AARHUS UNIVERSITET
DCE - NATIONALT CENTER FOR MILJØ OG ENERGI

NIRAS

Hesselø Offshore Wind Farm

Marine mammals
Technical report

Energinet Eltransmission A/S

Date: 14 March 2022

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02	14 March 2022	Technical report Marine mammals	DCE: Signe Sveegaard, And Anders Galatius NIRAS: Maria Wilson	DCE: Line Kyhn and Jesper Fredshavn. NIRAS: Stine Vest	Rikke Holm

Preface

This report was commissioned by Energinet to the consortium of NIRAS and Aarhus University and constitutes a description of the baseline status as well as a sensitivity analysis for the three marine mammal species: harbour porpoise, harbour seal and grey seal relevant in connection with the construction of the proposed Hesselø OWF. The report builds upon existing knowledge as well as new data and analysis collected and conducted during this project.

The report is divided in eight chapters and begin by introducing the aim of the report (chapter 2). In Chapter 3 the methods used in the field work are described and chapter 4 describes the results as well as the baseline situation within the Hesselø OWF area for each species. In chapter 5, the sensitivity analysis is described.

The work within the consortium was divided so that Signe Sveegaard and Anders Galatius, DCE have been the main authors and responsible for Chapter 3 (3.2 -3.4) and 4 with Line Kyhn responsible for scientific review and Jesper Fredshavn responsible for quality assurance for these chapters. NIRAS have been main author and responsible for the other chapters and conducted quality assurance for these chapters. All contributors have however consensus with regard to the main conclusion in the assessment and the sensitivity analysis.

Contents

1 Summary

This technical report presents information on marine mammals (harbour seal, grey seal and harbour porpoise) in and near the area planned for Hesselø Offshore Wind Farm (OWF). Data acquired during field surveys are used together with other available information to characterise the importance of the plan area for the three most common marine mammal species in and near the area.

Harbour seals in and around the plan area for Hesselø OWF are part of the Kattegat population, consisting of approximately 14,000 animals and is shared with Sweden. The plan area is located approximately 20 km from three important haul-outs for harbour seals; Anholt, Hesselø and Hallands Väderö. Counts of harbour seals from previous surveys as well as aerial counts conducted in 2021 during the current project show that that fewest harbour seals are registered in the winter and spring, and the counts peaks in August with 2700 harbour seals (coinciding with their moulting period). Anholt (Totten) and Hesselø are two of the most important haul-out sites for harbour seals in Kattegat with more than hundred pups born annually at both haul-out sites. The plan area is considered to be of medium/high importance for harbour seal due to the short distance (approximately 20 km) to important haul-out sites for the Kattegat population of harbour seals, which means that it is likely to be used for foraging or migration by the seals utilizing these haul-outs.

Grey seals move over much larger distances than harbour seals, and in consequence, grey seal populations cover much larger areas. In Kattegat, grey seals from two distinct populations occur, namely the greater North Sea population and the Baltic population. The observations during 2021 indicate that the majority of the grey seals in the plan area originate from the Baltic population. In this population 40,000 individuals were counted in 2020, this count does not include animals at sea during the survey. There is no estimated correction factor for individuals at sea for Baltic grey seals, but based on data from other species the total abundance is likely at least 25% higher. The highest number that was counted during the aerial surveys was 50 grey seals in June (coinciding with their moulting period for the Baltic population). There were no registrations of pups on the four nearest haul-out sites to the plan area for Hesselø OWF, but pupping has occurred several times at Totten in recent years. The plan area is considered to be of low importance for grey seal due to the low counts of grey seal at the four nearest haul-out sites. However, grey seal was historically the most abundant seal species in the area, and is currently recovering from local extinction in Denmark in the early 20th century, and the area is probably important for the further recovery of the species in Kattegat.

Harbour porpoises in and near the plan area belong to the Belt Sea population. The latest abundance of this population is from 2020 and is estimated to consist of 17,301 harbour porpoises. Passive acoustic monitoring (PAM) of harbour porpoises within the plan area for Hesselø OWF, show that porpoises are present in the area every day. The density is, however, relatively low in most of the area compared to nearby hot-spots at Store Middelgrund and in the northern Sound. Based on three aerial surveys conducted in the summer 2021 in and around the plan area, the highest densities were found in the eastern part along the Danish-Swedish border (mainly outside the OWF planning area) and in the northern part of the plan area for Hesselø OWF. The average density of harbour porpoise in the survey area varied between 0.42 – 1.34 individuals/km^2. Specific breeding grounds for harbour porpoise in Kattegat are unknown, however, based on observations of mother-calf pairs in connection with the aerial surveys in and near the plan area for Hesselø OWF, the plan area may be an important area for harbour porpoise during the breeding season (May-August). This is supported by data from the PAM study, where the highest detection of harbour porpoises is from the summer months. The plan area is considered to be of medium importance for harbour porpoise outside their breeding season, however

in the breeding season, a high calves ratio is observed in and near the plan area indicating that the Hesselø OWF survey area could be a relatively important breeding site.

The sensitivity analysis provides a categorisation of sensitivity, from ***Not Sensitive*** to ***High***, for each of the three receptors (harbour seal, grey seal and harbour porpoise) in relation to the pressures, which are expected to result from the activities planned for the construction, operation and decommissioning of the offshore wind farm.

Underwater noise from pile driving is a key pressure on marine mammals during construction of the offshore wind farm. Sensitivity to permanent threshold shift (PTS) is high for all three receptors/marine mammals species, and sensitivity for temporary threshold shift (TTS) is medium for all three receptors/marine mammals species for the unmitigated underwater piledriving noise. Underwater noise from pile driving may in addition cause behavioural avoidance responses in all three receptors/marine mammals species and the sensitivity for harbour porpoises is ranked as high because of the long impact ranged for the unmitigated underwater noise from pile driving. For harbour seal the sensitivity for avoidance responses is medium because of the high number of pups at the nearest haul-out sites, whereas the sensitivity pressure outside the pupping season is considered to be lower. For grey seal the sensitivity for avoidance responses is low, because of the low number of grey seals in and near the plan area all year round. However, grey seals are currently recolonising Kattegat as a breeding species, and it is not known if substantial noise during the breeding season may delay this process.

The effect of underwater noise from pile driving can be considerably reduced with application of abatement systems such as for example the use of bubble curtains alone or in combination with other abatement systems. Application of a soft start procedure where onset of the piling process is conducted with low energy, will further reduce the effect on marine mammals. The energy per stroke then increases gradually until full energy per stroke is applied. With increasing amount of energy, the emitted noise increases as well, allowing the marine mammals to move away from the construction site before the noise becomes physically dangerous to them.

For all three receptors/marine mammal species sensitivity to other pressures (sediment spillage, habitat change, increased underwater noise from vessels and operation and electromagnetic fields) is ranked as low or not sensitive.

1.1 List of terms

A list of terms (in English and Danish) and their explanations in relation to the establishment of Hesselø Offshore Wind Farm, including terminology applied in the sensitivity analysis, is provided here.

English (abbreviation)	Danish	Explanation
General terms		
Hesselø Offshore Wind Farm (Hesselø OWF)	Hesselø Havvindmøllepark	
Export cable	Ilandføringskabel	
Offshore cable corridor	Søkabelkorridor	The planned area for the offshore export cables.
Onshore cable corridor	Landkabelkorridor	The project area for the onshore cables.
Turbines	Vindmøller	
Point of connection (POC)	Tilslutningspunktet	Det punkt, hvor strømførende kabler tilsluttes højspændingsstation (Hovegård) evt. via en kompenseringsstation (Bavnebakke)
Landfall	Ilandføringspunktet	The point where the offshore export cables reach land.
Sensitivity analysis terminology		
Sensitivity	Følsomhed	The tolerance of a species or habitat to change caused by an external factor and the time taken for its subsequent recovery.
Receptor	Receptor	A species, population, community or habitat that is subject for external changes.
Resistance	Tolerance	Resistance characteristics indicate whether a receptor can absorb disturbance or stress without changing character.
Recoverability	Genopretningsevne	The ability of a receptor to recover from changes.
Activity	Aktivitet	Human-mediated activity that may lead to pressure(s).
Pressure	Belastning	Mechanisms through which an activity has an effect on receptors, and can be of physical, chemical or biological character.
Effect	Effekt	The effect of a pressure, which may affect the receptor.
Sensitivity score	Sensitivitetsscore	Resistance and recoverability of a receptor is scored according to one of four categories, which in turn is used to score the overall sensitivity into one of four categories.

2 Introduction and aim

With the Energy Agreement in June 2018 and the following 'Climate agreement for energy and industry, etc. 2020' in June 2020, the Danish parliament decided to tender for a new offshore wind farm of 800 – 1200 MW with grid connection in 2027. The offshore wind farm will be located in the central Kattegat approx. 30 km north of Gilbjerg Hoved on the north coast of Zealand. The wind farm is named Hesselø Offshore Wind Farm (Hesselø OWF) after the small uninhabited island of Hesselø, which is located southwest of the area. The Hesselø OWF will have an installed capacity of minimum 800 MW and maximum 1,200 MW.

The planning area for Hesselø Offshore Wind Farm is shown in Figure 2.1.

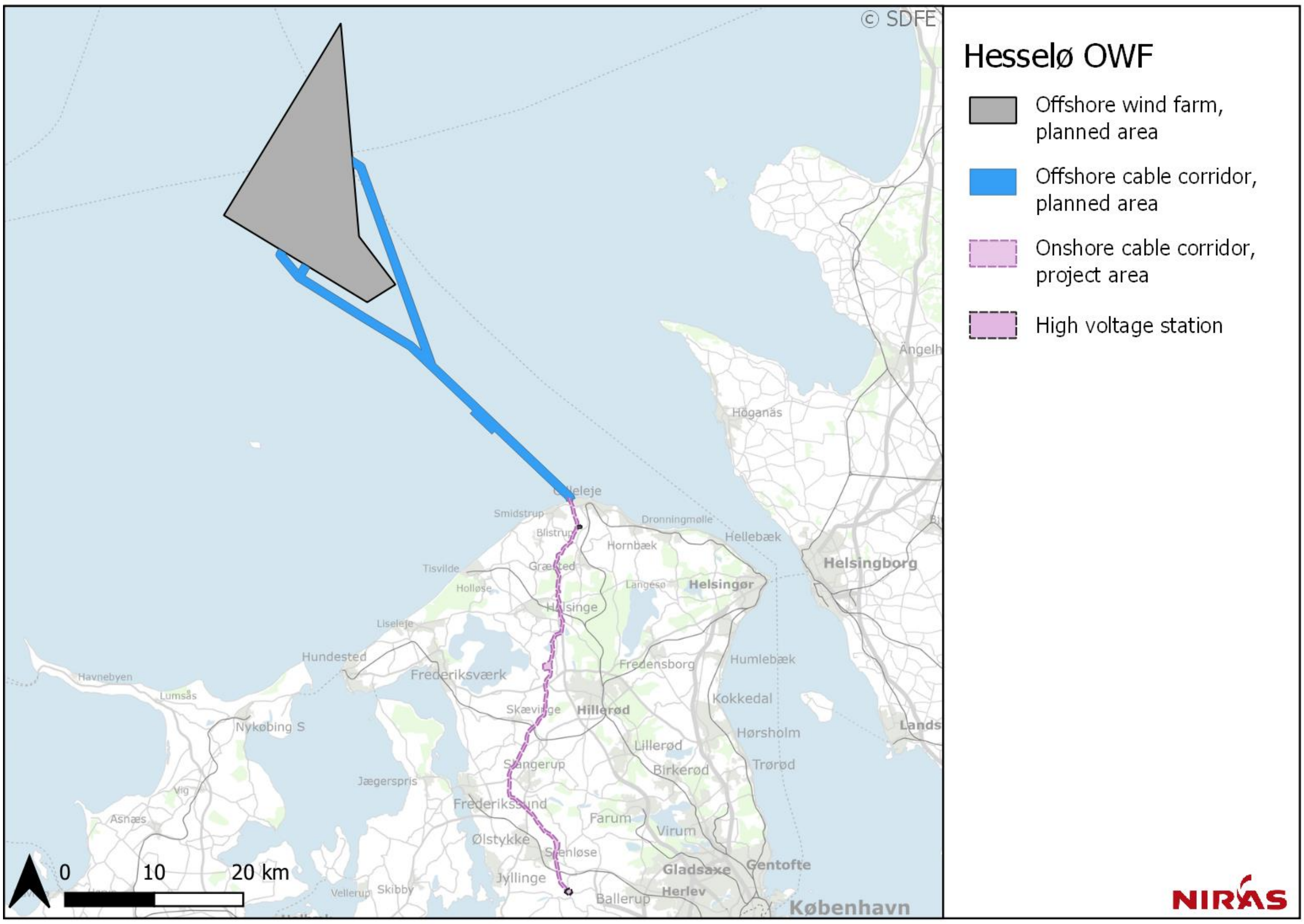

Figure 2-1: Planning area for Hesselø Offshore Wind Farm.

