animals mainly in region autumn /winter | Duration of the wind farm | |
| **Harbour porpoise/**<br>**Maintenance activities** | Low | Local interests | Medium | Permanent | Minor |
| **Argument** | Small increase in boat traffic | Only around boats | Animals mainly in region autumn/winter | Duration of the wind farm | |
| **Harbour porpoise/**<br>**Changed habitat** | Possibly positive effect depending on the effect on fish | Local interest | Low | Permanent | Minor |
| **Argument** | Reef effect of the foundations | Around each foundation | Unlikely to occur for majority of prey species | Duration of the wind farm | Minor |
| **Seals/**<br>**Operating wind turbines** | Low | Local interests | Medium | Permanent | Minor |

| Marine mammals – Operation phase | | | | | |
|---|---|---|---|---|---|
| **Source**<br><br>**Type**<br><br>**Receptor** | **Degree of di-sturbance** | **Importance** | **Likelihood** | **Duration** | **Extend of impact** |
| **Argument** | Displacement due to noise is likely very low | Only in near vi-cinity of the turbines | Only a fraction of seals will come into that range | Duration of the wind farm | |
| **Seals/**<br><br>**Maintenance activities** | Low | Local interests | Medium | Permanent | Minor |
| **Argument** | Small increase in boat traffic | Only around boats | Only a fraction of seals will come into that range | Duration of the wind farm | |
| **Seals/**<br><br>**Changed habitat** | Possibly positi-ve effect | Local interest | Medium | Permanent | Minor |
| **Argument** | Reef effect of the foundations | Around each foundation | Unlikely to oc-cur for majori-ty of prey spe-cies | Duration of the wind farm | Minor |

# 9 Assessment of effects of the decommissioning

Decommissioning of the wind farm is likely to represent an impact comparable to the construction or less, depending on methods and to which degree structures are removed.

Removal of superstructures (turbines, transformer etc.) is basically the reverse operation of construction and will thus involve the same degree or more of construction work and ship traffic associated disturbance to seals and porpoises in the area. The same is the case for removal of power cables buried in the sea bed.

Gravitational foundations will require considerable effort to remove, as ballast rocks must be taken out before each foundation can be lifted away by a heavy crane. For decommissioning of such foundations, several methods could be considered for the removal, which are highly varying in noise profile. These are drilling, cutting and shipping.

Behavioural disturbances will be expected at far distances from the construction site, similar to those described for construction. Although the disturbance in itself may not be greater than during construction, the fact that it will likely extend over a considerably longer period will increase the impact. Judging from effects seen during construction of Nysted Offshore Wind Farm, this could have a significant effect on the abundance of harbour porpoises in the area, and probably in a lesser degree on seals.

Decommissioning of a wind farm could thus potentially affect a large number of animals, depending on the decommissioning method utilized. It could therefore be considered from case to case whether removing the foundation is completely necessary. No negative impact of the abandoned concrete structures on seals and porpoises can be imagined. On the contrary, the artificial reef created by the foundations may constitute a permanent improvement of the habitat, and thus benefit seals and porpoises. Before any activities take place, a thorough investigation of effects should be conducted to secure the use of proper mitigation methods.

Removal of steel monopile foundations is considered less problematic than gravitational foundations, as the monopiles can be cut just above the seabed and covered with a protective layer of gravel or boulders. Such work can be expected to be conducted over a relatively short time span, thus reducing the impact on seals and porpoises. As for the gravitational foundations, no negative effects of the monopiles themselves can be imagined and leaving them in place is the best solution seen from the marine mammals' point of view.

**Assessment of the severity of impacts during decommissioning**

The results of the impact assessment of a possible dismantling of the wind farm are assessed in Table 31. The effects on harbour porpoises and seals are generally thought to be minor to moderate, but this will depend on the type of foundation to be removed, and on the method of removal.

*Table 31: Overall effect of dismantling the wind farm on marine mammals*

| **Marine mammals – Decommissioning phase** | | | | | |
|---|---|---|---|---|---|
| **Source**<br><br>**Type**<br><br>**Receptor** | **Degree of disturbance** | **Importance** | **Likelihood** | **Duration** | **Extend of impact** |
| **<u>Harbour porpoise/</u>**<br><br>**Ship noise** | Medium | Local interest | High | Temporary | Minor |
| **Argument** | Displacement due to increased ship activity | Locally around boats | The wind farm has to go through some degree of dismantling | During dismantling period | |
| **<u>Harbour porpoise/</u>**<br><br>**Decommissioning activities** | Medium | Regional interest | Medium | Temporary | Moderate |
| **Argument** | Noise will disturb animals far away | Can be heard in the region | Depending on the choice of decommission | During decommissioning period | |
| **<u>Seals/</u>**<br><br>**Ship noise** | Medium | Local interest | High | Temporary | Minor |
| **Argument** | Displacement due to increased ship activity | In the area around shipping | The wind farm has to go through some degree of decommission | During decommissioning period | |
| **<u>Seals/</u>**<br><br>**Decommissioning activities** | Medium | Regional interest | Medium | Temporary | Moderate |
| **Argument** | Noise will disturb animals within _ km | Can be heard in the region | Depending on the choice of decommission | During decommissioning period | |

# 10 Uncertainties

The modelled densities and the impacted proportion of the animals in the area and of the populations are based on satellite tracked harbour porpoises, grey and harbour seals. Whether the number of animals tracked has been sufficient to model their densities in the entire study area is uncertain. Due to limited data we decided not to model the densities of porpoises in the winter and spring. While the two seal species were modelled for all seasons, it is clear that data from some seasons give a better model fit.

The impact assessment we are presenting here comes with a number of uncertainties, especially during the construction phase. Pile driving is broadband, but has most of its energy at the lower frequencies (i.e. < 1 kHz). There is no indication that a TTS at these frequencies can affect the ability of porpoises to navigate and forage using echolocation (main frequencies around 130 kHz). Potentially, the ability to detect low frequency vessels could be affected. However, most vessel noise is much below 1 kHz where porpoise hearing is poor. The biological relevance of a low frequency TTS is thus difficult to assess, although it is considered a temporary physical damage to the animal (see Kastelein et al., (2012) for a discussion on this point).

We have shown that impact of multiple noise exposure may occur at substantial ranges. The threshold levels used were based on the recommendation of the Working Group (2015) established by Energinet.dk. There are some uncertainties regarding these criterions for multiple strikes as well as the validity of the underlying assumptions. For example, in the noise modelling we have followed best practice by assessing the cumulative exposure over 24 h (or one turbine construction lasting 6 hours; see details in the noise modelling report). It is not known whether this criterion is sufficient, especially as we would expect porpoises (and other marine mammals) to avoid aversive sound fields resulting in a constant change of the acoustic dose received. There are draft recommendations by NOAA (2013) that are currently under review to base the assessment of cumulative impacts on 1 hour periods to account for responsive movement. In our case, the number of strikes would have to be reduced to approx. one-third. Thus, the values given for cumulative exposure have to be treated with caution.

Also, since the recommendations of the working group were given, Kastelein R. A., Gransier, Marijt, & Hoek (2015) published new results on temporary threshold shift in harbour porpoises. They found a much higher threshold (180 dB SEL) than the one recommended by the Working Group (164 dB SEL). There is thus, at present some uncertainty regarding this threshold and it is possible that the level which the modelling is based on here is over-estimated.

The behavioural impact ranges during construction have been estimated at few attempts in reality.  The 140 SEL criterion is unweighted, meaning broad band levels of the sound without consideration of the detection characteristics of porpoises. As pile driving mainly consists of low frequency noise, it is outside the range of best hearing of harbour porpoises. At ranges of several tens of km, the frequencies at which harbour porpoises are most sensitive will have been attenuated more than the lower frequencies in the sound. Therefore, though the total energy may still be significant at 43 km, the energy that affects harbour porpoise behaviour may not be as pronounced. A behaviour disturbance range of 43 km is thus still speculative for porpoises. The long term effects of this displacement are also uncertain. In some cases, porpoises have returned (or other animals have entered the area) of the wind farm site shortly after the end of the construction period (Tougaard, et al., 2005), (Scheidat, et al., 2011). Still, at Nysted Offshore Wind Farm, animals may be very slow in returning or have been permanently displaced (Teilmann & Carstensen, 2012).

For seals, the impact ranges of cumulative strikes stretches far from the source, but similar to the harbour porpoises, the criterions for multiple strikes are fraught with uncertainty due to very few experimental data, on a very limited number of individuals. The assumption of equal energy is not tested on pinnipeds either ( (NOAA, 2013) and see discussion above on porpoises). In addition, we have to consider that NOAA is currently revising the TTS and PTS criteria for pinnipeds. The cumulative noise effect ranges are therefore still speculative.

# 11 Cumulative effects

Cumulative effects (not to be confused with the cumulative effect of multiple strikes) are defined as the combined effects, larger than the simple sum of the individual effects on population level. Identifying and assessing effects of a wind farm at a given location along with the species that occur there, is fundamentally different from predicting cumulative effects on a population as a whole. The latter remains one of the greatest challenges in the marine spatial planning process. Assessing cumulative impacts of multiple human stressors requires detailed knowledge of population dynamics and the way these factors interact in space and time. This requires integration of information from the entire area used by each population that may be affected. In the case of marine mammals, assessing cumulative effects would require information originating from hundreds of kilometres away and integrating all other pressures affecting the population throughout the annual cycle and throughout the natural range. To date, wind farm developments have suffered from too few replicated, controlled, long term evaluations of impact comparing conditions before and after construction, as well as monitoring of too short duration and poor study design. We also need improved modelling tools to quantify the complex interplay between changes in habitat quality and availability, responses to environmental stimuli, changes to ecological community structure and function. Foreseeing and mitigating the ecological consequences of exploitation of the marine environment will require spatially and temporally explicit monitoring of physical drivers within and outside of wind farm areas. Until we improve our ability to quantify the biological responses of communities to these drivers and their interactions, the cumulative impacts of wind farms on top of all other human induced pressures is not possible. The most informative studies for assessing the consequences of offshore installations are those that have monitored community changes in time and space prior to construction and decades into the life of the wind farm. Such monitoring will help to increase our post-EIA audit to assess the accuracy of model predictions, and enhance the ability to make quantitative assessments of how ecological changes may develop in locations of offshore installations. We also need to focus on new responses (e.g. habituation to stimuli), and track offshore developments with regard to larger turbines, larger farm areas, novel foundation types and in new locations.

In the case of cumulative impacts at Kriegers Flak, near shore wind farms in Danish waters may be relevant, yet the closest sites such as Rødsand I and II are too distant to have any measureable impact due to underwater noise emissions. The Baltic 1 offshore wind farm in German waters is located more than 20 km away from the planned site at Kriegers Flak and thus outside acoustic range. The only existing wind farm in close vicinity of Kriegers Flak is the EnBW Baltic II (Germany). The wind farm is constructed in spring 2014 with 39 monopiles and 41 Jacket foundations (source: http://www.4coffshore.com). The constriction of this wind farm will likely have had some effect on the local populations of marine mammals. However, it can be also predicted that the construction period for the wind farm that falls under German regulation has been applying the BSH noise exposure criteria (sound levels shall not exceed 160 dB SEL at 750 m from the construction site). Thus, most likely the whole construction period has been performed using mitigation measures to reduce noise levels such as bubble curtains (see Pehlke, et al., (2013). These will have led to a reduction of impact ranges to some extent. Also in the Kriegers Flak area, a Swedish wind farm is planned, that will have additional cumulative effects of the marine mammals in the area. Due to the very close vicinity, the impacts during construction and operation will most likely be very similar to the ones predicted in this assessment leading to potential large scale response and physiological impacts on marine mammals (see Carstensen, Henriksen, & Teilmann (2006) for changes in porpoise abundance during construction of wind farms).

Dredging activities for sand and gravel in middle of the Kriegers Flak bank will also contribute to the cumulative disturbances in the area, but the type of activities and the noise produced is not known.

# 12 Mitigation measures

## 12.1 The construction phase

**Air-bubble curtain**

The potential for serious detrimental effects of pile driving of the 10 m diameter worst case monopile foundation creates a need for serious consideration of mitigation measures, if the situation becomes relevant. The best way to reduce impact is to reduce the energy radiated into the water column. Air-bubble curtains have been used on various occasions to reduce sound pressures from construction activities e.g. Würsig, Greene, & Jefferson (2000), (Reyeff, 2006).

A bubble curtain is a sheet or “wall” of air bubbles that is produced around the location where the pile driving will occur. Air bubbles in a bubble curtain create an acoustical impedance mismatch which is effective in blocking sound transmission (Spence, Fischer, Bahtiarian, Boroditsky, Jones, & Dempsey, 2007).

The mitigation of the sound from the pile driving using bubble curtains has recently been documented in detail by (Pehlke, et al., 2013) performing measurements from the FINO3 platform in the North Sea. The frequency dependent reduction in sound level is shown in Figure 85. It can be seen that the sound reduction is strongly depending on frequency with the best mitigation effect at around 1 kHz.