In order to ensure that Hesselø OWF will be supplying electricity by 2027, the Minister of Climate, Energy and Utilities has instructed Energinet to initiate the preliminary studies for the project – both offshore and onshore. This includes strategic environmental assessment (SEA) of the plan for the overall project, completion of relevant environmental surveys etc., investigation of a grid connection from the coast to the connection point at Hovegaard High Voltage (HV) station and preparation of an environmental impact report (EIA) for the onshore facilities.

The location of Hesselø OWF is based on a detailed screening of multiple areas for offshore wind farms in Danish waters carried out for the Danish Energy Agency and reported in spring 2020 (COWI, 2020).

The plan for Hesselø OWF is described in a memorandum from the Danish Energy Agency (Energistyrelsen, 2021a) and in the scoping report for the environmental assessment of the plan (Energistyrelsen, 2021b), which was issued in connection with the first public consultation (February 12th to March 19th 2021).

2.1 Aim

The current report provides a baseline description of relevant marine mammal species in an near the plan area for Hesselø OWF based on existing knowledge as well as field work conducted in the plan area in 2020/2021. Furthermore the report describes the sensitivity of marine mammals in the area in relation to the plan to establish Hesselø OWF. The first section of the report presents the plan for Hesselø OWF including a description of project scenarios followed by a method description. In the second section, existing conditions (baseline) will be outlined, including seasonal occurrence, distribution and movements of relevant marine mammal species present in and around the plan area for Hesselø OWF and the export cable corridor. Based on this a sensitivity assessment on the marine mammal species in relation to the construction, operation and decommissioning of Hesselø OWF is presented. The report include proposals for measures to mitigate the potential impacts of Hesselø OWF on marine mammals.

3 Methodology

3.1 Scenarios for Hesselø Offshore Wind Farm

At the order from the Minister of Climate, Energy and Utilities, Energinet was instructed to initiate a series of preliminary studies for the offshore part of the project. The results of the studies will be provided to the tenderes for the offshore wind farm and will form important input for the environmental impact assessment of the specific project.

To ensure that the studies have the right focus and are relevant for an offshore wind farm (anno 2027) of 800 – 1,200MW, a set of key technical parameters has been considered and a number of scenarios have been developed. The key technical parameters and scenarios listed in Table 3.1 are used in relation to the sensitivity assessment in this report.

Wind turbines with a capacity in the range of 8-20 MW is the base for the assessment. The minimum turbine capacity of 8 MW corresponds to the installation of up to 150 turbines, and the maximum turbine capacity of 20 MW corresponds to the installation of up to 60 turbines. A grid of inter-array cables (66kV) installed in the seabed will connect the individual turbines to the offshore transformer platform, which will connect the wind farm to the onshore grid via 2-3 export cables also installed in the seabed.

Table 3.1: Technical parameters for the scenarios for Hesselø OWF included in this report.

Technical parameters			
Offshore wind turbines			
	8 MW turbine	15 MW turbine	20 MW turbine
No. of WTGs	100 - 150	54 - 80	40 - 60
Rotor diameter, meter	170	260	280
Hub height, meter	105	150	170
Tip height, meter	190	280	310
Nacelle (length, width, height), meter	20x8x8	29x13x13	32x15x15
Foundations			
Monopile diameter, meter	10	13	15
Pile driving; hammer size, blow strength and blow rate	IHC S-4000, 6000kJ, 7000 blows. Rate: 4 seconds for 'soft start-procedure' thereafter 2 seconds.		
Scour protection	15 – 20 meter in diameter		
Offshore transformer platform*			
Dimensions (length/width), meter	40/25		
Inter array cables			
	66 kV	66 kV	66 kV
Export cables			
No. of cables	2-3		
Voltage level	220 kV – 345 kV (AC)		
Investigated cable corridor (offshore), meter	1.000		
Distance between cables in Natura 2000 sites/other areas, meter	50/150-200		
Depth of cable trench, centimeter	60-100		
Length of directional drilling (at landfall), meter	Up to 1,000		

* One platform is expected to be established, but two possible locations are included in the preliminary investigations and in the strategic environmental assessment.

The parts of the project located on land are described in the technical project description that forms the basis for the environmental impact assessment of the project on land.

The layout of the offshore wind farm and turbines is not decided at present, as this will be determined by the future Concessionaire. The current assessments have therefore been made at an overall level, taking into account the different variations regarding total installed capacity, sizes of turbines and the consequent difference in the number of turbines and layouts of Hesselø OWF. For each of the turbine sizes (8MW, 15MW and 20MW) specific layouts have been developed to support the visualizations and other parts of the assessment. An environmental impact assessment will be prepared for the specific offshore project by the Concessionaire.

3.2 Marine mammals

The plan area for Hesselø OWF is inhabited by at least three marine mammal species: Harbour porpoise (*Phocoena phocoena*), harbour seal (*Phoca vitulina*) and grey seal (*Halichoerus grypus*).

Harbour porpoises is the most common cetacean species in the inner Danish waters and based on previous surveys in the area, e.g. MiniSCANS in 2012 and SCANS-III in 2016 (both large-scale ship and aerial surveys studying the distribution and abundance of cetaceans) no other cetacean species was observed in the area (Viquerat, et al., 2014; Hammond, et al., 2021). Despite of the results from the SCANS surveys, there is the possibility that other cetacean species (most likely dolphin species) may occur in the area. However, their occurrence is sporadic and irregular and no general patterns in abundance can be given.

The plan area for Hesselø OWF is located approximately 20 km from three important seal haul outs, namely Anholt, Hesselø and Hallands Väderö. Furthermore, the Sjællands Rev haul-out is located approx. 50 km away. All locations hold important resting and breeding grounds for seals. These haul-outs are mainly used by harbour seals, but grey seals also occur, and Anholt is very important to this species, having the greatest numbers of grey seals in the entire Kattegat area.

3.2.1 Protection status of marine mammals

Marine mammals are listed in different conventions aiming to protect populations and their living environment. In table 3.2 a list of the international conventions and protection conditions for harbour porpoises, harbour seals and grey seals are provided as well as their conservation status.

Table 3.2: International conventions and protection status of the marine mammal species occurring in plan area for Hesselø OWF.

	Harbour porpoise (*Phocoena phocoena*)	Harbour Seal (*Phoca vitulina*)	Grey seal (*Halichoerus grypus*)
Red list	Belt Sea population Least concern (LC)	Least concern (LC)	Least concern (LC)
CITES (Washington Convention)	Annex II, IV	-	-
EU's Habitat directive (93/43/EEC)	Annex II, IV	Annex II, V	Annex II, V
Marine Framework Strategy Directive (EC, 2008/56/EY)	Descriptor 1 "Biodiversity"	Descriptor 1 "Biodiversity"	Descriptor 1 "Biodiversity"
Bern Convention	Annex II	Annex III	Annex III
Bonn Convention	Annex II	Annex II	Annex II
ASCOBANS	Included	Not relevant	Not relevant
HELCOM (Helsinki Convention)	Included	Included	Included
OSPAR (Oslo Convention)	Included	Included	Included

3.2.1.1 Harbour porpoise

In European waters, the harbour porpoise is listed in Annex II and IV of the Habitats Directive (European Commission, 1992) aiming for favourable conservation status and it's included in descriptor 1 "Biodiversity" of the Marine Framework

Strategy Directive (European Commission, 2008/56/EY) aiming for a good environmental status. It is also listed in annex II of the Bern Convention, annex II of the Bonn Convention and annex II of the Washington Convention (CITES). Furthermore, the harbour porpoise is covered by the terms of the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS), a regional agreement under the Bonn Convention and HELCOM (The Helsinki Commission; protection of the marine environment of the Baltic Sea).

According to the Danish Red list from 2019 the Belt Sea population of harbour porpoises is classified as of least concern (LC) (Moeslund, et al., 2019) and the conservation status in the marine Atlantic region are generally considered to be favorable (Fredshavn, et al., 2019).

3.2.1.2 Harbour Seals

The harbour seal is protected under the EU Habitats Directive and included under descriptor 1 "Biodiversity" of the Marine Framework Strategy Directive ((European Commission, 2008/56/EY) aiming for a good environmental status. Furthermore, harbour seals are included under the Convention for the Protection of Migratory Species (Bonn Convention) as well as protected under national legislation. The harbour seal is listed on the EU Habitats Directive's annex II, which means that it should be protected by the designation of special areas of conservation where activities compromising conservation status should be avoided. For seals, these areas are primarily placed in connection with important haul-outs on land. Furthermore, harbour seals are listed on annex V of the Habitats Directive, meaning that hunting, derogation shooting or removal of wild seals should be compatible with maintaining or achieving favourable conservation status.

Harbour seals occur in the entire Kattegat and the population in Kattegat is shared between Sweden and Denmark. According to the Danish Red list from 2020 the population in Kattegat is classified as of least concern (LC) (Moeslund, et al., 2019). The harbour seal conservation status according to the Habitats Directive was assessed as 'favourable' in the marine Atlantic Region (Fredshavn, et al., 2019).

3.2.1.3 Grey Seals

The grey seal is a protected species listed in Annex II and Annex V of the EU Habitats Directive and Annex III of the Bern Convention and included under descriptor 1 "Biodiversity" of the Marine Framework Strategy Directive ((European Commission, 2008/56/EY) aiming for a good environmental status. Furthermore, grey seals are included under the Convention for the Protection of Migratory Species (Bonn Convention) as well as protected under national legislation. The listing on the EU Habitats Directive annex II means it should be protected by the designation of special areas of conservation where activities compromising its conservation status should be avoided. For seals, these areas are primarily placed in connection with important haul outs on land. Furthermore, grey seals are listed on annex V of the Habitats Directive, meaning that hunting, derogation shooting or other removal of wild seals should be compatible with maintaining or achieving favourable conservation status.

Grey seals occur in the entire Kattegat and the seals there originate from two large population centers in the greater North Sea and the Baltic Sea, respectively. According to the Danish Red list from 2020, the population in Kattegat is classified as of least concern (LC) (Moeslund, et al., 2019). The grey seal's conservation status according to the Habitats Directive was assessed as 'unfavourable - inadequate' in the marine Atlantic Region (Fredshavn, et al., 2019).

3.3 Seal methodology

In the following section a description on survey methodology and field surveys for seals are described.