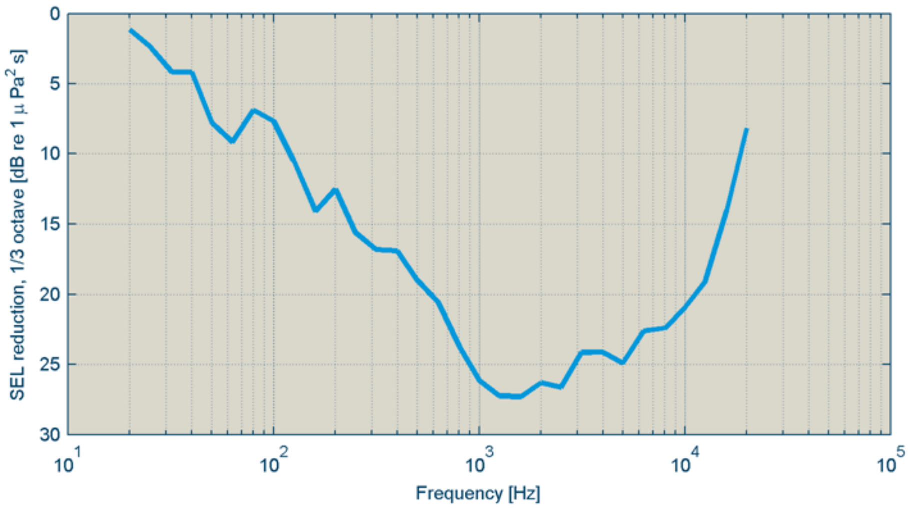



*Figure 85: Frequency dependent reduction in SEL from a bubble curtain. From Pehlke, et al., (2013).*

Considerable experience has been gained in connection to various construction works on bridge piers in the San Francisco Bay area (Reyeff, 2006) (Rodkin & Reyff, 2004). The San Francisco Bay area is home to several species of marine mammals, including harbour porpoises and seals, and the air bubble curtains were implemented in order to reduce the exposure of marine life to excessive levels of underwater noise. This air-bubble curtain was able to reduce the radiated sound pressures by 25-30 dB, equal to a reduction in energy of 20-30 times. This reduction was most pronounced at low frequencies, but even at 5 kHz (the highest frequency at which measurements are available) a reduction of about 10 dB was observed.

A large number of different versions of air-bubble curtains and cofferdams have been used in the San Francisco Bay projects, with different success, depending on type of pile, bottom conditions and water depth. It is too early to conclude whether some of these systems could be transferred directly to the less sheltered conditions at Kriegers Flak, or if new systems would need to be developed. The experience from San Francisco Bay nevertheless raises promise that it is technically possible to develop such systems.

**Acoustic deterrent devices**

If pilings are performed without reduction in radiated energy, as would be the case for standard sheet pile drivings, if these should be needed, the risk that porpoises are exposed to dangerously high levels of noise in the immediate vicinity of the pile can be reduced or eliminated by the use of acoustic alarms. Underwater acoustic alarms, such as gillnet pingers or seal-scarers switched on immediately before piling commences will deter porpoises out to distances of at least a few hundred meters (pingers) or up to 7.5 km (seal scarers, (Brandt, et al., 2012)), which would bring them out to safer distances. Pingers have been used in connection to previous pilings, together with a seal-scarer. The latter is designed to deter seals from aquaculture farms and fishing nets. Because seals are generally more tolerant to loud underwater noise, the seal scarer operates at a considerably higher sound level than porpoise pingers. Seal scares use signals at frequencies well within hearing range of porpoises and they are thus likely to be deterred more strongly by the seal-scarer than the pingers, which means that it is likely that only a single seal-scarer would be needed to keep porpoises away. Acoustic alarms should not be engaged continuously during the construction period to avoid long term displacement from the area and potential habituation to the sounds. They should rather be engaged prior to each piling and turned off when the operation is completed (or as soon as the piling is in process, as the piling sounds themselves will prevent animals from coming too close to the pile).

**Ramp up procedures**

Ramp up procedures, where the energy delivered to the pile by the pile driver is increased gradually over the first blows may have the same protective effects as deployment of acoustic alarms although it is difficult to control the intensity from the first ramp up strikes. This method is generally used during seismic airgun operation in areas where marine mammals are likely to occur.

**Alternative foundation**

In many previous wind farms constructions, including the majority of the foundations around Nysted Offshore Wind Farm and at Rødsand 2 Offshore Windfarm, gravitational foundations were used. Piling may however be needed in order to stabilise the seabed below the concrete foundations with a sheet pile wall or similar. Gravitational foundations alone are unlikely to cause physical effects, while behavioural disturbance at the wind farm site during construction and possibly also during operation must be expected. Steel monopile and jacket foundations, however, will produce significant impacts because of the high intensity of underwater noise.

# 13 Conclusion and recommendations

For harbour porpoises, the most important habitat areas are in the south-western part of the study area, in the waters between Møn, Falster and Germany and along the coast of Zealand.

For harbour seals, the most intensively used areas were located north of the construction site during autumn and somewhat more to the east during winter.

For the grey seals, the areas that were predicted to be intensely used were mostly located along the coasts of Sweden and Germany, but also in the relatively shallow waters in the northern part of the construction site and just north and east of the site.

However, all three species showed seasonal variation in the dispersal and migrations.

Gravitational foundations alone are unlikely to cause effects other than behavioural disturbance at the wind farm site during construction. Steel monopile and jacket foundations, however, will produce significant impacts because of the high intensity underwater noise. Jacket foundations will have lower sound pressure level emissions since the pile diameter is much smaller compared to the worst case scenario used here (see for example Thompsen et al., (2006)). However, it will also take many more strikes to install one turbine compared to a single steel monopile, so the overall acoustic energy emitted could be similar.

For porpoises, permanent physical impact (Permanent Threshold Shift; PTS) due to the exposure of cumulative pile driving strikes (7000 strikes per monopile) may be inflicted at substantial ranges from the source (17 km). Temporary noise induced hearing threshold shifts (TTS) can occur at even more considerable distances (approx. 49 km) from the noise source. By estimating the proportions of the population exposed from the model, PTS is likely to occur in 3.6 % (1 465 individuals) and TTS in 11.7 % (4 748 individuals) of the local porpoise stock. If we only look at the modelled area for the summer and autumn seasons, these proportions increase up to 13 % and 55 % for PTS and TTS respectively. The level on behavioural changes in harbour porpoises is also severe. A single strike will potentially induce avoidance behaviour in up to 47 % of the individuals in the modelled area during summer and autumn, effectively displacing half of all individuals in the area. On the scale of the population, 10.7 % (4 311 individuals) would be displaced. The short-term effect is therefore quite severe. Deterrence with acoustic harassment devices and a 16 dB reduction in source level, achieved by the use of bubble curtains or other similar mitigation measures, would remove the risk of inflicting PTS in porpoises. Though ranges for TTS (22 km), and behavioural disturbances are still large this reduction in distance will reduce the number of individuals affected significantly.

For the seals, no studies have estimated behavioural changes from pile driving activities, so this effect could not be evaluated. In seals, PTS due to exposure to a cumulative pile strikes are restricted to very close ranges relatively close to the source (approx. 590 m), however, cumulative strikes may cause TTS in seals out to a distance of 28 km. In harbour seals, PTS could therefore potentially be induced in less than 2 % of the local harbour seal population calculated as mean of the whole year, or 6 individuals. TTS could annually be induced in 49.2 % (226 individuals) of the local population or 14.7 % if evaluated from the entire Western Baltic harbour seal management unit. The impacts on the local harbour seal population, as well as on the total management unit are therefore very high. However, TTS is a short-term effect and will only be present during construction. It should be noted that harbour seals has a very local distribution with few alternative haul-out sites, which means that they may not be able to find alternative sites while construction noise levels are very high and would have to stay in the area. For grey seals, cumulative strikes may only potentially induce PTS in maximum 1 % of the individuals in the modelling area during the year (27 individuals). For the whole year, 5.6 % of the local or 3.9 % of the total population (1 644 individuals) are at risk of developing TTS. The assessed physical impact on the whole population during the whole year is hence intermediate compared to the effect on the harbour seals population.

To remove the risk of PTS in seals, it would require a noise reduction of 8 dB by use of bubble curtains or the like if a seal was 10 m from the source. This would reduce the range of inflicting TTS to 6 km. Behavioural responses of seals will likely be a moderate impact, though depending on whether the effect is evaluated on a local or regional scale, and depending on the expected time of return for the displaced animals it may become a major impact. A very slow ramp-up will make it possible for the animal to swim out of the zone of physical damage before the real pile driving goes on. However, it will still take animals several hours to escape the noise exposure.

During the operation period, noise from the turbines will only likely be a disturbing factor to the harbour porpoises, and while noise from increased boat traffic can have a moderate effect it is less unlikely that the electromagnetic fields will have a significant effect. Changes in habitat are unlikely to be detrimental, but there is no evidence that changes may be positive to marine mammals, although it remains a possibility around the foundations.

Cumulative effects of other anthropogenic disturbances on top of those related to the new wind farm may further increase the impacts assessed in this report. Impacts from existing wind farms in the vicinity are expected to be negligible. Construction of the German EnBW Baltic II which is on the immediate vicinity of Kriegers Flak could lead to identical impacts as those predicted here. Yet, it is expected that mitigation measures will reduce the impact ranges to a large extent. With the present knowledge and models it is not possible to assess cumulative effects on local or population level in more detail.

The decommissioning of the wind farm may constitute impacts comparable to construction or less, depending on the methods employed. Decommissioning methods may cause effects similar to those described for construction, and will likely extend over a longer period, which will increase the impact. If the foundations are not removed, these impacts would be greatly reduced. There is no evidence of adverse effects from the foundations. Steel monopile foundations would be less problematic to remove, and this could be done in a shorter time-span, reducing the impact on seals and porpoises.

**Recommendations**

It is clear from this assessment that under a worst-case scenario, impacts of the monopile construction for Krieger's Flak could be substantial for marine mammals. Yet, we have also pointed out the uncertainties in the assessment. It has to be repeated here that numerical noise modelling was following a very precautionary approach picking periods of the year where sound transmission would be maximised. Furthermore, the methods for assessing the cumulative impacts of a number strikes is currently under scientific revision. Finally, our population assumptions are very conservative. Thus, the numbers presented here shall be viewed with caution.

Having said that, we are in a position to conclude that the impact on porpoise and seals warrant a consideration of noise mitigation measures. This could be accomplished by using acoustic harassment devices for porpoises and employing bubble curtains around the monopile ramming. A 16 dB reduction in emitted sound levels would remove the risk of causing PTS in both porpoises and seals and greatly reduce the range of TTS. Again, the assumptions of noise emissions and impact ranges used here are conservative and have been considered for a worst case scenario.

The use of gravitational foundations would eliminate the severe underwater noise impact of the steel monopile foundation ramming on the marine mammals to a large extend. Therefore the use of gravitational foundations is recommended, provided that the effect of associated sheet piling are kept to a minimum and mitigated using e.g. seal-scarers.

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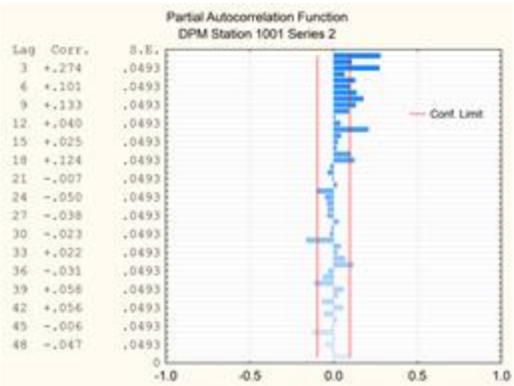
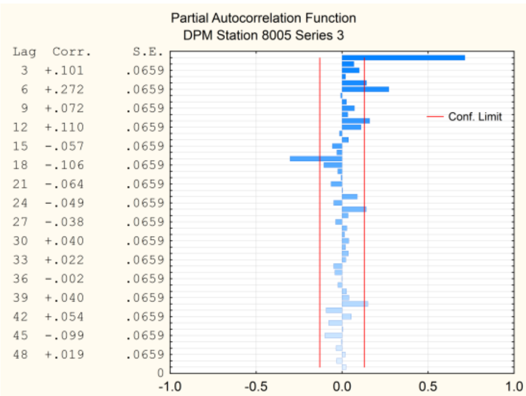
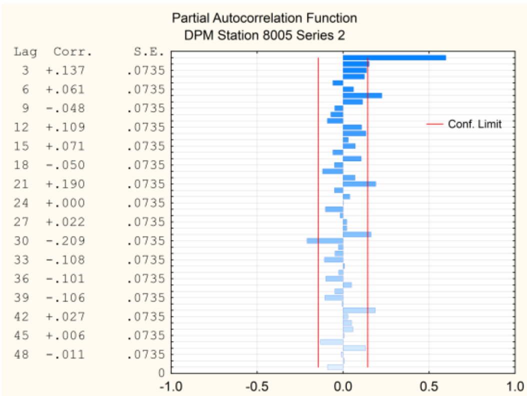
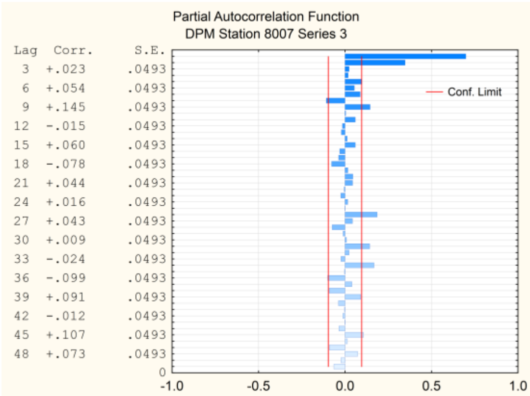
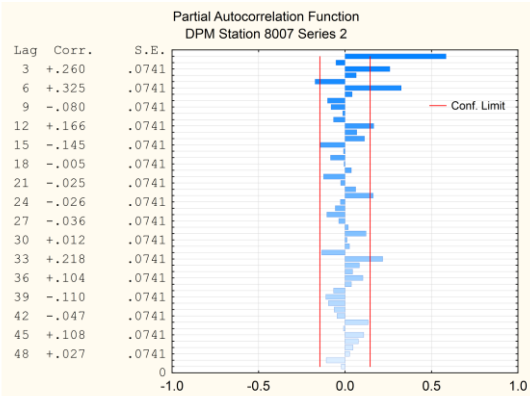
*Appendix 1: Partial serial autocorrelation functions of daily DPM values recorded at the three SAMBAH stations. Autocorrelation coefficients and associated confidence intervals (red lines) are shown for 50 days. Lags indicate k-1 days. The two longest continuous daily record series are included for station 8005 and 8007, whereas only one long time series was recorded at station 1001.*






## *Appendix 2: Setting for the SAS Argos-Filter v7.03*

| Parameters | Setting |
|---|---|
| Minoffh | 0.0001 |
| Maxredun | 5 |
| Minrate | 10 |
| Ratecoef | 10 |
| R_only | 1 |
| R_or_a | 0 |
| Keep_lc | 3 |
| Keepplast | 0 |
| Pickday | 0 |
| Test_Oa | 2 |
| Test_bz | 2 |

## *Appendix 3: Correlation of environmental variables used in MaxEnt modelling*

Spearman rank correlation coefficient (r) of the environmental variables. Correlation is based on 10 000 randomly picked cells.