3.3.1 Aerial surveys

Aerial surveys of seals were conducted to collect data on the numbers of seals hauled out at localities in the vicinity of the OWF plan area and cable corridor (Figure 3.1). Data collection consisted of two observers taking overlapping photographs of hauled out groups of seals with high quality DSLR cameras with 100-200 mm lenses. Photos were taken from a high-wing single engine aircraft (e.g., Cessna 172) through an open window on the passenger side at 600'-700' altitude. To minimize variation in the data, surveys were conducted under a range of predefined conditions: no precipitation during the survey and the preceding 6 hours, observations conducted between 9 am and 15 pm and winds below 10 ms^{-1}. Notes on observations besides what was photographed, time points at key localities and any deviations from the planned procedure were taken by the leader of the survey.

Aerial surveys of seal haul-outs do not directly provide information on the at-sea distribution of the seals. Haul-outs are an important factor in the distribution of seals, which are often regarded as 'central place foragers' with the haul-out as the central place. However, other biotic and abiotic factors are also important for seal distribution, including prey distribution, bathymetry/geomorphology, seasonality, disturbance and individual preferences. Thus, the aerial seal surveys mostly inform about the expected relative density of seals in the area when data are compared to other areas, and about the density at or around the haul-outs at the time of the surveys. These are also important pieces of information as seals use the haul-outs for key life cycle events such as giving birth, nursing, mating, moulting their fur and resting between foraging trips. Knowledge regarding at sea distribution of seals is procured by equipping a representative sample of seals with satellite transmitters, relaying the seals' positions. This is a much costlier operation, which was not selected for this investigation.

Six aerial surveys of Danish localities in Kattegat were already planned under the national monitoring programme NOVANA, during the moulting and pupping seasons of grey seals and harbour seals, respectively (1 in February, 1 in March, 2 in June and 2 in August). These surveys were extended to cover the Swedish locality at Hallands Väderö and were supplemented by surveys in January, April and October to provide data points throughout the year of seal distribution and haul-out activity.

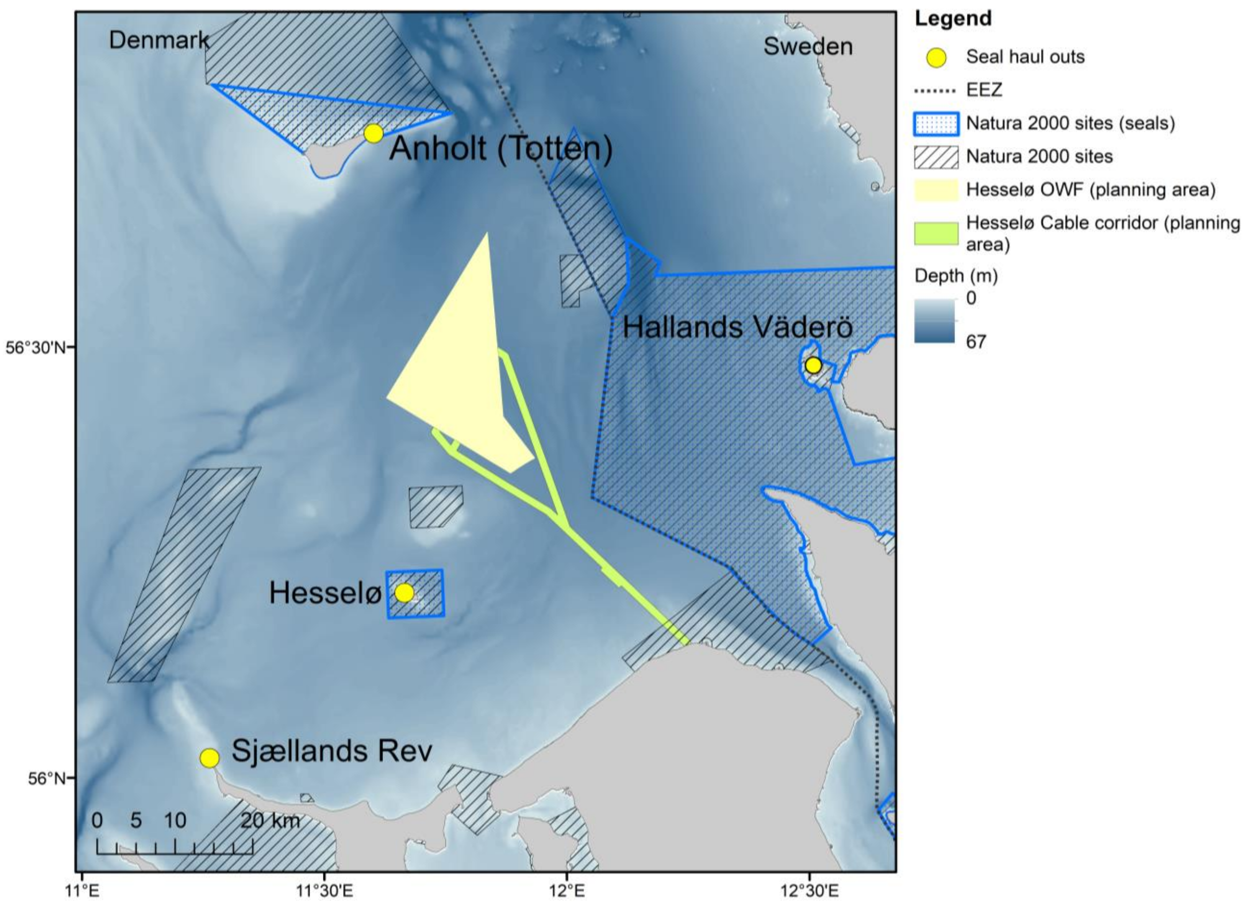

Figure 3-1 Location of seal haul-outs in relation to the plan area for Hesselø OWF. The map is shown in UTM32/ETRS89

Photographs and notes were uploaded to a safe network storage upon return from each aerial survey.

Aerial surveys of harbour seals in the Danish part of Kattegat during the moulting season in August have been conducted since 1978. Surveys to assess pup production of harbour seals during the pupping season in June were initiated in 2010. Surveys of moulting grey seals in late May/early June grey seal pupping season in late February and early March were initiated in 2012. Data from the surveys since 2010 was included to provide a baseline for the results obtained during 2021. These data were collected with the same methodology as the 2021 data.

Previous survey data since 2010 are available for Hesselø and Anholt from February, March, late May/early June, mid-June and August as these localities have been surveyed both during harbour and grey seal pupping and moulting seasons. Sjællands Rev has only been surveyed during harbour seal moulting and pupping seasons in June and August, while Hallands Väderö has only been covered during the harbour seal moulting season in August.

The four haul-outs have rather different characteristics. The haul-out at Hesselø consists of two low stone reefs in extension of one another, pointing towards the northwest from the island, both ca 100 m long. In between them, there are single large stones, where several hundred seals may also rest. At Anholt, the haul-out consists of the sandy beach at the eastern tip of the island. The beach and tip are constantly reshaped by wind and currents and sandbanks may form off the beach, where seals also rest. The primary haul-out at Sjællands Rev is an artificial boulder structure that supports the smaller of the two lighthouses along the reef. When the water level is low, the shallowest part of the reef is further exposed as a sand/shingle bank, where seals also rest when it is available. The haul-outs at Hallands Väderö consist of 11 smaller and larger rock skerries spread around the main island.

3.3.2 Analysis

For each survey, seals were counted from the two series of photographs by two independent observers. If the discrepancy between the two counts exceeded 5%, a third, independent count was conducted.

3.4 Harbour porpoise methodology

In the following section a description on survey methodology and the field surveys for harbour porpoise are described.

The data collection for harbour porpoises was divided in two parts:

1. Three aerial surveys was conducted from May to August 2021 (the reproduction season) to determine the abundance and density of harbour porpoise in and near the plan area, and especially to determine whether calves were observed in the area, since this would be important information for the temporal planning of the windfarm construction. The aerial surveys coverered the windfarm area as well as the cable corridor and is the only method to inform on density and abundance in the area albeit it is limited spatially to the days of the surveys.
2. Deployment of passive acoustic monitoring (PAM) systems across the impacted areas i.e. the wind farm and where the cable crosses the Natura 2000 site for harbour porpoises near Gilleleje. This data will provide temporal knowledge of porpoise use of the area across the year.

3.4.1 Aerial surveys

Three aerial surveys were planned from May to August 2021 (the reproduction season of harbour porpoises) to determine the abundance and density of harbour porpoise in the wind farm area. The aerial surveys covered the plan area, the cable corridor. A 20 km buffer zone around the windfarm and cable corridor was included in order to cover the area where harbor porpoises may be affected behaviourally during piling of the turbine foundations.

The survey area is assessed to be the largest area that could potentially be affected by underwater noise generated during the construction from piling of pin piles/monopiles for the foundations. This was identified by reviewing current literature. The largest impact on porpoises is the underwater noise generated during pile driving, where the foundations are hammered into the seabed. Several studies have estimated the impact on porpoises during the construction phase of a wind farm, by comparing the presence of porpoises before, during and after construction work has ended. All studies concluded that when using mitigation in the form of soft start/ramp up and acoustic deterrent devices (to drive porpoises out of the core area) and bubble curtains (to lower the generated noise level), the maximum distance affected ranged between 10 and 15 km (Dähne, et al., 2013; Dähne, et al., 2017; Brandt, et al., 2018).). Thus, it is chosen that the survey area included a 20 km buffer around the planned area for Hesselø Offshore Wind Farm. The cable corridor and the northern part of the Sound was also included, as this area is a known hotspot for harbour porpoises. In total, the Hesselø aerial survey area was 3659 km^2. The transect lines had a 5 km spacing and an average length of 49 km (total of 732 km). This design enabled us to survey the entire core area that may be expected to be impacted by the construction of the wind farm and cable laying (Figure 3.2).

Aerial surveys followed pre-designed transect lines (parallel design and equal spacing of 5 km) that ensure equal coverage probability. In all, 15 transects were laid out in a parallel design of East-West lines. With this method it is standard procedure to lay out the transect perpendicular to the depth contours. In the planned survey area, there are no clear depth gradient and so the east-west lines were chosen to optimize the length of the survey transects: Each transect should not take more than 30 minutes, since observers will become tired on longer transects and then unintentionally may miss some porpoise observations (Figure 3.2).

The observation method followed the standard described in Scheidat et al. (2008) and Gilles et al. (2009). In short, there were three experienced scientists onboard the aircraft (Partenavia with bubble windows): two observers positioned at the bubble windows and one data collector, sitting either behind the observers or in the co-pilot seat. Once a harbour porpoise was observed, the observer informed on number of individuals, angle to observation (90 degrees is directly below the plane and 0 degrees is horizontal), observation cue, behaviour and so on. Environmental data on sea state, cloud cover and glare were also collected continuously. Continuously, each observer also assessed their own subjective sightability as either good, moderate or poor. Sightability will indirectly include several of the other variables collected e.g. wind and glare. This variable was in previous surveys, e.g. SCANS-II and SCANS-III, shown to be the best predictor of porpoise presence. The data recorder noted all this information in the program VOR on the field laptop. During line transect distance sampling, the perpendicular distance of a porpoise sighting to the track line is estimated from the angle to the observation. These distances are used in later abundance analyses to estimate the effective strip width covered by the plane. To measure the distance, the plane flies at a constant height (183m) and the vertical or 'declination' angle to the animal is measured when it comes abeam. The plane flies at a constant speed of 100 knots.