Summer (Jun-Aug)

| | Slope | Curv. | Dist. | Ship | Front | Sal. | Temp. | u-Vel | v-Vel |
|---|---|---|---|---|---|---|---|---|---|
| Depth | -0.40 | 0.10 | -0.80 | -0.61 | 0.14 | -0.29 | 0.46 | -0.26 | 0.37 |
| Slope | | -0.02 | 0.29 | 0.34 | 0.35 | 0.43 | -0.03 | 0.30 | 0.00 |
| Curvature | | | -0.05 | -0.07 | -0.08 | -0.08 | -0.02 | -0.03 | 0.01 |

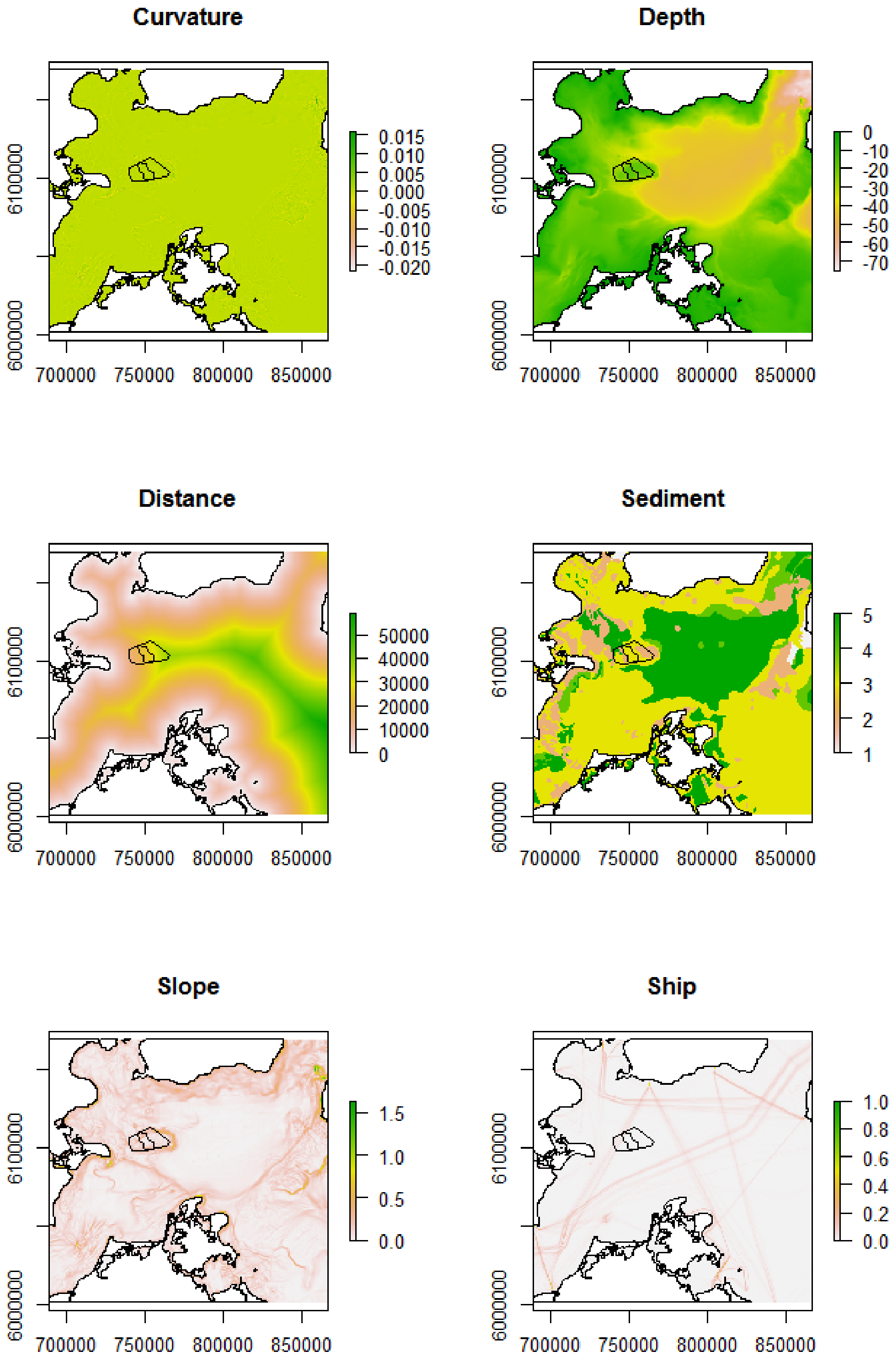
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Distance | | | | 0.43 | -0.22 | 0.36 | -0.05 | 0.31 | -0.38 |
| Skip | | | | | 0.06 | 0.39 | -0.19 | 0.12 | -0.17 |
| Front | | | | | | 0.33 | 0.11 | 0.14 | 0.16 |
| Salinity | | | | | | | 0.09 | 0.12 | -0.08 |
| u-Velocity | | | | | | | | | -0.03 |

<u>Autumn (Sep-Nov)</u>

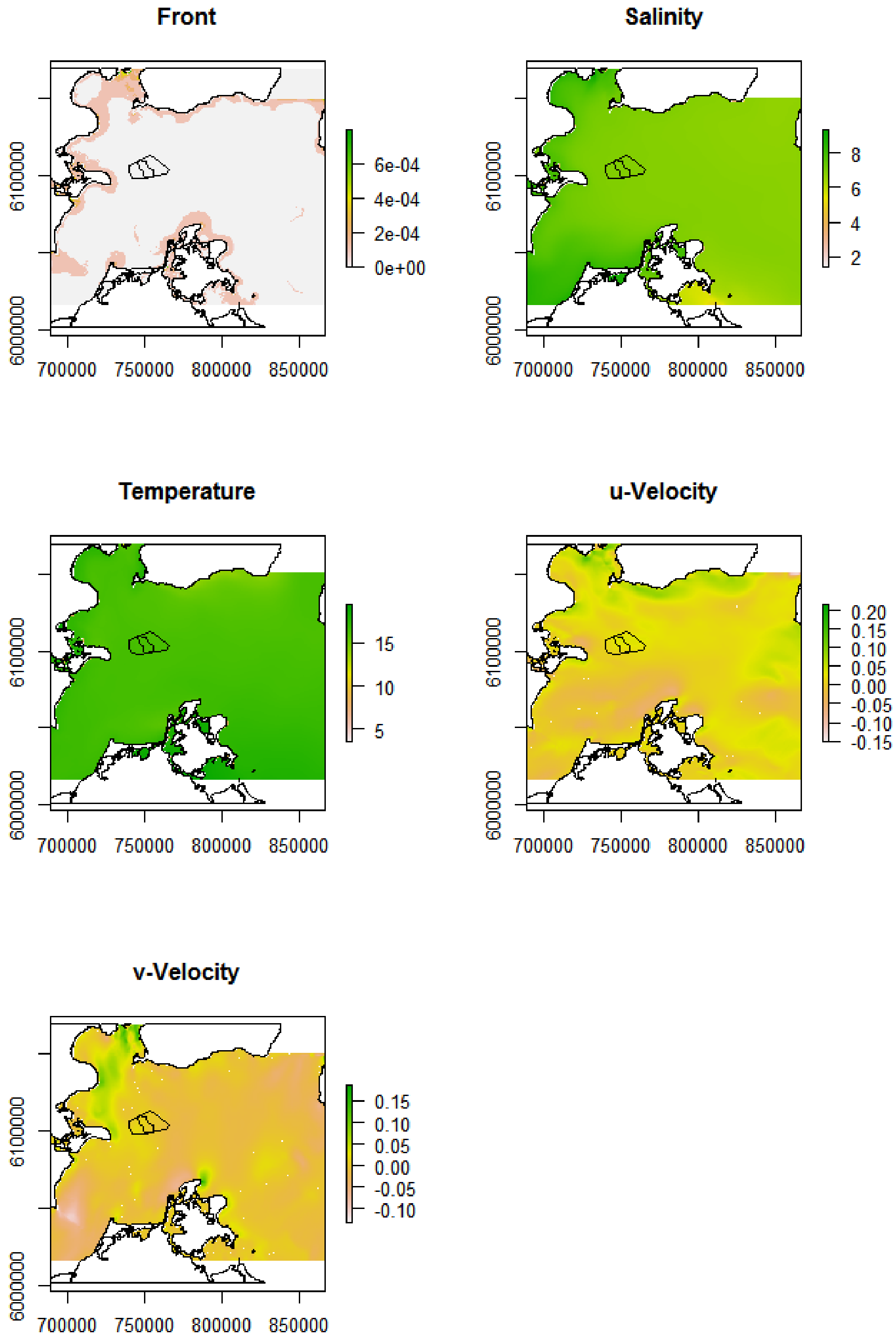
| | Slope | Curv. | Dist. | Ship | Front | Sal. | Temp. | u-Vel | v-Vel |
|---|---|---|---|---|---|---|---|---|---|
| Depth | -0.40 | 0.10 | -0.80 | -0.61 | 0.09 | -0.34 | -0.41 | -0.32 | -0.09 |
| Slope | | -0.02 | 0.29 | 0.34 | 0.41 | 0.42 | -0.22 | 0.28 | 0.24 |
| Curvature | | | -0.05 | -0.07 | -0.08 | -0.09 | 0.03 | -0.04 | -0.03 |
| Distance | | | | 0.43 | -0.18 | 0.31 | 0.56 | 0.41 | 0.24 |
| Ship | | | | | 0.15 | 0.45 | 0.08 | 0.19 | 0.14 |
| Front | | | | | | 0.47 | -0.33 | 0.12 | 0.20 |
| Salinity | | | | | | - | 0.18 | 0.21 | 0.29 |
| u-Velocity | | | | | | | | | 0.28 |

*Appendix 4: Maps of environmental variables used in MaxEnt modelling.*

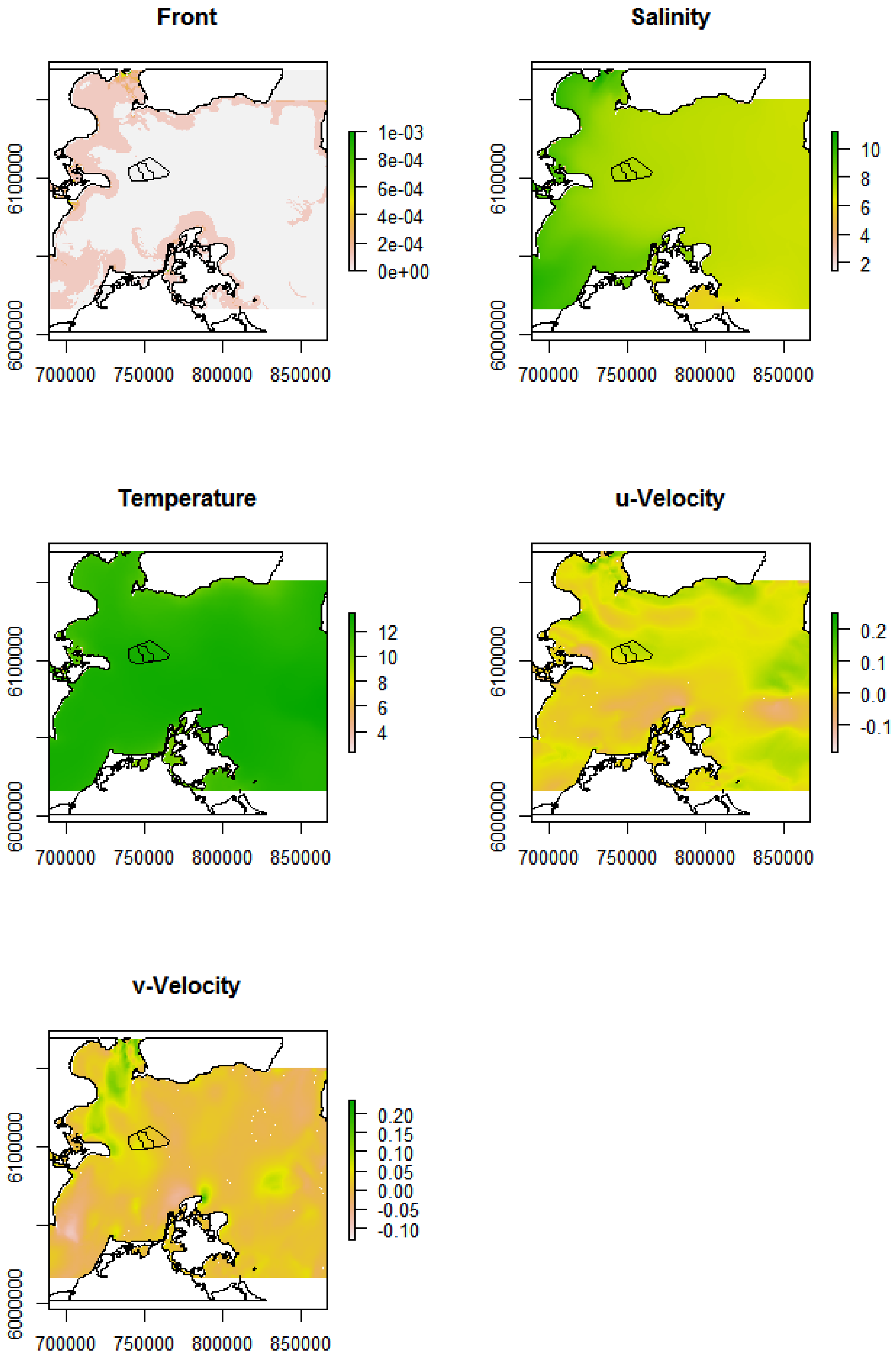
Static variables:



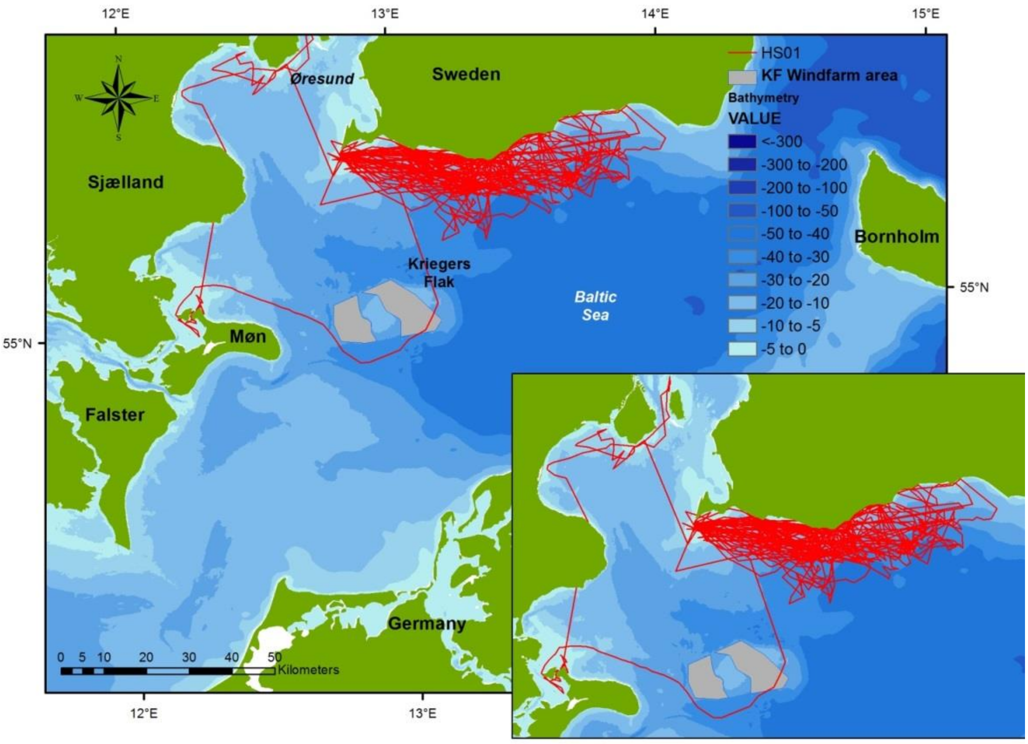

Dynamic variables – summer (June-August):

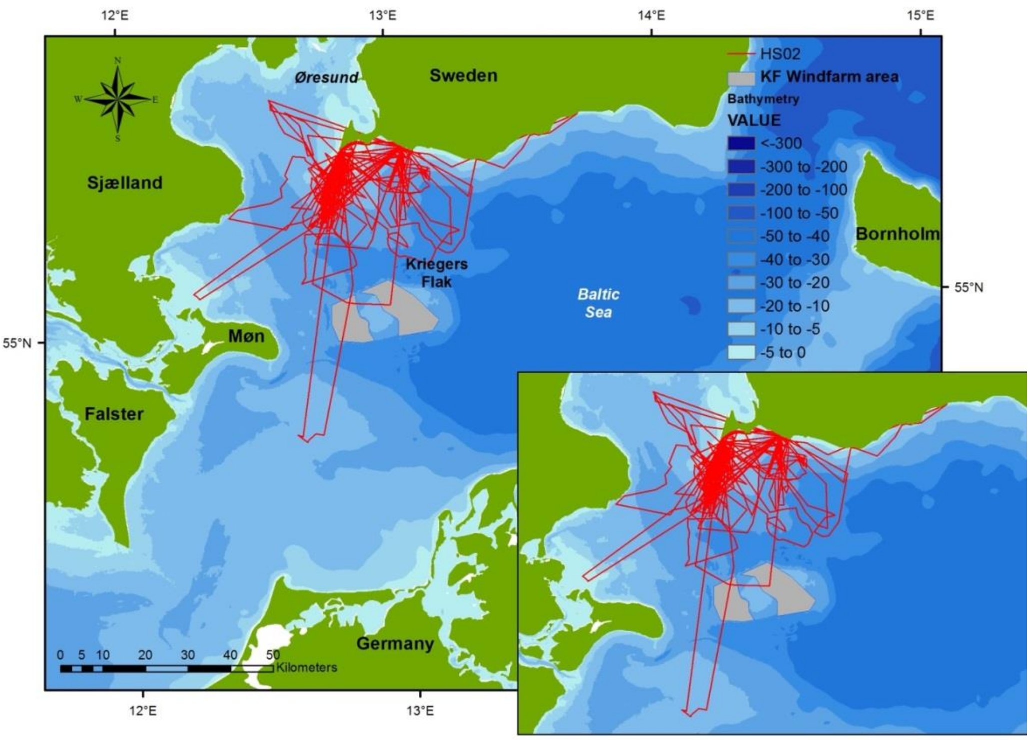


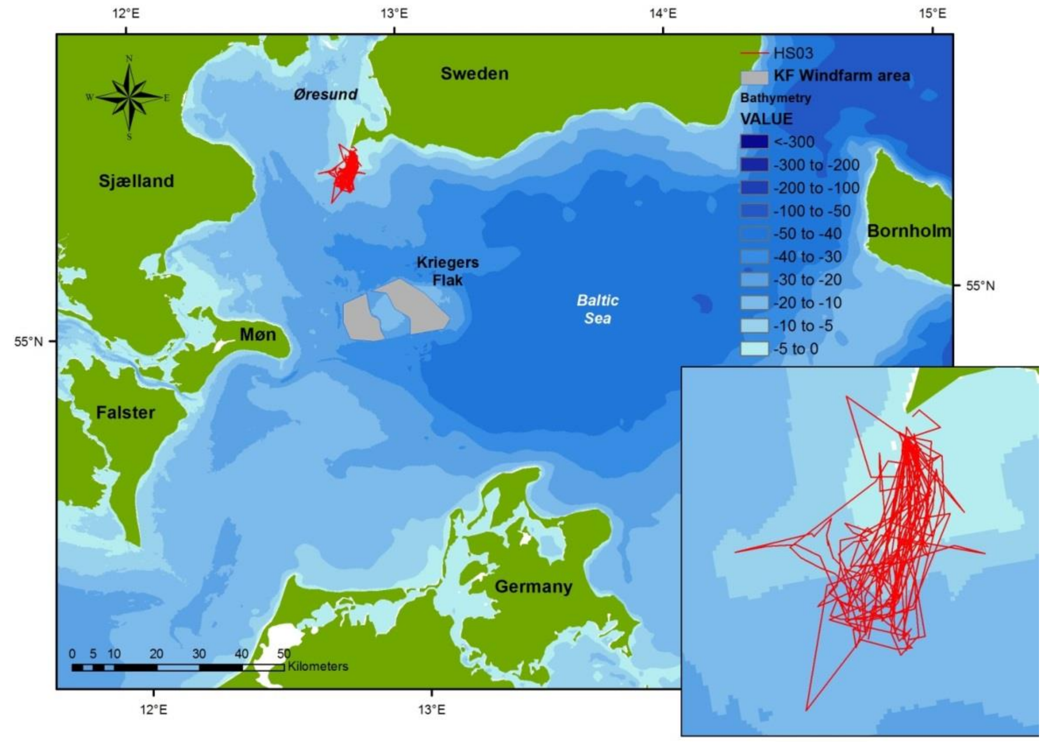

Dynamic variables – autumn (September-November):


Front
1e-03
8e-04
6e-04
4e-04
2e-04
0e+00
Salinity
10
8
6
4
2
Temperature
12
10
8
6
4
u-Velocity
0.2
0.1
0.0
-0.1
v-Velocity
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
6000000
6100000
700000
750000
800000
850000

*Appendix 5: Harbour seals tagged at Måkläppen, Falsterbo during the autumn 2012 in connection with the Kriegers Flak EIA. Lines shows the movements of the individual seals, green polygon shows the 95% kernel home range of all 10 harbour seals and the white polygons shows the Kriegers Flak concession area.*


12°E
13°E
14°E
15°E
HS01
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
Øresund
Sweden
Sjælland
Kriegers
Flak
Baltic
Sea
Bornholm
55°N
Møn
Falster
Germany
0 5 10 20 30 40 50
Kilometers


12°E
13°E
14°E
15°E
HS02
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
Øresund
Sweden
Sjælland
Kriegers
Flak
Baltic
Sea
Bornholm
55°N
Møn
Falster
Germany
0 5 10 20 30 40 50
Kilometers