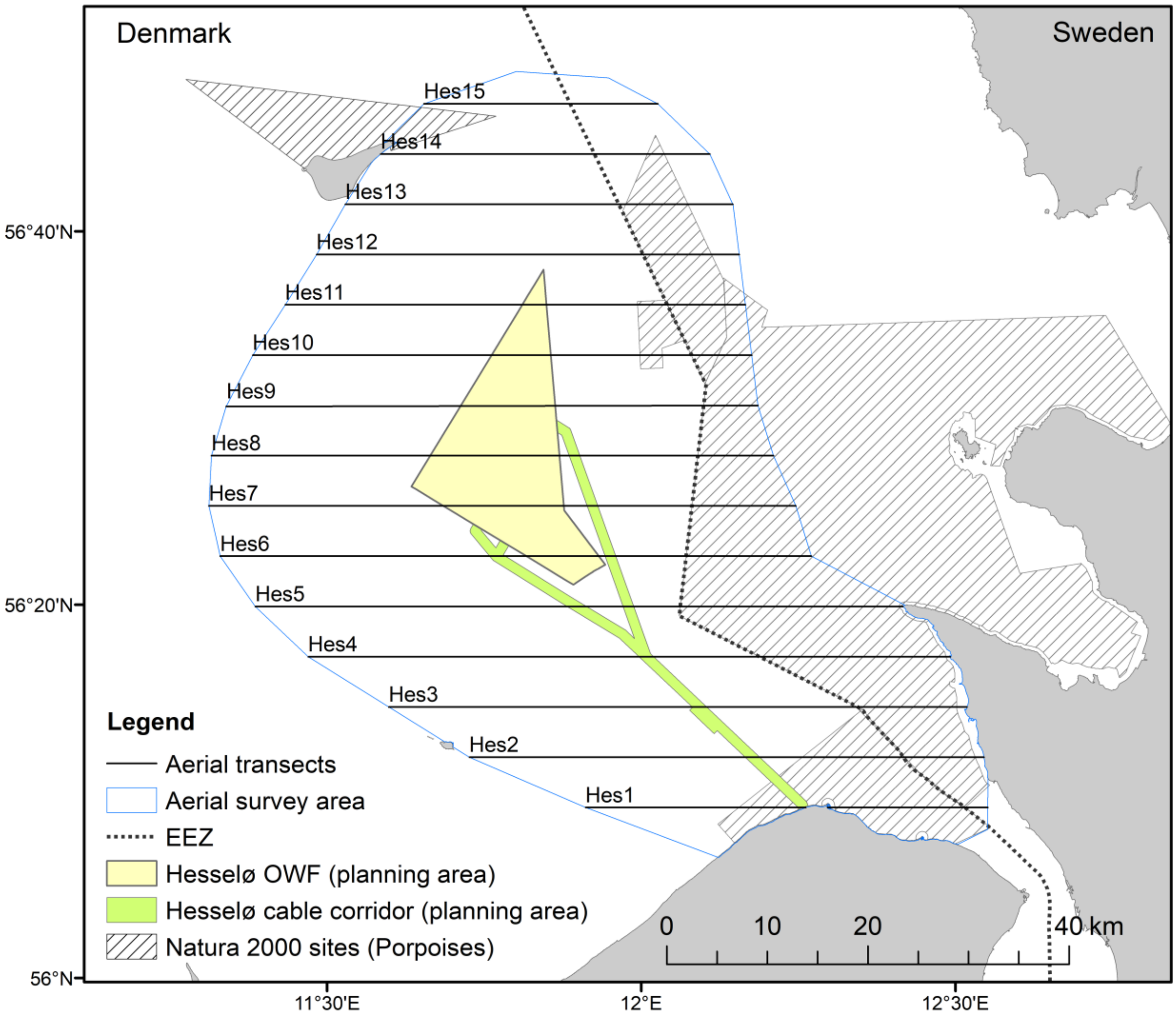

Figure 3-2: Aerial survey transects covering the plan area for Hesselø Offshore Wind Farm and the Gilberg cable corridor as well as a 20 km buffer area and the northern Sound. Maps are shown in UTM32/ETRS89.

Data validation and storage: Once the aerial survey was finished all data files were backed up on an external drive. The data are stored in file-types that may be viewed in any text program such as notepad, so subsequently, the data are validated by one observer going through all entries (environmental and observational) and visually checking for errors such as implausible observation angles, misspellings and so on. The data are then ready for analysis.

3.4.2 Analysis

The number of porpoise sightings within an area depends not only on the number of individuals observed, but also on the probability of the individual being visible (called availability bias) and the probability of an observer detecting it (called perception bias). The parameter quantifying the combined probability is known as g(0). This factor has been estimated during previous surveys conducted in German and Danish waters by using the "racetrack" method. Details of the racetrack method and the analyses are described in Hiby and Lovell (1998) and Hiby (1999) . For the analysis at Hesselø OWF, the observer team, methodology and the survey plane were consistent with the one used during SCANS-III in 2016 in European (incl. Danish) waters and thus we applied the g(0) value and other relevant information such as the effective strip width used during SCANS-III (Hammond, et al., 2021). The major advantage of this method is that it takes into account both availability and perception bias with the same data collected.

Animal abundance in the Hesselø OWF study area (v) was estimated as:

$$\hat{N}_v = \frac{A_v}{L_v}\left(\frac{n_{gsv}}{\hat{\mu}_g} + \frac{n_{msv}}{\hat{\mu}_m}\right)\bar{s}_v$$

Where A_v is the area of the stratum, L_v is the length of transect line covered on-effort in good or moderate conditions, n_{gsv} and n_{msv} are the number of sightings collected in good conditions and moderate conditions respectively, $\hat{u}_g$ is the estimated effective strip width (ESW) in good conditions, $\hat{u}_m$ is the estimated ESW in moderate conditions and $\bar{S}_v$ is the mean observed group size in the stratum. ESW will be small if the weather conditions are poor and larger in good condition. Coefficients of variation (CVs) and 95% confidence intervals (CIs) were estimated by bootstrapping (999 replicates) within strata, using transects as the sampling units. More details on survey method and abundance estimation are described in Scheidat et al. (2008), Gilles et al. (2009), Hammond et al. (2013) and Nachtsheim et al. (2021).

3.4.3 Passive acoustic monitoring

In addition to the aerial survey of harbour porpoise, deployment of passive acoustic monitoring (PAM) systems in the plan area was conducted. CPODs (Chelonia Limited) were used as the PAM system. This system is specially developed to detect porpoise sound signals and is the most widely used PAM system for porpoises in Danish waters, which allows for the use and comparison of the results from other former and ongoing monitoring studies of porpoises in Danish waters.

Six CPODs were deployed within the plan area for Hesselø OWF at 2 m above the bottom using acoustic releasers and/or large yellow surface buoys (depending on the location and trawling intensity). The CPODs were deployed in a random grid also used in the Swedish and Danish national monitoring programs for harbour porpoises ensuring unbiased representation of the harbour porpoise distribution in the area (Figure 3.3).

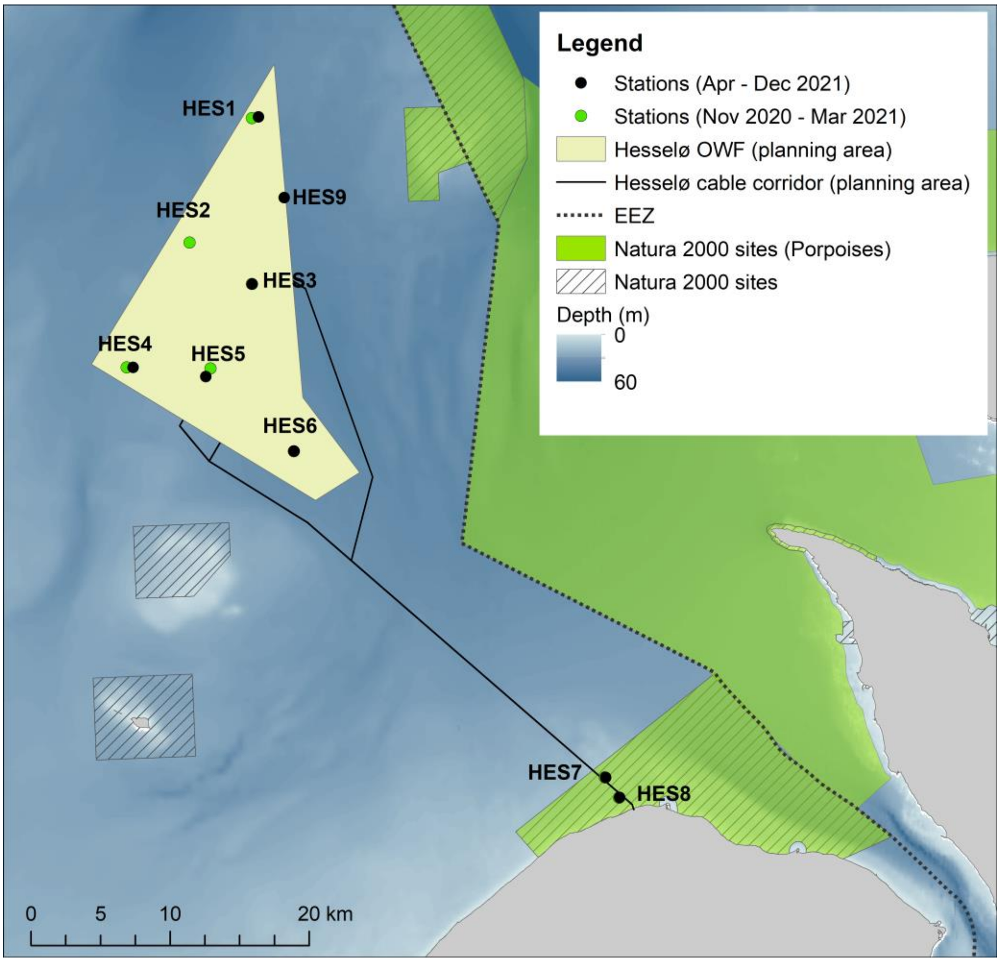

Figure 3-3: Overview of the passive acoustic harbour porpoise monitoring with eight CPOD stations. Natura 2000 sites for harbour porpoises are shown in green and Natura 2000 sites designated for other species and habitats are shaded.

In the cable corridor two additional CPODs were deployed north of Gilleleje within the Natura 2000 area no. 195 “Gilleleje Flak og Tragten”. The area has been particularly appointed to protect porpoises.

The CPOD station setup is shown in Figure 3.4 and consists of two stone sacks of each 25 kg connected with hemp rope to the Sub Sea Sonic acoustic releaser. The releaser can be released by using a deck unit onboard the survey vessel to transmit the release signal to the releaser at the bottom. The releaser is connected to the CPOD with rope and finally to two orange floats for positive buoyancy. To prevent equipment loss, large yellow buoys with top signal including radar reflection, yellow cross and solar panel light (Fl(5)Y.20s) were deployed 10-20 m from each CPOD at the PAM station in the wind farm area.