12°E
13°E
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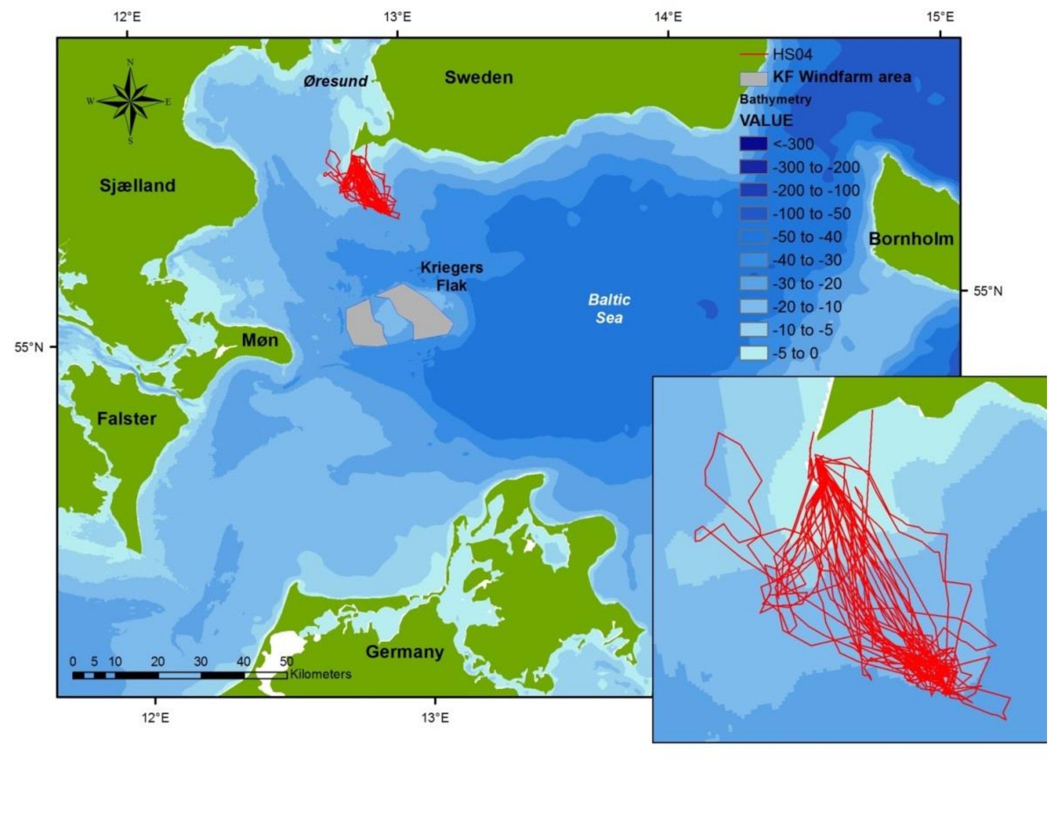
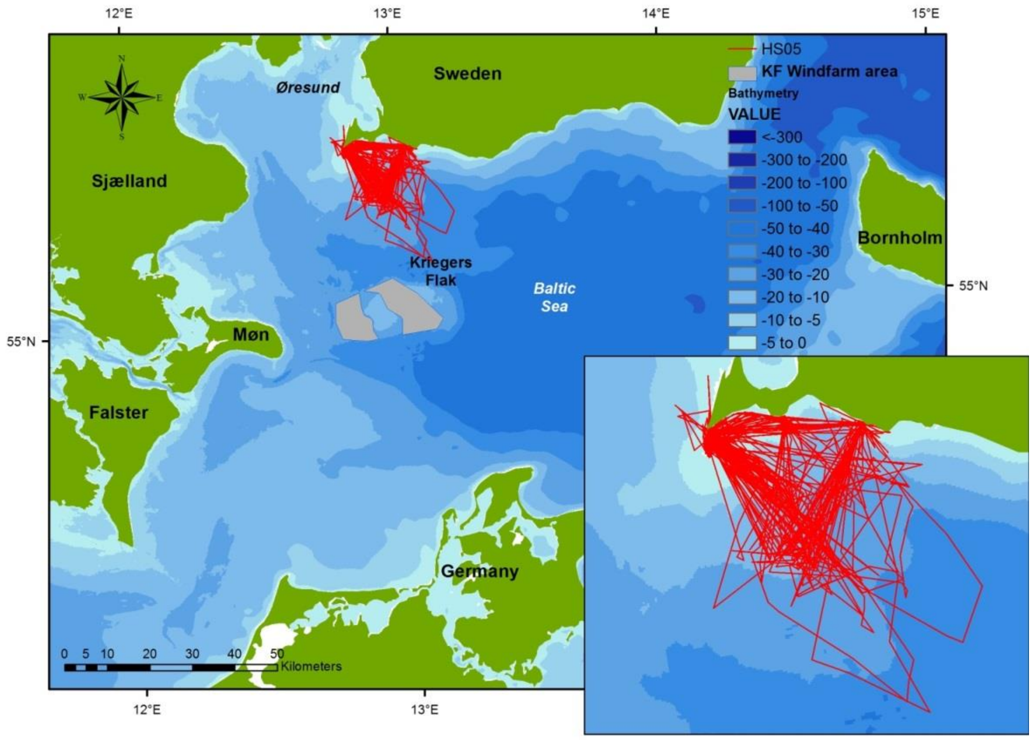
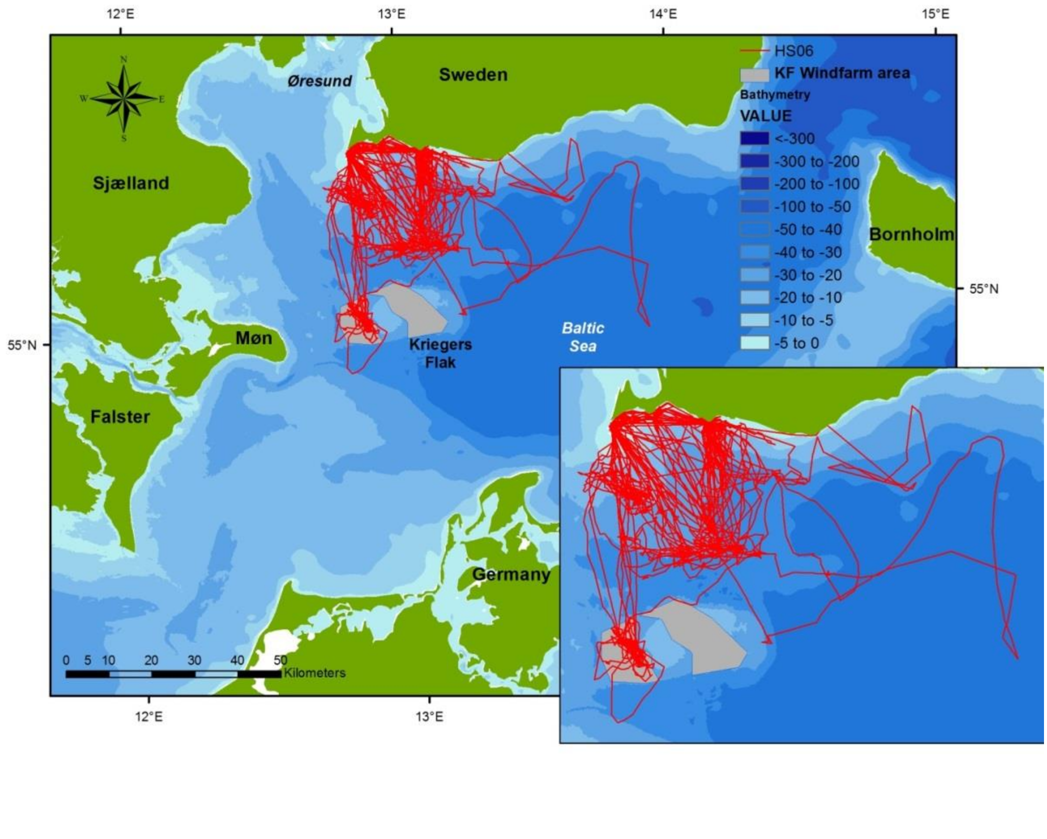
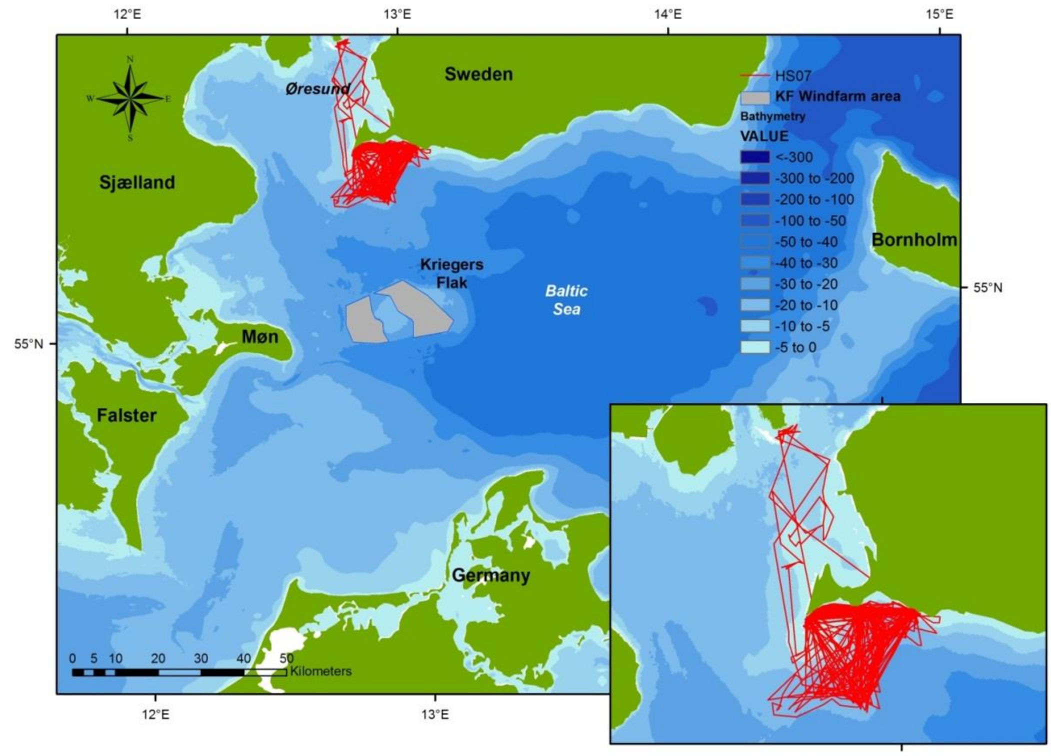
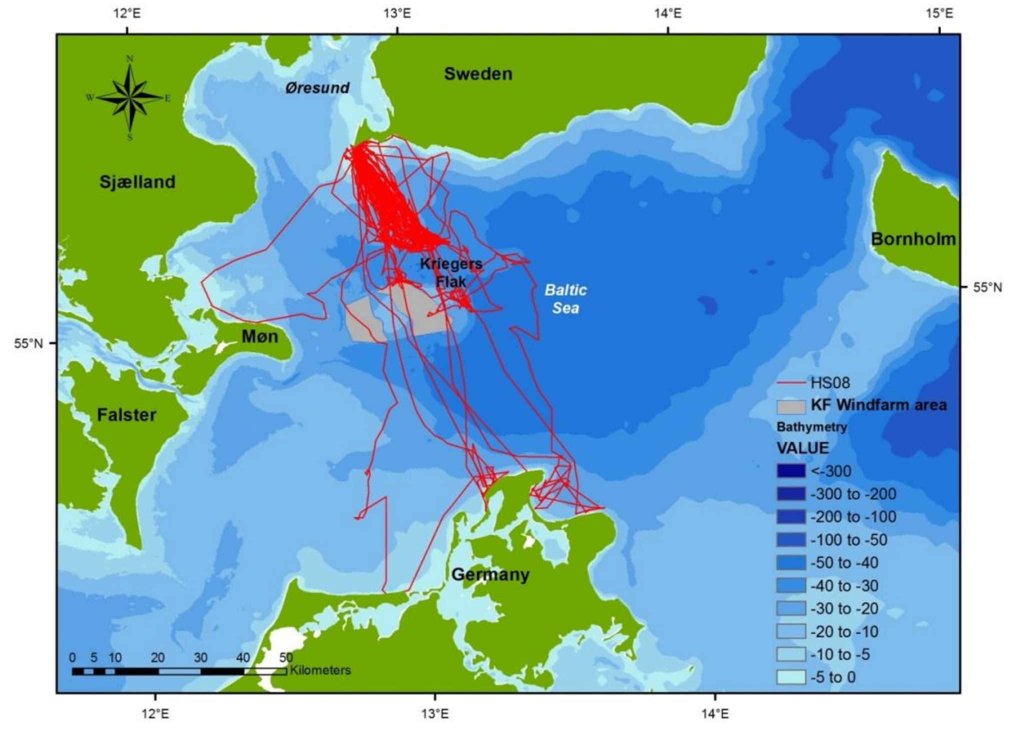
15°E
HS03
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
Øresund
Sweden
Sjælland
Bornholm
Kriegers
Flak
Baltic
Sea
Møn
Falster
Germany
55°N
0 5 10 20 30 40 50
Kilometers

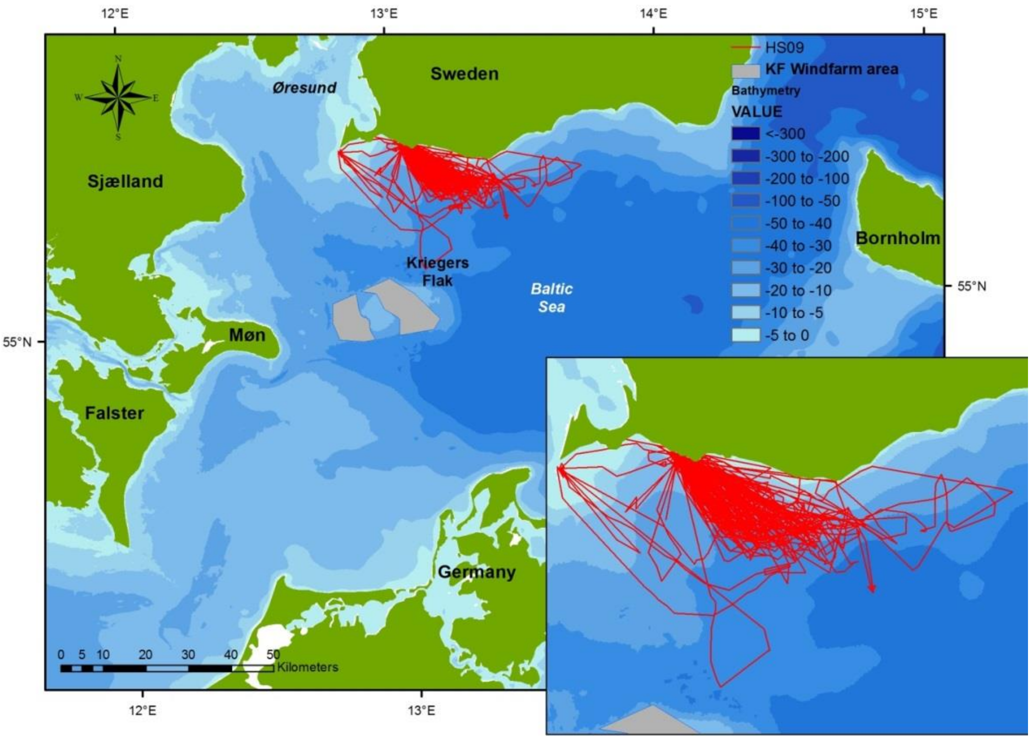

12°E
13°E
14°E
15°E
HS04
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
Øresund
Sweden
Sjælland
Bornholm
Kriegers
Flak
Baltic
Sea
Møn
Falster
Germany
55°N
0 5 10 20 30 40 50
Kilometers

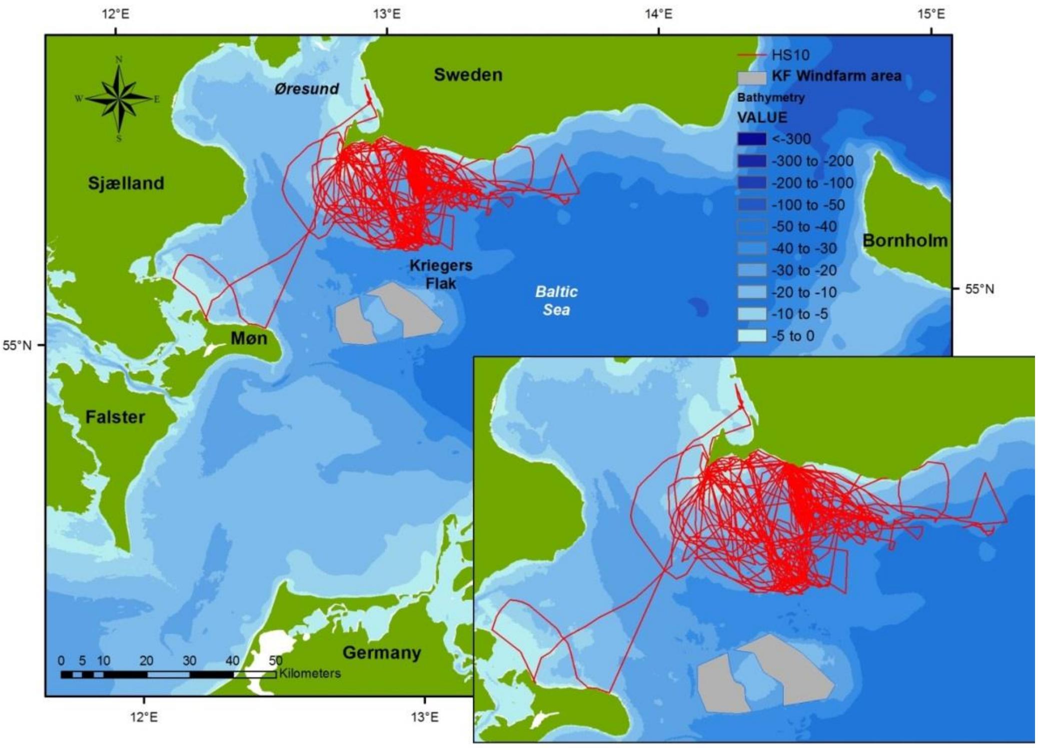

12°E
13°E
14°E
15°E
HS05
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
Øresund
Sweden
Sjælland
Kriegers
Flak
Baltic
Sea
Bornholm
55°N
Møn
Falster
Germany
0 5 10 20 30 40 50
Kilometers

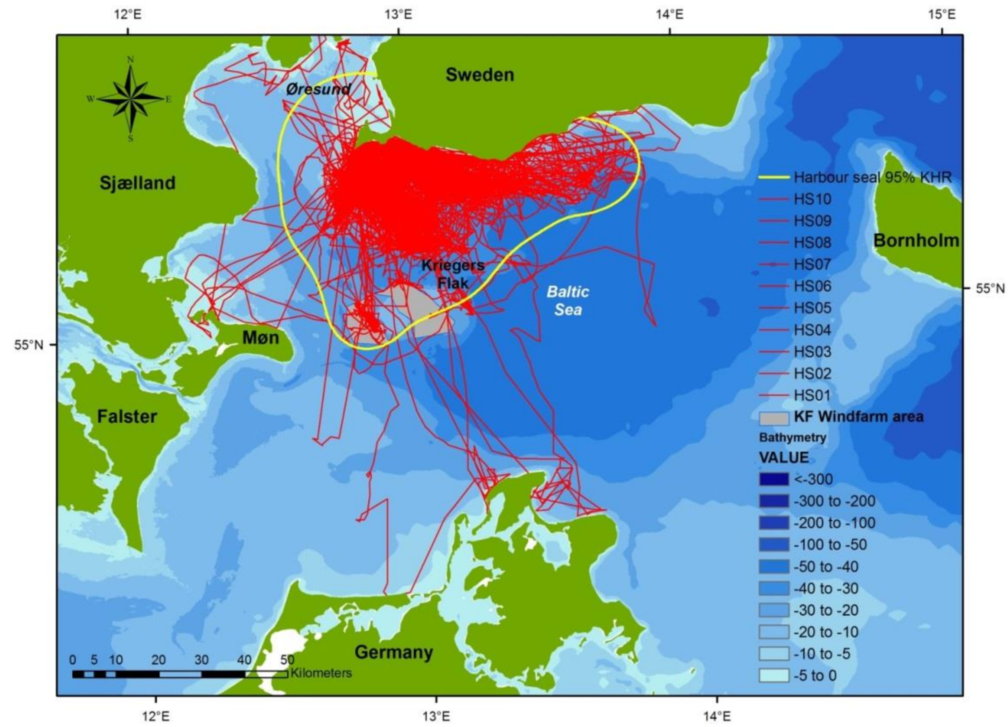

12°E
13°E
14°E
15°E
HS06
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
Øresund
Sweden
Sjælland
Kriegers
Flak
Baltic
Sea
Bornholm
55°N
Møn
Falster
Germany
0 5 10 20 30 40 50
Kilometers


12°E
13°E
14°E
15°E
Sweden
Øresund
Sjælland
Kriegers
Flak
Baltic
Sea
Bornholm
Møn
Falster
Germany
55°N
HS07
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
0 5 10 20 30 40 50
Kilometers

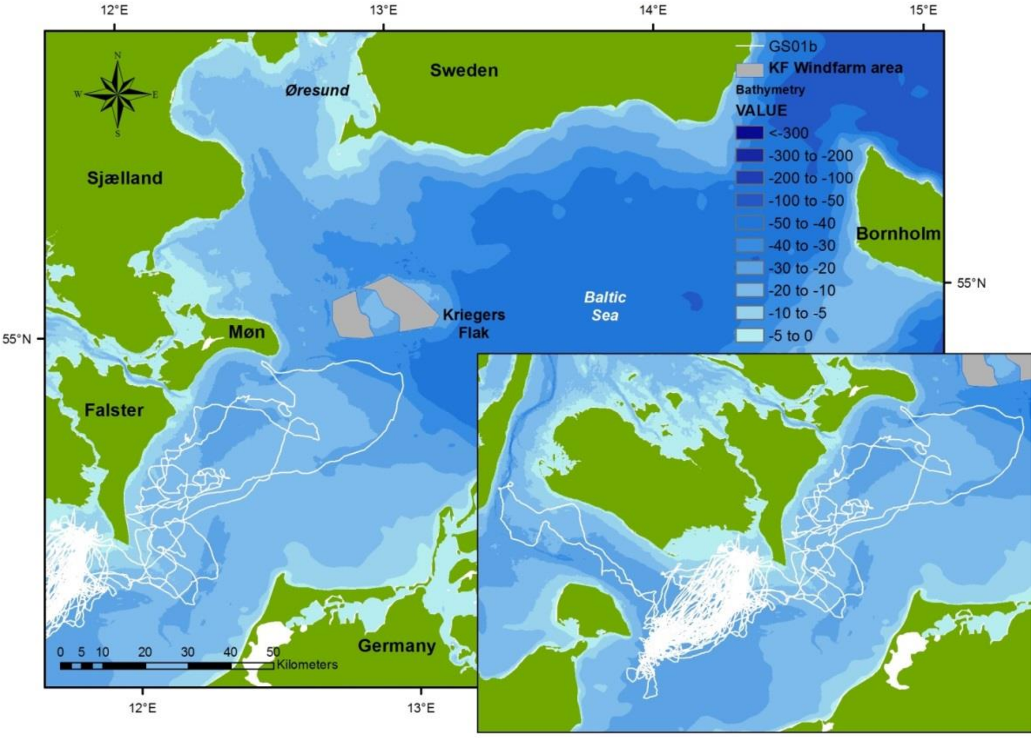

12°E
13°E
14°E
15°E
Sweden
Øresund
Sjælland
Kriegers
Flak
Baltic
Sea
Bornholm
Møn
Falster
Germany
55°N
HS08
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
0 5 10 20 30 40 50
Kilometers

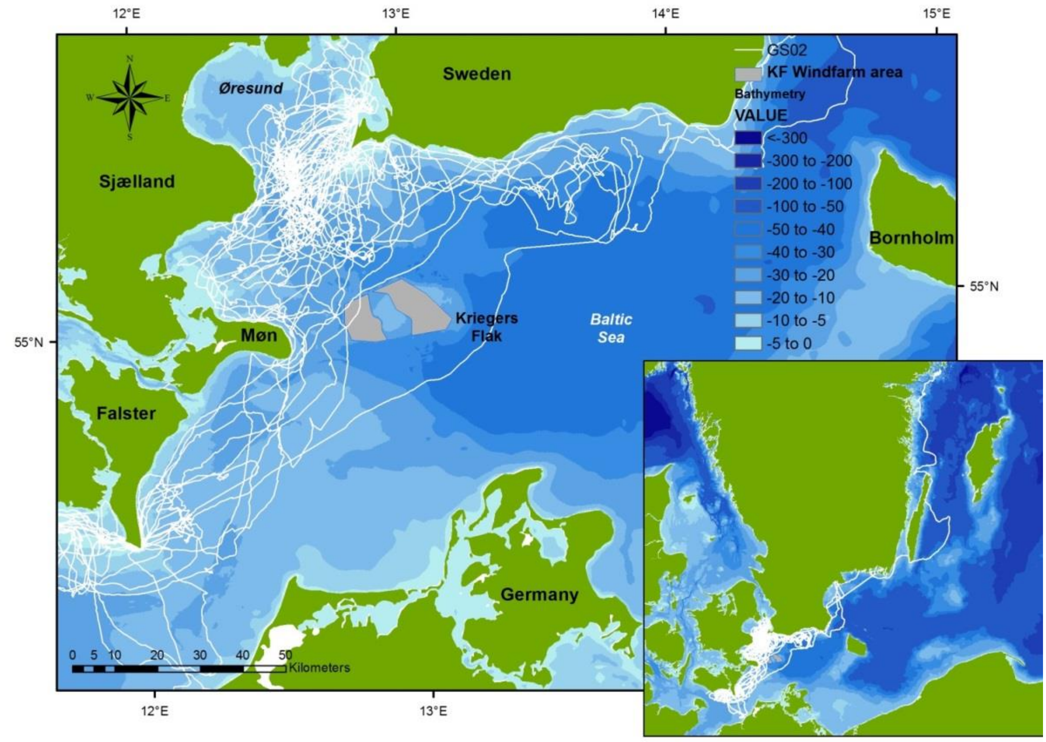

12°E
13°E
14°E
15°E
HS09
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
Øresund
Sweden
Sjælland
Bornholm
Kriegers Flak
Baltic Sea
Møn
Falster
Germany
55°N
0 5 10 20 30 40 50 Kilometers

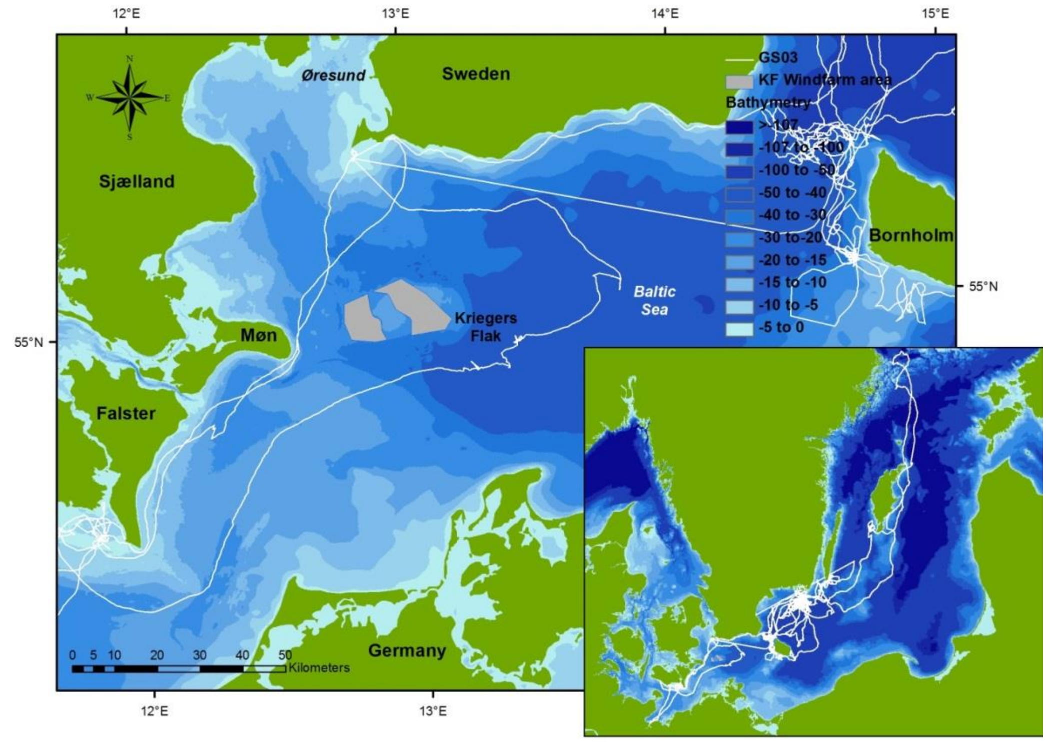

12°E
13°E
14°E
15°E
HS10
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
Øresund
Sweden
Sjælland
Bornholm
Kriegers Flak
Baltic Sea
Møn
Falster
Germany
55°N
0 5 10 20 30 40 50 Kilometers

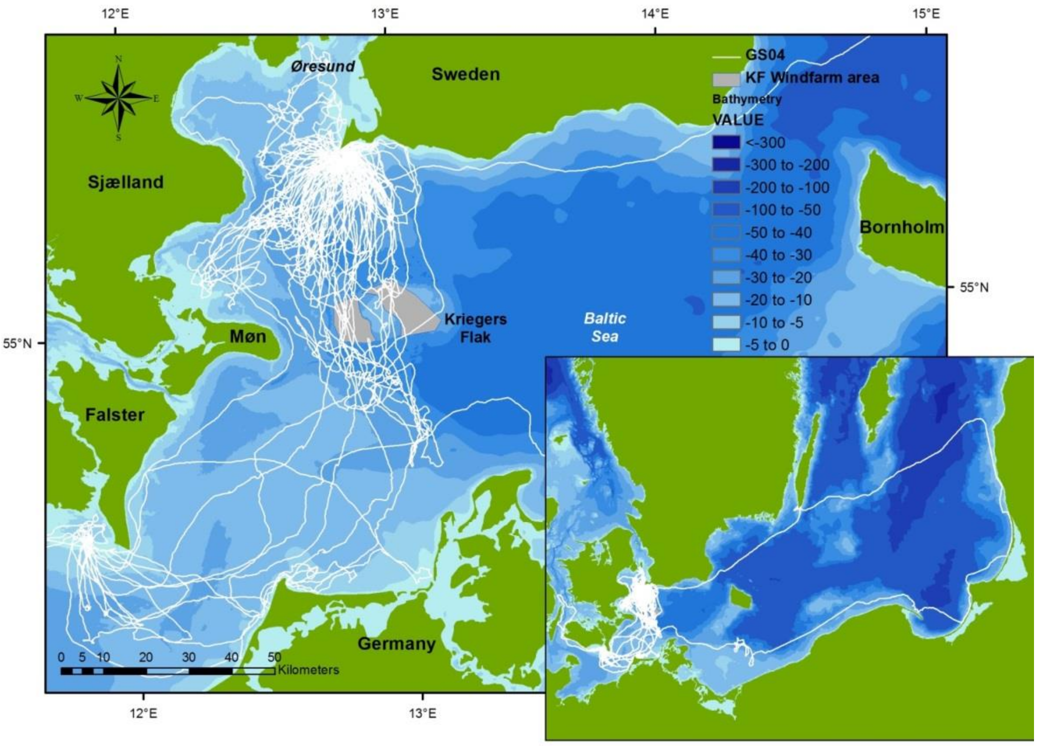

12°E
13°E
14°E
15°E
Øresund
Sweden
Sjælland
Bornholm
Kriegers
Flak
Baltic
Sea
Møn
Falster
Germany
55°N
55°N
Harbour seal 95% KHR
HS10
HS09
HS08
HS07
HS06
HS05
HS04
HS03
HS02
HS01
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
0 5 10 20 30 40 50
Kilometers