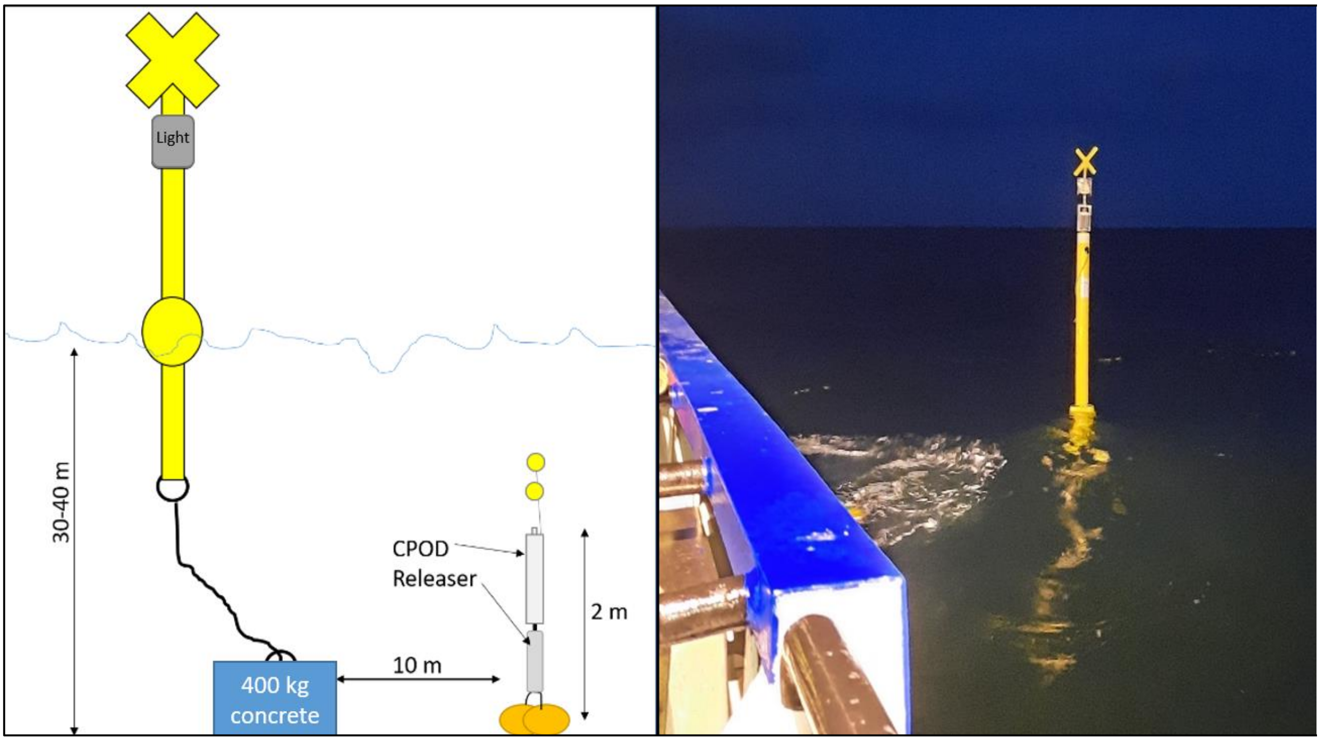

Figure 3-4: Setup: PAM station with yellow buoy and CPOD (left) and photo of deployed buoy at the surface (right).

During deployment the equipment was lifted into the water surface by a crane and released once the deployment vessel was at the correct position. The exact deployment position of the station was registered upon release.

During equipment retrieval the hydrophone cable connected to the acoustic release deck unit was lowered into the water where it transmits the release code and releases the equipment from the sandbags on the sea floor. Upon release, the equipment drifted to the surface where it was retrieved. Once the CPOD was dry and open, the SD-card was removed and data downloaded and stored.

3.4.4 Analysis

The raw data was copied and backed-up directly, while simultaneously the data was read in the programme CPOD.exe (Chelonia Limited) where a so called CP1-file was created. This file was then visually validated to see if data looked normal and if the CPOD had recorded throughout the deployment period. CPOD data were processed prior to analysis in CPOD.exe. Harbour porpoise click trains were identified by running the build in "Hel1"-algoritm." Hel1" was developed during the SAMBAH project (http://www.sambah.org/) during a meeting in the Polish city, Hel, to minimize the number of false detections and is as such a rather restrictive method of detecting porpoises in extremely low density areas. Hel1 is however not restrictive in high density areas such as Kattegat, and is only used in order to compare data with the national monitoring data in Denmark and Sweden that uses the Hel1 classifier because part of the national monitoring includes low density areas in the Baltic Proper.. Following identification of porpoise click trains, data were exported as detection positive minutes (DPM) per day, which are minutes with porpoise click trains.

4 Results and baseline

4.1 Seals

All six originally planned surveys were successfully conducted and a further three surveys in the Kattegat area were extended to cover the relevant haul-outs, resulting in 9 surveys completed on January 26th, February 26th, March 17th, April 8th, June 2nd and 15th, August 23rd and 25th and October 12th 2021. A few localities were not covered on certain occasions. At Sjællands Rev, military activity precluded access on January 26th and August 25th. Local rain showers precluded survey of Hallands Väderö on April 8th and August 25th, on the latter occasion, this location and all areas were covered two days previously on August 23rd as planned. Table 4-1 provides an overview of surveys and location coverage.

Table 4-1 Summary of conducted seal count at the four nearest seal haul-outs. += successful count, %= no count.

Survey Date	Sjællands Rev	Hesselø	Hallands Väderö	Anholt Totten
26/1-2021	%	+	+	+
26/2-2021	+	+	+	+
17/3-2021	+	+	+	+
8/4-2021	+	+	%	+
2/6-2021	+	+	+	+
15/6-2021	+	+	+	+
23/8-2021	+	+	+	+
25/8-2021	%	+	%	+
12/10- 2021	+	+	+	+

4.1.1 Baseline data

Anholt: In 2010 to 2013, there were at least several hundred harbour seals at Anholt during all surveys from February to August. From 2014, usually there were few harbour seals during the early surveys in February and March (<10), and several hundred (300-1000) during the surveys in May to August. At this location, there has been a general declining trend in the number of harbour seals since 2010, for all survey periods, with 250-800 seals during moult in August om 2018-2020 compared to 750-1300 in 2010-2013 (Figure 4.1). Grey seal numbers at Anholt are by far the highest in the study area. The largest occurrences are during May and June, in accordance with the moulting season of the Baltic subspecies. Up to 151 grey seals have been recorded. Numbers have generally been increasing since 2010 (Figure 4.2). Anholt is an important pupping locality for harbour seals, usually several hundred pups are recorded every year with a record of 387 in 2011 (Figure 5-3). As with the general occurrence of harbour seals, pup numbers have shown a declining trend with 170-200 pups recorded in the period 2018-2020. Anholt is the only locality in the study area where grey seal pups have been recorded. One pup was recorded in each of the years 2015, 2017 and 2019.

Hallands Väderö: Baseline data from Hallands Väderö are only available from August. During this month, harbour seal counts have been increasing from 2010 to 2014 (Ca 500 to 900), where there was a drop, coincident with the harbour seal Influenza A epidemic that year. The numbers grew again from 2015 to 2019 (ca 400 to 1200), before another drop with ca 600 harbour seals in 2020.

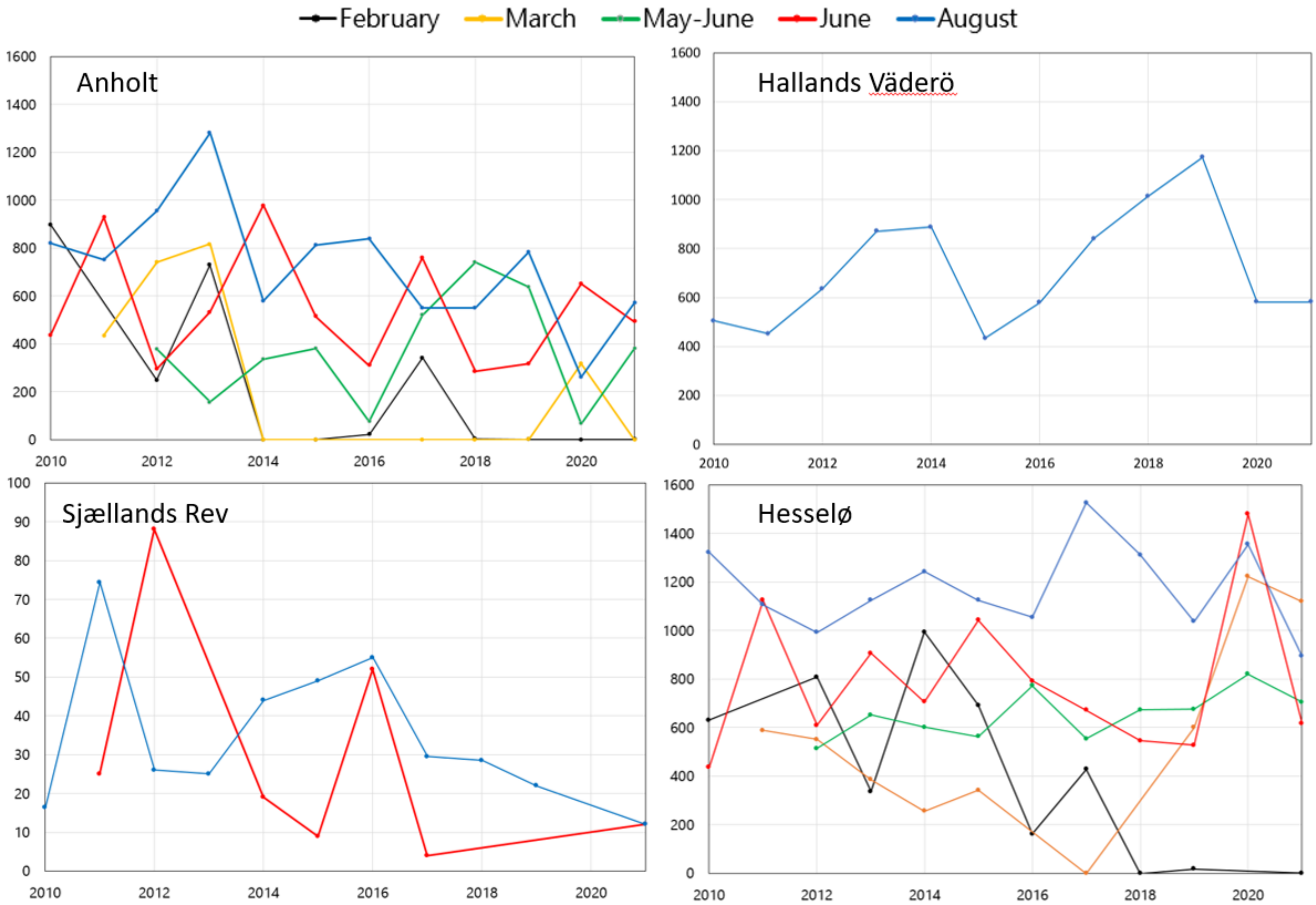

Figure 4-1 Baseline data on number of harbour seals (Y-axis) at the four haul-outs in the study area in sequential years since 2010 (X-axis). Hallands Väderö and Sjællands Rev are only surveyed during the harbour seal moulting season and moulting and pupping seasons, respectively. Notice the different scale for Sjællands Rev.

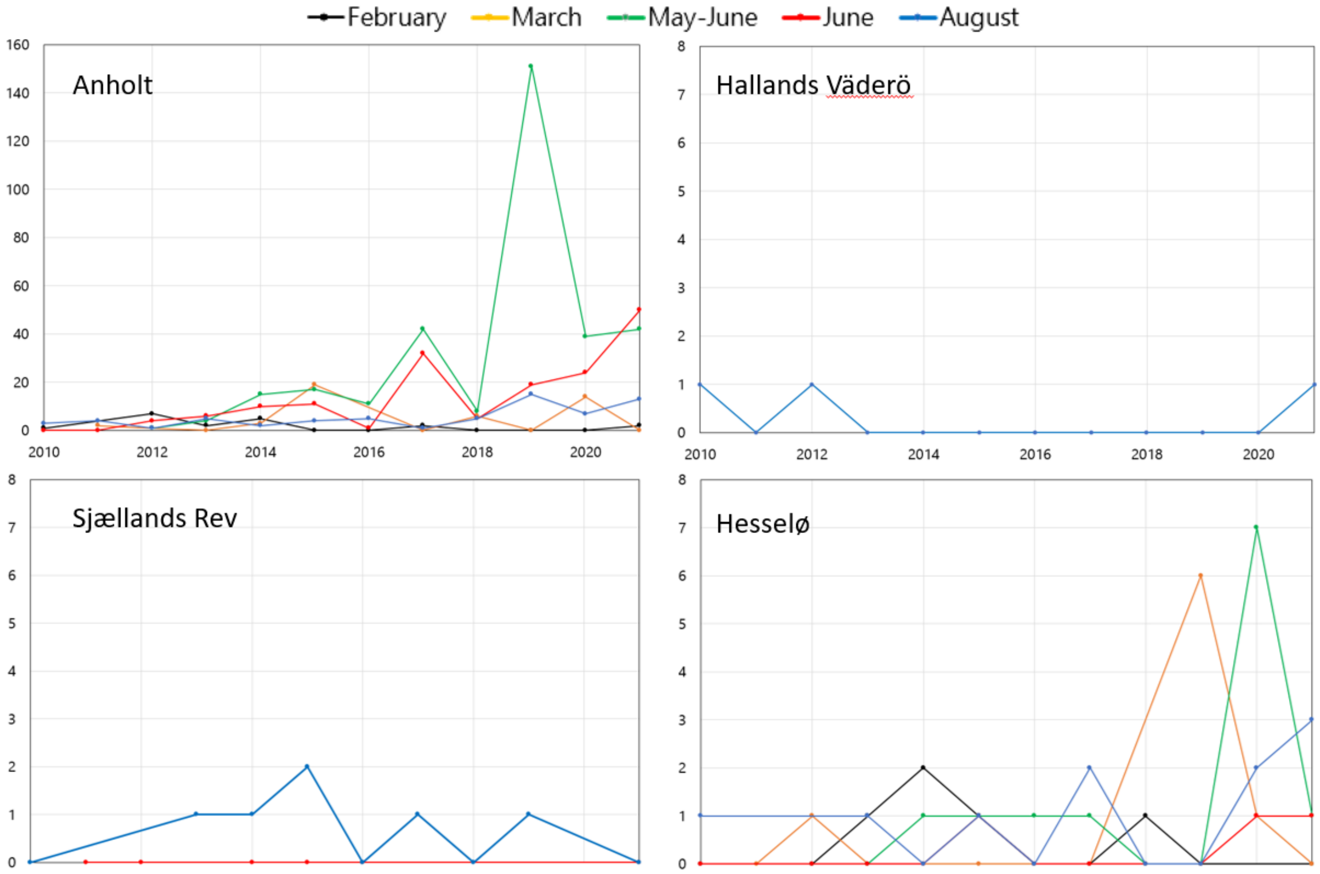

Figure 4-2 Baseline data on number of grey seals (Y-axis) at the four haul-outs in the study area in sequential years since 2010 (X-axis). Hallands Väderö and Sjællands Rev are only surveyed during the harbour seal moulting season and moulting and pupping seasons, respectively. Notice the different scale for Anholt.

Sjællands Rev: Baseline data from Sjællands Rev are only available from June and August. Harbour seal counts range between 4 and 88 with an average of 35 and with no apparent trend (Figure 4.1). No grey seals have been recorded in June, one to two grey seals are regularly recorded in August. A few harbour seal pups (maximum 14 in 2012) have been recorded here in June in years with low water level, where a sand bank is exposed.

Hesselø: Hesselø has the highest occurrences of harbour seals in the study area with >300 seals usually being recorded on surveys throughout the period February to August. On a few occasions, less than 20 harbour seals have been recorded in February and March, but >1200 have also been recorded in March. Numbers are generally highest during the moult in August (average: ca 1200), followed by the pupping season in June (average: ca 800, not counting pups). The occurrence of harbour seals at Hesselø appears stable between 2010 and 2020 (Figure 4.1). Grey seals occur sporadically at Hesselø with no marked seasonal trend (Figure 4.2). The highest number recorded was 7 during the grey seal moulting season in 2020. Hesselø is an important breeding locality for harbour seals with ca 200-400 pups being recorded annually (Figure 4.3). No grey seal pups have been recorded at Hesselø.

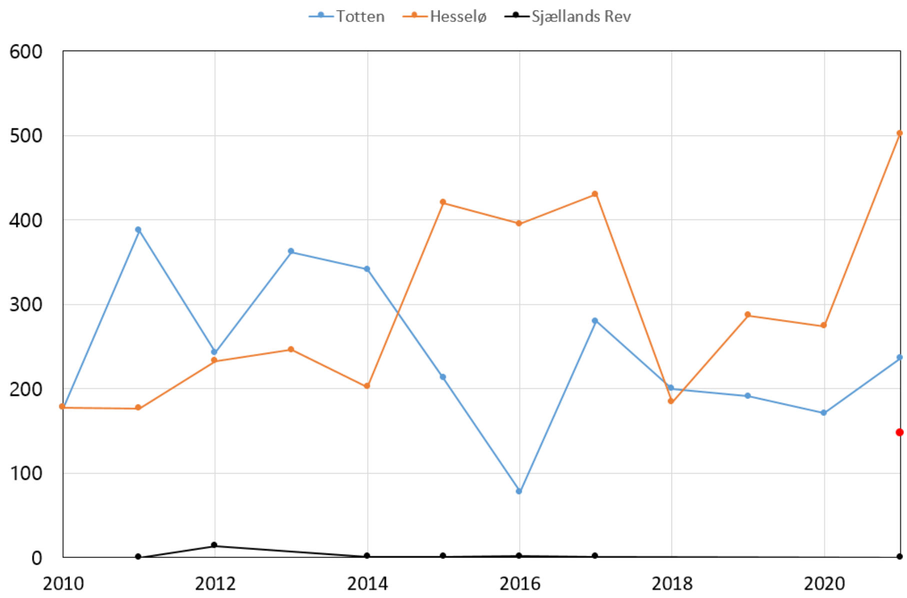

Figure 4-3 Baseline data on harbour seal pups at the three haul-outs surveyed during the pupping

4.1.2 Surveys during 2021

Harbour seals: The numbers of harbour seals hauled out in the study area grew from January to August, the maximum coinciding with the moulting season. 233 harbour seals were counted in January and only 3 in February, ca 1300 in March, 1500 in April, 1700 in early June, 2300 in mid-June (not counting newborn pups), 2700 in August and 1000 in October. The largest numbers were consistently recorded at Hesselø (maximum 1469) with Anholt (maximum 1135) and Hallands Väderö (maximum 618) showing similar counts. Sjællands Rev had much fewer seals with a maximum of 82 harbour seals (Figure 4.4).

Harbour seal pups: During the peak of the pupping season on June 15th, 886 pups were counted in the study area, 236 at Anholt, 148 at Hallands Väderö, 502 at Hesselø and none at Sjællands Rev.

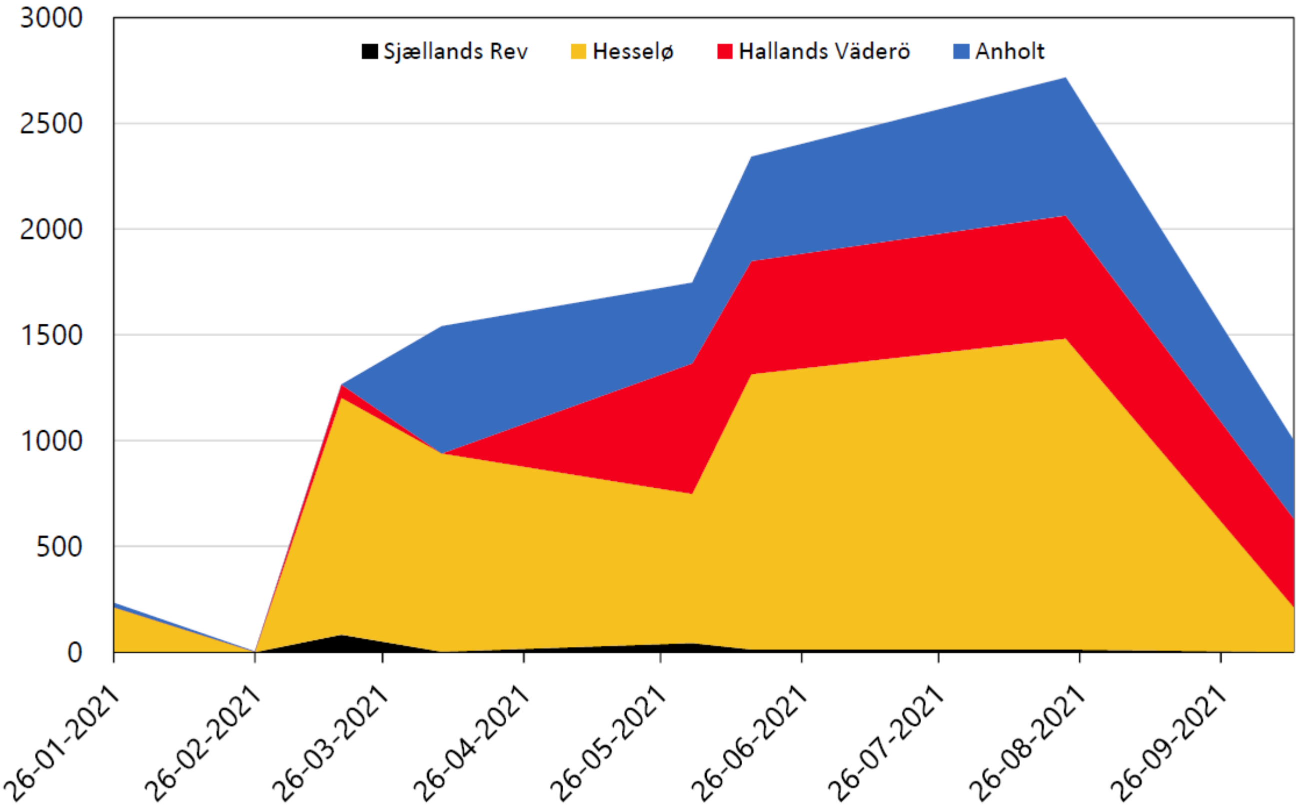

Figure 4-4 Survey data on harbour seals from the study area from January 26th to October 12th 2021, with partitioning between the localities. Y-axis shows number of individuals counted and X-axis shows date of the count.

Grey seals: The numbers of grey seals hauled out in the study area grew from January to the Baltic grey seal moulting season in June and declined again in August. Only one grey seal was recorded in the study area before the April survey, where 19 were counted at Anholt. Only 9 grey seals were recorded outside Anholt, 5 of these at Hesselø in August. At Anholt 42, and 50 were recorded during the two June surveys, 9 and 17 during the two August surveys and 27 in October. Only two grey seals were recorded at Hallands Väderö, one in August and one in October, and no grey seals were recorded at Sjællands Rev (Figure 4.5).

Grey seal pups: No grey seal pups were recorded in the study area in 2021.