*Appendix 6: Grey seals tracked in the Baltic and around Kriegers Flak between 2009 and 2013 made available for the Kriegers Flak EIA. Lines shows the movements of the individual seals, yellow polygon shows the 95% kernel home range of all 11 grey seals and the white polygons shows the Kriegers Flak concession area.*

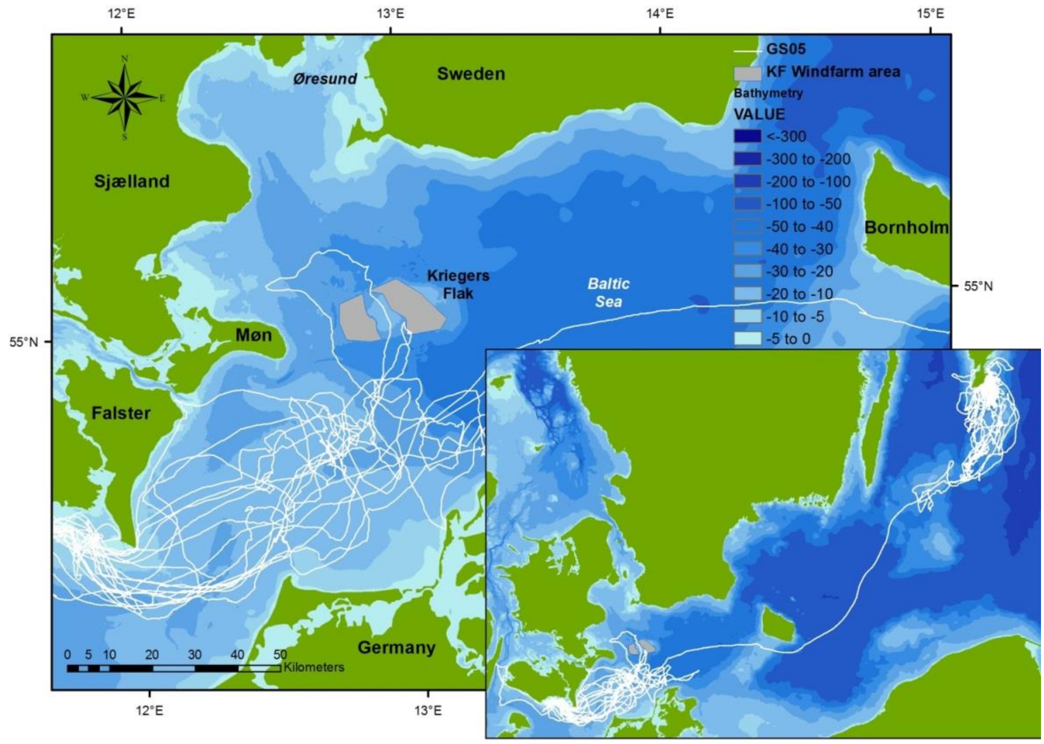


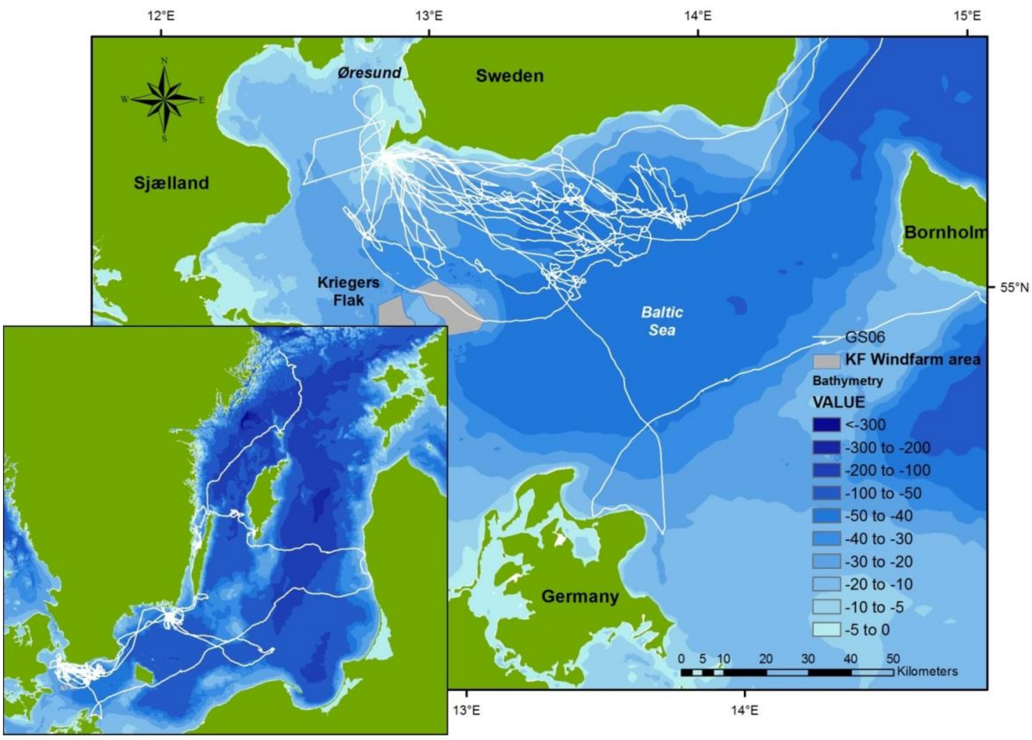

12°E
13°E
14°E
15°E
GS02
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
Øresund
Sweden
Sjælland
Bornholm
55°N
Kriegers
Flak
Baltic
Sea
Møn
Falster
Germany
0 5 10 20 30 40 50
Kilometers

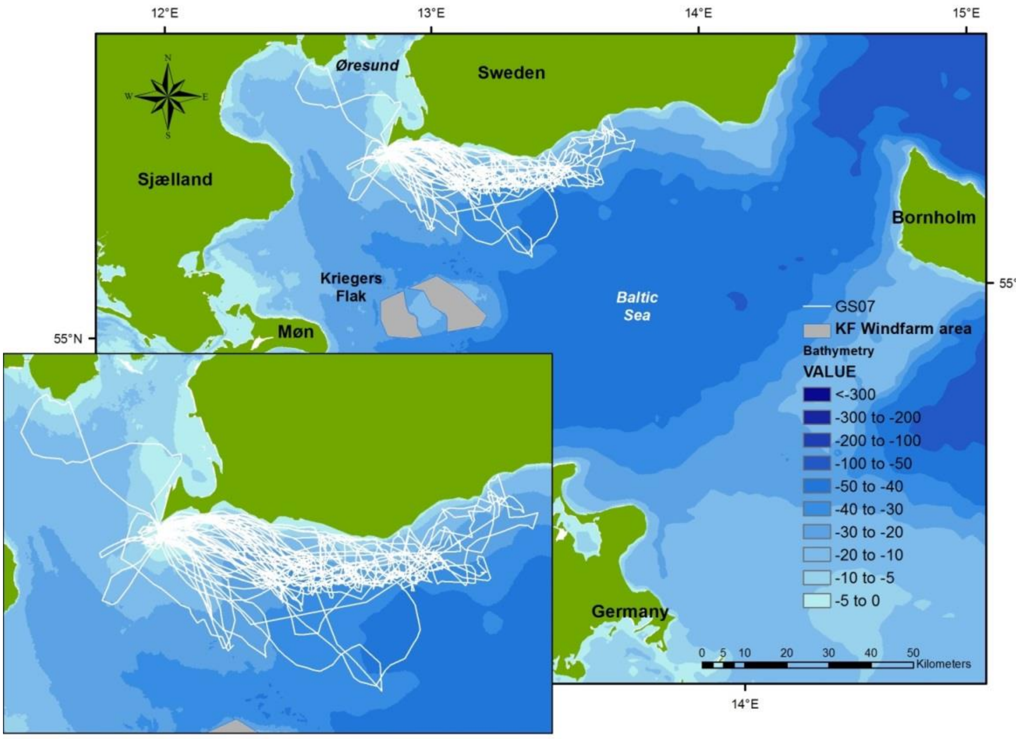

12°E
13°E
14°E
15°E
GS03
KF Windfarm area
Bathymetry
Øresund
Sweden
Sjælland
Bornholm
55°N
Baltic
Sea
Kriegers
Flak
Møn
Falster
Germany
0 5 10 20 30 40 50
Kilometers

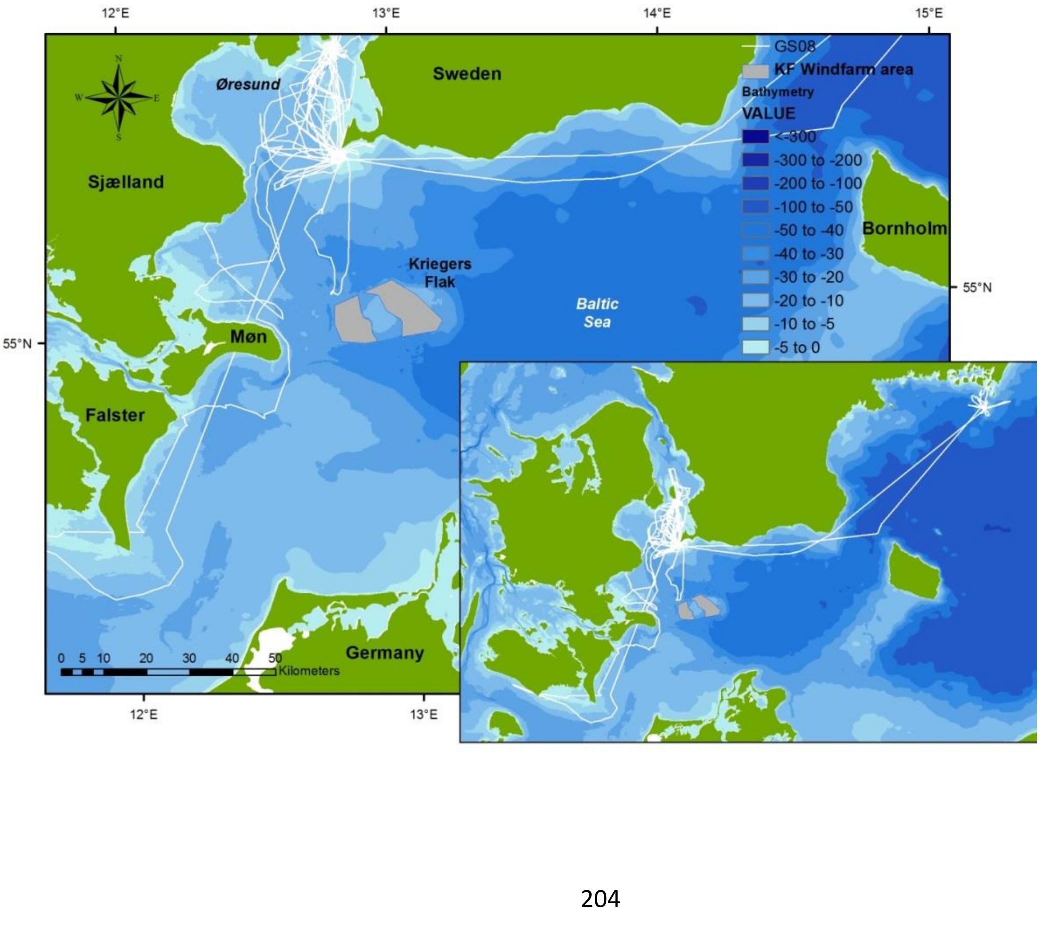


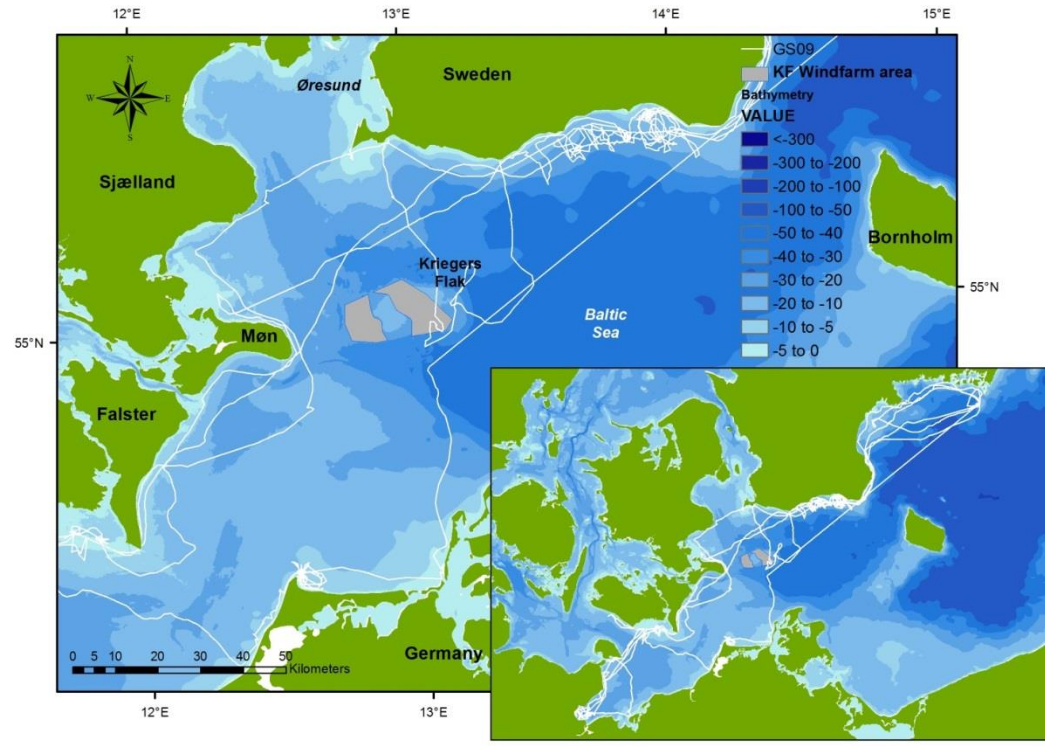
12°E
13°E
14°E
15°E
Øresund
Sweden
GS04
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
Sjælland
Bornholm
55°N
Kriegers
Flak
Baltic
Sea
Møn
Falster
Germany
0 5 10 20 30 40 50
Kilometers