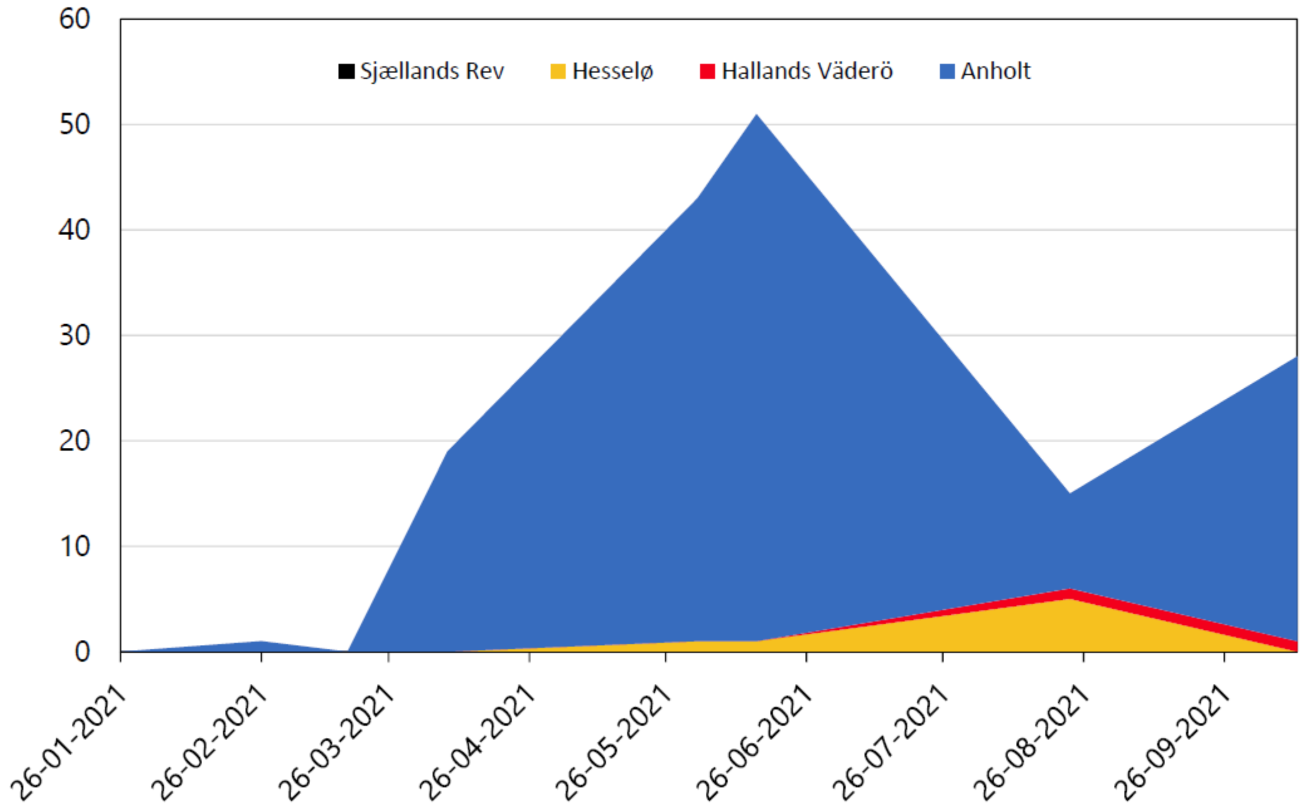

Figure 4-5 Survey data on grey seals from the study area from January 26th to October 12th 2021, with partitioning between the localities. Y-axis shows number of individuals counted and X-axis shows date of the count.

4.1.3 Conclusions and perspective for seals (comparison with other areas in the Kattegat and inner Danish waters)

Harbour seals

The study area is part of the Kattegat harbour seal population (Olsen, et al., 2014), which is shared between Sweden and Denmark. In both countries, seals were hunted intensively during the early 20th century, leading to a population collapse (Heide-Jørgensen & Härkönen, 1988). In the latter half of the 20th century, harbour seals were protected in Sweden (1967) and later Denmark (1976), and several haul-outs were protected. In the late 1970s, there were around 3000 harbour seals in Kattegat, the great majority of these along the Swedish coast (Olsen, et al., 2010). From this time, the population grew at 10-12 % annually interrupted by the two phocine distemper virus outbreaks in 1988 and 2002 that killed ca 50 % of the population on both occasions (Härkönen, et al., 2006). After 2002, the population has grown at a slower pace of ca 4 % annually (Figure 4.6), probably slowing down because of density dependence as the population approaches the carrying capacity of the environment (Silva, et al., 2021). The study area ranges from the central to the southeastern part of the population area, the area held an average of 28 % of the Kattegat population count in the five seasons 2016-2020, with 6 % at Anholt, 9 % at Hallands Väderö, 13 % at Hesselø and 0.3 % at Sjællands Rev. Figure 5-6 shows harbour and grey seal moult distribution during 2015-2017. Combined, Anholt, Hesselø and Hallands Väderö account for all harbour seals hauling out in the southeastern part of the population area and each represent substantial fractions of the pups counted in the Kattegat area. Pups are not counted in Sweden, but Anholt and Hesselø accounted for 11 % and 18 % of the pups counted in the Danish part of Kattegat in the five seasons 2017-2021 (the Danish haul-outs representing ca 45 % of the Kattegat total during moult). These haul-outs in the southeastern part of the population area have more distance between them than in the rest of Kattegat, ca 40 km. Compared to other seal species, harbour seals move over relatively small distances. Kernel home ranges of adult harbour seals tagged at Anholt did not extend to include the areas around Hesselø and Hallands Väderö (Dietz, et al., 2013). Thus, if seals are permanently displaced from one of the haul-outs, it is likely that reestablishment will be slow.

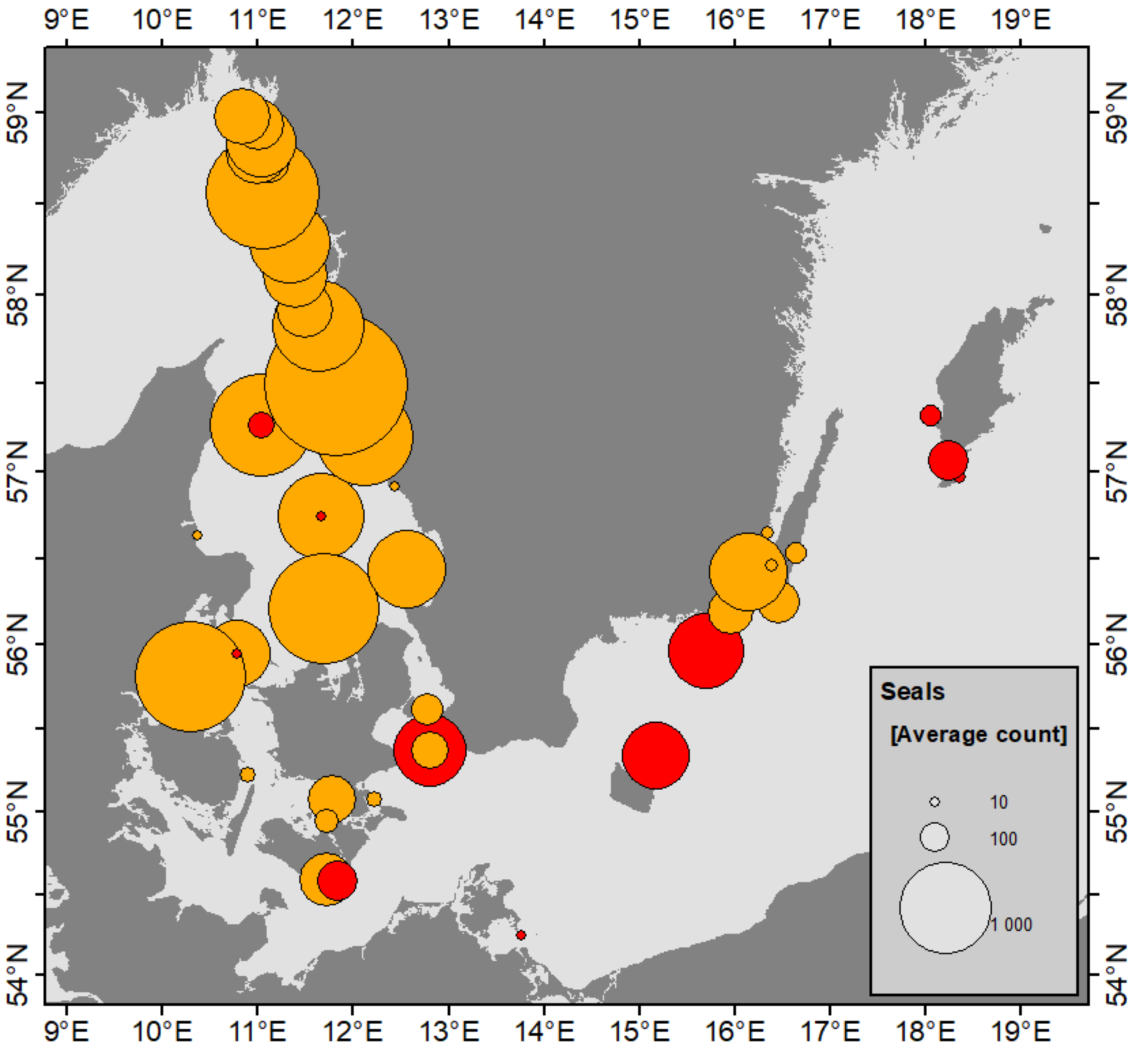

Figure 4-6 Harbour and grey seal haul-out distribution in their respective moulting seasons in the southwestern Baltic and Kattegat 2015-2017, from Sokolova et al. (2018). Harbour seals in orange, grey seals in red.

Both previous and 2021 data show that harbour seals in the area spent most time hauled out during the summer months and least during winter and early spring and in this regard, the study area is similar to other parts of Kattegat and the inner Danish waters. There are few data on harbour seal haul-out attendance outside the breeding and moulting season in the Baltic region as grey seals are few and not monitored during their breeding and moulting seasons on most of the harbour seal haul-outs. The Danish part of Kattegat is an exception, where the study area and Læsø are surveyed during key seasons for both species. The seasonal pattern at Læsø is very similar to that reported here (Aarhus University, unpublished data). A telemetry study of seals tagged at Anholt (Dietz, et al., 2013) showed that seals increased their distance to the haul-out during the fall and winter months, where they haul out less, so harbour seal occurrence in the study area may be lower during this part of the year.

Harbour seals are generally recognized to be most vulnerable to disturbance during the breeding season, where pups are dependent on their mothers, and the moulting season, where they need to go ashore to avoid excessive heat loss due to the increased perfusion of blood to the skin associated with the growth of new hair. Outside these seasons, seals still need to haul out between foraging trips (Brasseur, et al., 1996). Densities in the vicinity of the haul-outs can be expected to be highest during the months with peak haul-out activity. Habitat suitability modelling based on telemetry data shows a moderate to high suitability for harbour seals throughout most of the study area (van Beest et al. in prep).

Grey seals

Grey seals move over much larger distances than harbour seals, and in consequence, grey seal populations cover much larger areas. In Kattegat, grey seals from two distinct populations occur, namely the greater North Sea population and the Baltic Sea population (Fietz, et al., 2016). The two populations have different moulting and breeding seasons (North Sea breeding: November-December, North Sea moulting: March-April, Baltic Sea breeding: February-March, Baltic Sea moulting: May-June). Fietz et al. reported that most genetic samples collected in Kattegat were from the North Sea, but data collected during this project show that the highest numbers of hauled out grey seals in the area coincides with the Baltic moulting season. As was the case for the harbour seal, the grey seal was hunted intensively and was extinct as a breeding species in inner Danish waters including Kattegat early in the 20th century (Galatius, et al., 2020). Archeological finds and historical sources indicate that it was the most common seal species in Denmark, including Kattegat, prior to the 19th century (Olsen, et al., 2018). After the extinction of the species in the southern Baltic and Kattegat, Baltic grey seals experienced a second dramatic collapse in the 1960s and 1970s as contaminants such as PCBs and DDT caused infertility in females and only ca 4,000 seals were estimated to remain in the population in the late 1970s. Since then, the species has recovered and since 2005 increasing numbers have been recorded in the southern Baltic and Kattegat. In 2019 ca 38,000 grey seals were counted in the Baltic-wide surveys (Galatius, et al., 2020), but only ca 2500 of these were counted in the southern Baltic and 160 in Kattegat. Grey seals breed sporadically in Kattegat, with pups recorded at Bosserne near Samsø, Borfeld near Læsø and at Anholt. A total of 10 pups have been recorded since 2011, three of these at Anholt. Anholt has held an average of 42 % of the grey seals counted in the Danish part of Kattegat during the Baltic Sea moulting season in 2017-2021 and 4 % of the count during the North Sea moulting season. For Hesselø, these figures are 2 % and 1 % respectively. There are no annual counts at Hallands Väderö outside August, but very few grey seals are seen along the Swedish west coast, usually 10-25 are counted along the entire coastline during an August survey. During six surveys, only one grey seal was encountered at Hallands Väderö, on August 23rd, and no grey seals were found at Sjællands Rev, which is also not surveyed annually outside June and August under the national monitoring programme. This is in line with the baseline data, where only low numbers of grey seals have been recorded at these haul-outs.