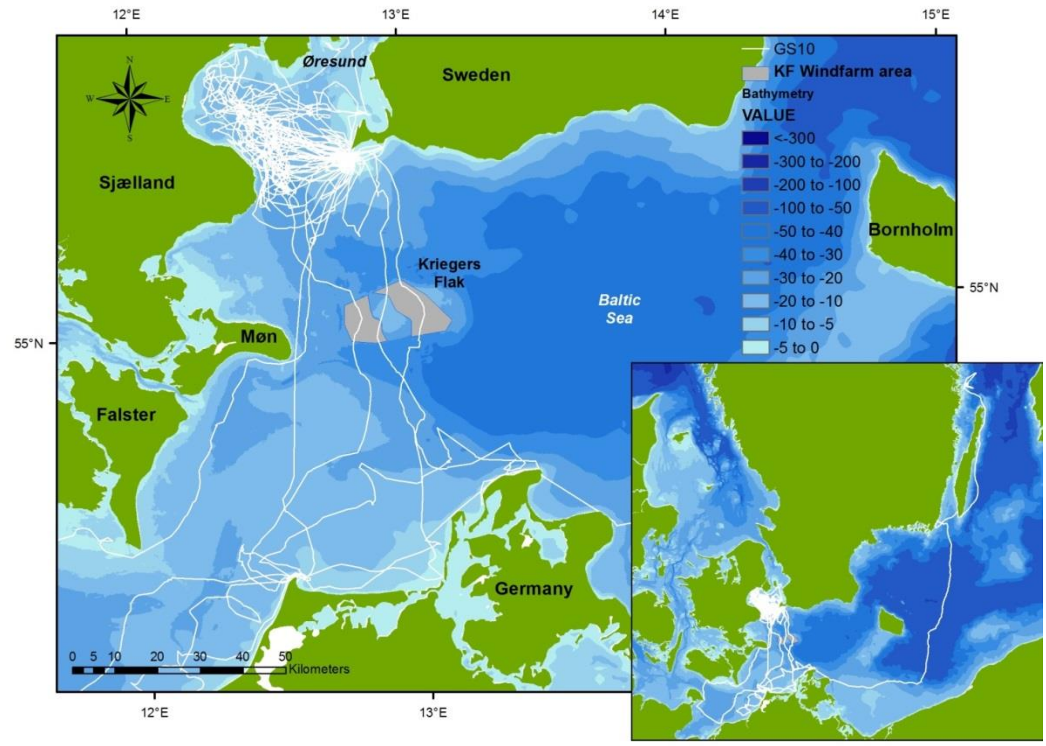

12°E
13°E
14°E
15°E
GS05
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
Øresund
Sweden
Sjælland
Bornholm
Kriegers Flak
Baltic Sea
Møn
Falster
Germany
55°N
0 5 10 20 30 40 50
Kilometers

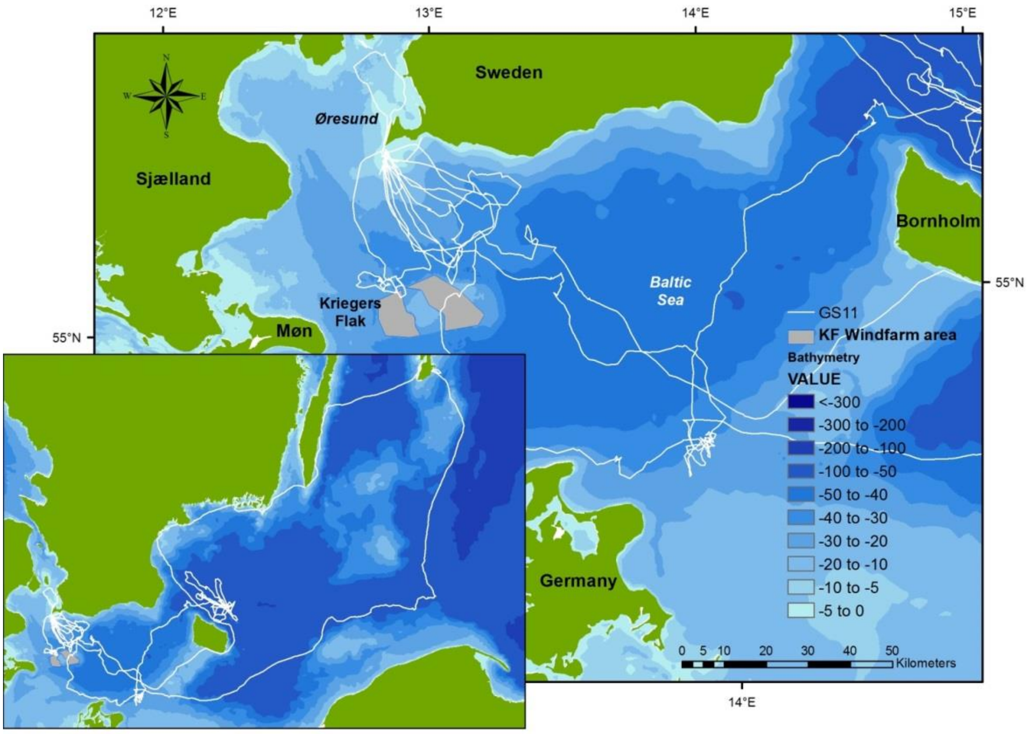

12°E
13°E
14°E
15°E
Øresund
Sweden
Sjælland
Bornholm
Kriegers Flak
Baltic Sea
55°N
GS06
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
Germany
0 5 10 20 30 40 50
Kilometers

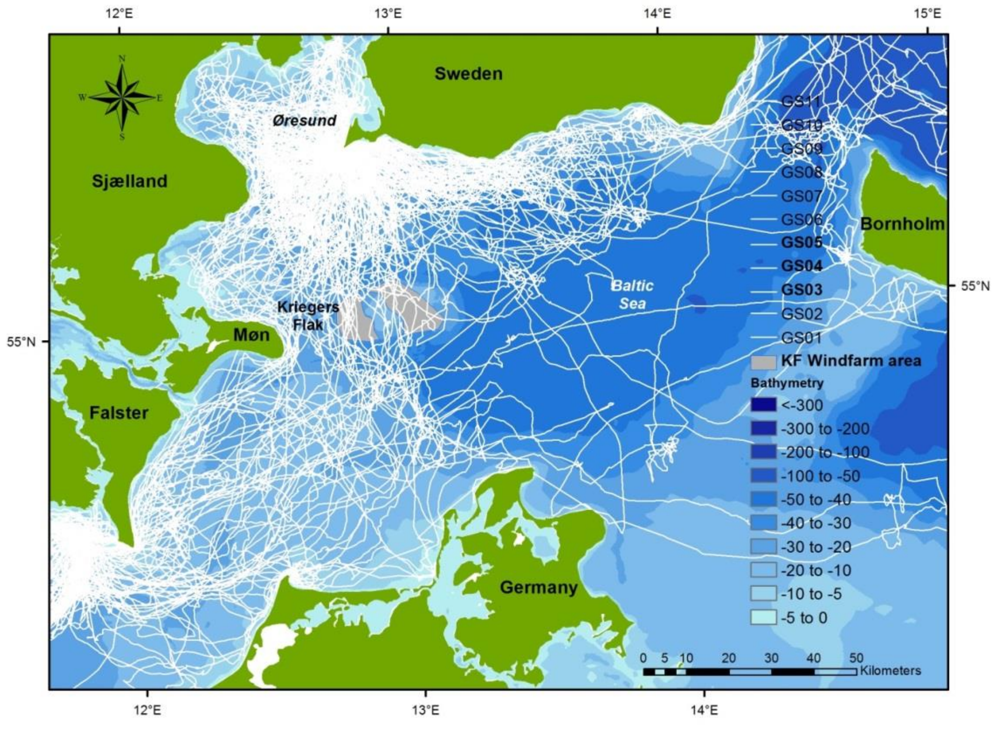

12°E
13°E
14°E
15°E
Øresund
Sweden
Sjælland
Bornholm
Kriegers
Flak
Baltic
Sea
Møn
Germany
55°N
GS07
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
0 5 10 20 30 40 50
Kilometers

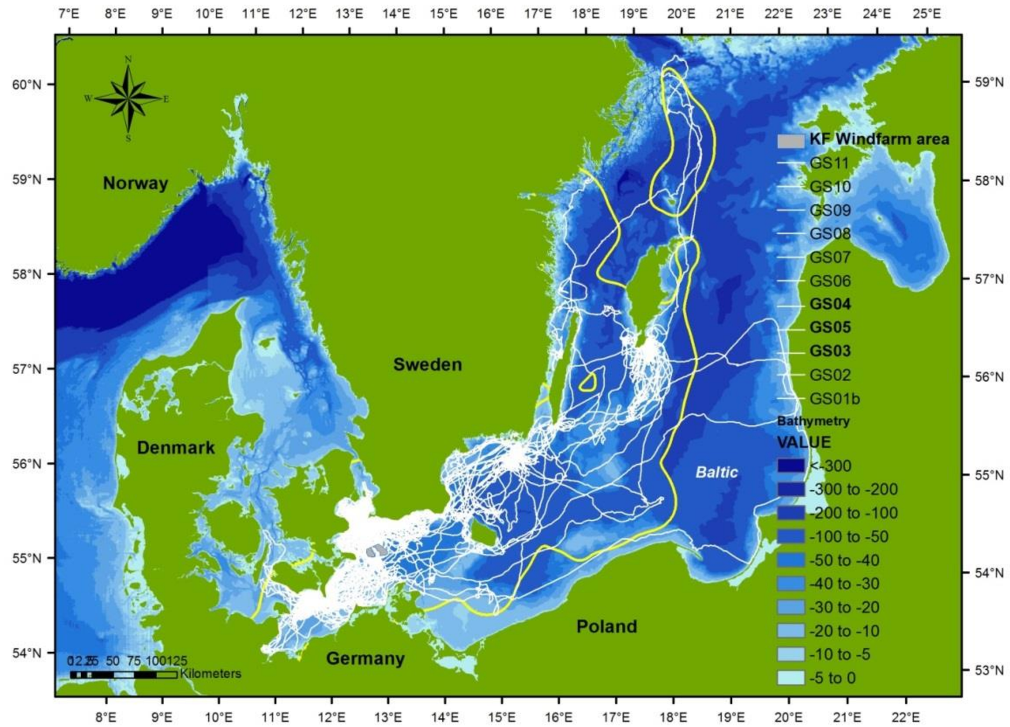

12°E
13°E
14°E
15°E
Øresund
Sweden
Sjælland
Bornholm
Kriegers
Flak
Baltic
Sea
Møn
Falster
Germany
55°N
GS08
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
0 5 10 20 30 40 50
Kilometers


12°E
13°E
14°E
15°E
GS09
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
Øresund
Sweden
Sjælland
Bornholm
Kriegers
Flak
Baltic
Sea
Møn
Falster
Germany
55°N
0 5 10 20 30 40 50
Kilometers


12°E
13°E
14°E
15°E
GS10
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
Øresund
Sweden
Sjælland
Bornholm
Kriegers
Flak
Baltic
Sea
Møn
Falster
Germany
55°N
0 5 10 20 30 40 50
Kilometers


12°E
13°E
14°E
15°E
Sweden
Øresund
Sjælland
Bornholm
55°N
Baltic Sea
Kriegers Flak
Møn
GS11
KF Windfarm area
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
Germany
0 5 10 20 30 40 50
Kilometers


12°E
13°E
14°E
15°E
Sweden
Øresund
Sjælland
Bornholm
55°N
Baltic Sea
Kriegers Flak
Møn
Falster
GS11
GS10
GS09
GS08
GS07
GS06
GS05
GS04
GS03
GS02
GS01
KF Windfarm area
Bathymetry
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
Germany
0 5 10 20 30 40 50
Kilometers



7°E
8°E
9°E
10°E
11°E
12°E
13°E
14°E
15°E
16°E
17°E
18°E
19°E
20°E
21°E
22°E
23°E
24°E
25°E
60°N
59°N
58°N
57°N
56°N
55°N
54°N
Norway
Sweden
Denmark
Germany
Poland
Baltic
KF Windfarm area
GS11
GS10
GS09
GS08
GS07
GS06
GS04
GS05
GS03
GS02
GS01b
Bathymetry
VALUE
<-300
-300 to -200
-200 to -100
-100 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
Kilometers