Although there are very few telemetry data, compared to harbour seals, haul-out counts are likely to reflect local occurrence near the haul-outs. This means that densities around the haul-outs are likely highest during spring and early summer and lowest during winter. The most vulnerable periods are around the breeding seasons, and grey seals are likely more vulnerable than harbour seals during this period as their pups are born in lanugo fur and cannot swim from birth. The study area has not been monitored during the North Sea grey seal breeding season in November-December, so it is unknown whether breeding occurs during this time. However, the observations during 2021 indicate that the majority of the grey seals in the study area originate from the Baltic population. Anholt and Hesselø have historically had grey seal breeding activity (Galatius, et al., 2020), while no reports of previous breeding activity are known for Sjællands Rev or Hallands Väderö.

4.2 Harbour porpoises

4.2.1 Aerial survey results

The three aerial surveys were conducted on 17th May, 25th June and 24th August 2021, respectively.

Aerial porpoise survey 17. May 2021

On the survey 17th of May 2021, all transects were covered. However, some low (lower than the flight height of 600 ft) scattered clouds (not foreseen by various weather reports) resulted in three transects having minor parts missing (Figure 4.7). Observations were conducted in Sea State 1-3. The subjectively assessed sightability for each observer is displayed in Figure 4.7. Here, 72 % were conducted in either good or moderate conditions, while 25 % were conducted with lower sightability. Variation in sightability is included and adjusted for in the Distance sampling analysis for calculating the abundance.

In total, 68 porpoises were observed including two calves (Table 4-2). Most porpoises were observed in the eastern part of the survey area and no porpoises were observed in the plan area for Hesselø OWF.

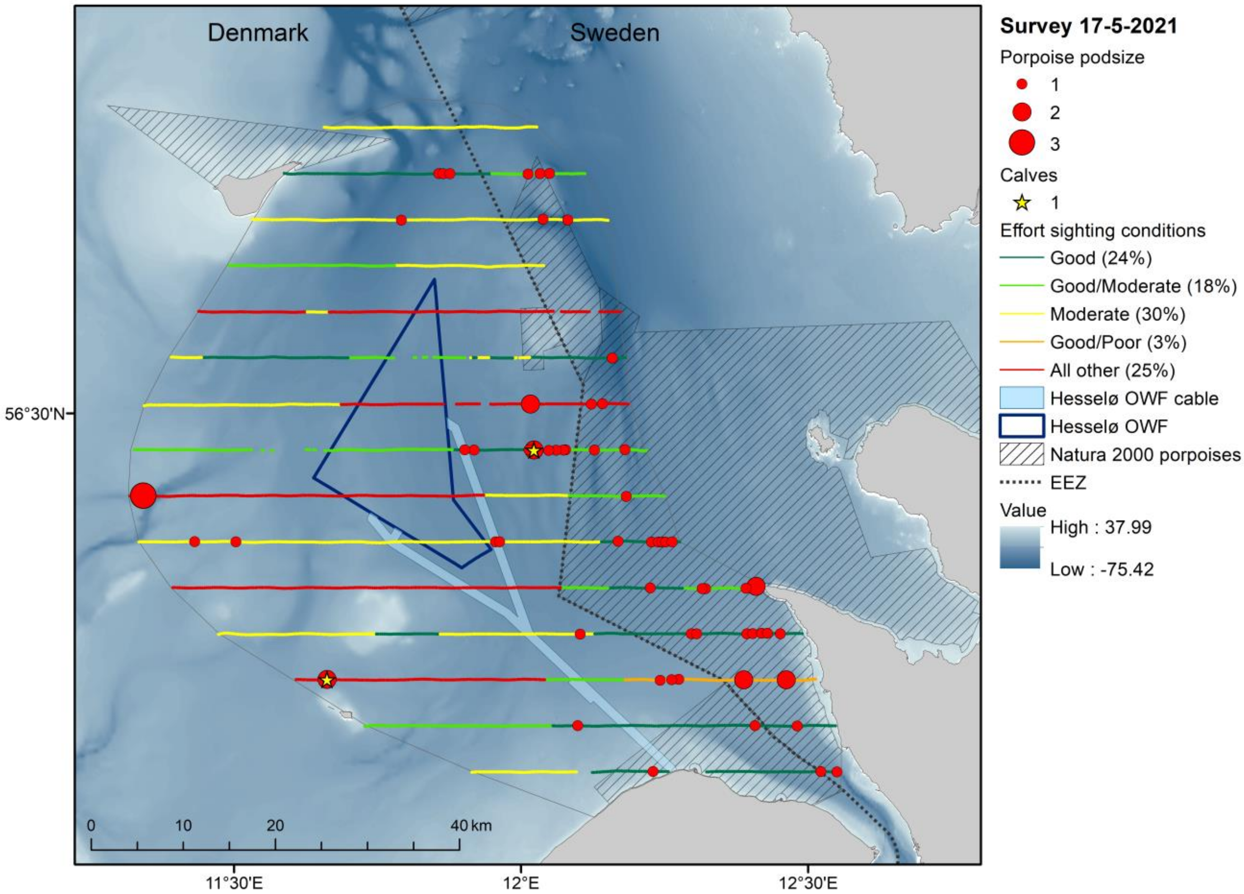

Figure 4-7: Harbour porpoise observations during the aerial survey on the 17th May 2021. The size of the dot indicates the group size at each observation and a star indicate a porpoise calf. The observer assessed sightability is indicated as Good = both observers assessed the sightability to be good, Good/Moderate = one observer assessed good and the other assessed moderate and so forth. Natura 2000 sites for harbour porpoises are shown in shade.

The abundance of porpoises in the survey area was estimated to 2786 harbour porpoises (95 % CI = 1777-4154; CV = 0.21). The average density within the area was 0.76 individuals/km² (95 % CI = 0.48-1.14) (Table 4-2).

Table 4-2 Data and results from the three aerial surveys conducted during the Hesselø OWF baseline studies. CV = Coefficient of Variation.

Survey date	Completed effort (km)	Abundance (95 % Confidence Interval)	Density (95 % Confidence Interval)	Mean group size	No. porpoises (incl. calves)	No. calves	Calves ratio	CV
17-5-21	674	2786 (1777-4154)	0.76 (0.48-1.14)	1.12	68	2	3 %	0.21
26-6-21	708	1532 (741 - 2623)	0.42 (0.2-0.72)	1.23	48	9	19 %	0.30
24-8-21	718	4919 (2963-7940)	1.34 (0.81-2.17)	1.60	141	17	12 %	0.25

Aerial porpoise survey 26th June 2021

On the 26th of June survey, all transects were covered completely in Sea State 1-2. The subjective sightability was better than in May with 100 % of the effort being conducted with Good or Moderate sightability (Figure 4.8). During this survey, 48 porpoises were observed in total and nine of these were calves, which gives a relative high calf ratio of 19 % (Table

4-2). The observations were mainly distributed in the northern and the southern part of the survey area and nine individuals were inside the plan area for Hesselø OWF.

The abundance of porpoises in the survey area was estimated to 1532 harbour porpoises (95 % CI = 741 - 2623; CV = 0.30). The average density within the area was 0.42 individuals/km² (95 % CI = 0.2-0.72) (Table 4-2).

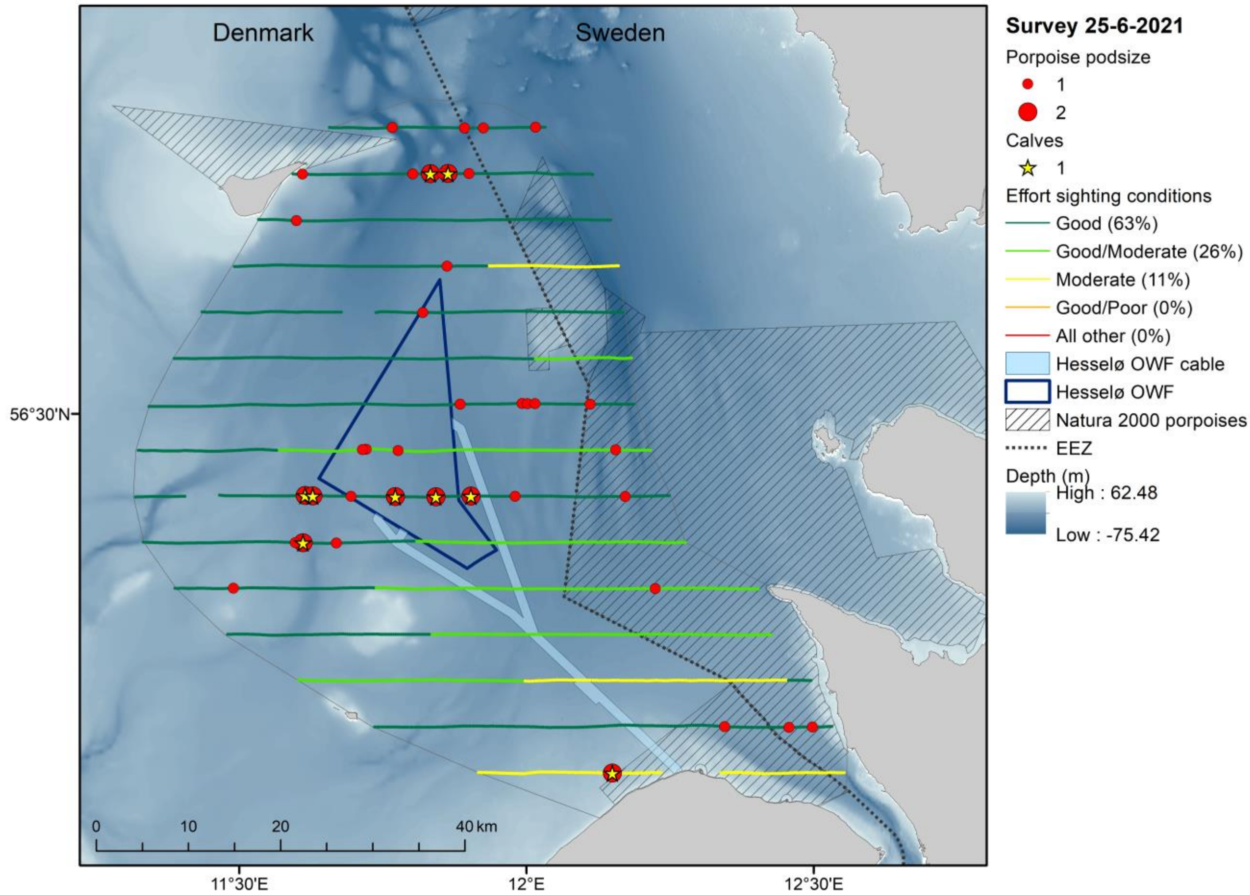

Figure 4-8: Harbour porpoise observations during the aerial survey the 25th June 2021. The size of the dot indicates the group size at each observation and a star indicate a porpoise calf. The observer assessed sightability are indicated as Good = both observers assessed the sightability to be good, Good/Moderate = one observer assessed good and the other assessed moderate and so forth. Natura 2000 sites for harbour porpoises are shown in shade.

Aerial porpoise survey 24th August 2021

On the survey, August 24th 2021, all transects were covered completely in Sea State 1-2. The subjective sightability was high with 88% of the effort being conducted in Good or Moderate sightability (Figure 4.9). During this survey, 141 porpoises were observed in total. 17 of these were calves, which gives a calf ratio of 12 % (Table 4-2). The observations were mainly distributed in the western and northern part of the survey area. One porpoise was observed inside the Hesselø OWF area.

The abundance of porpoises in the survey area in August was estimated to 4919 harbour porpoises (95% CI = 2963-7940; CV = 0.25). The average density within the area was 1.34 individuals/km^2 (95% CI = 0.81-2.17) (Table 4-2).

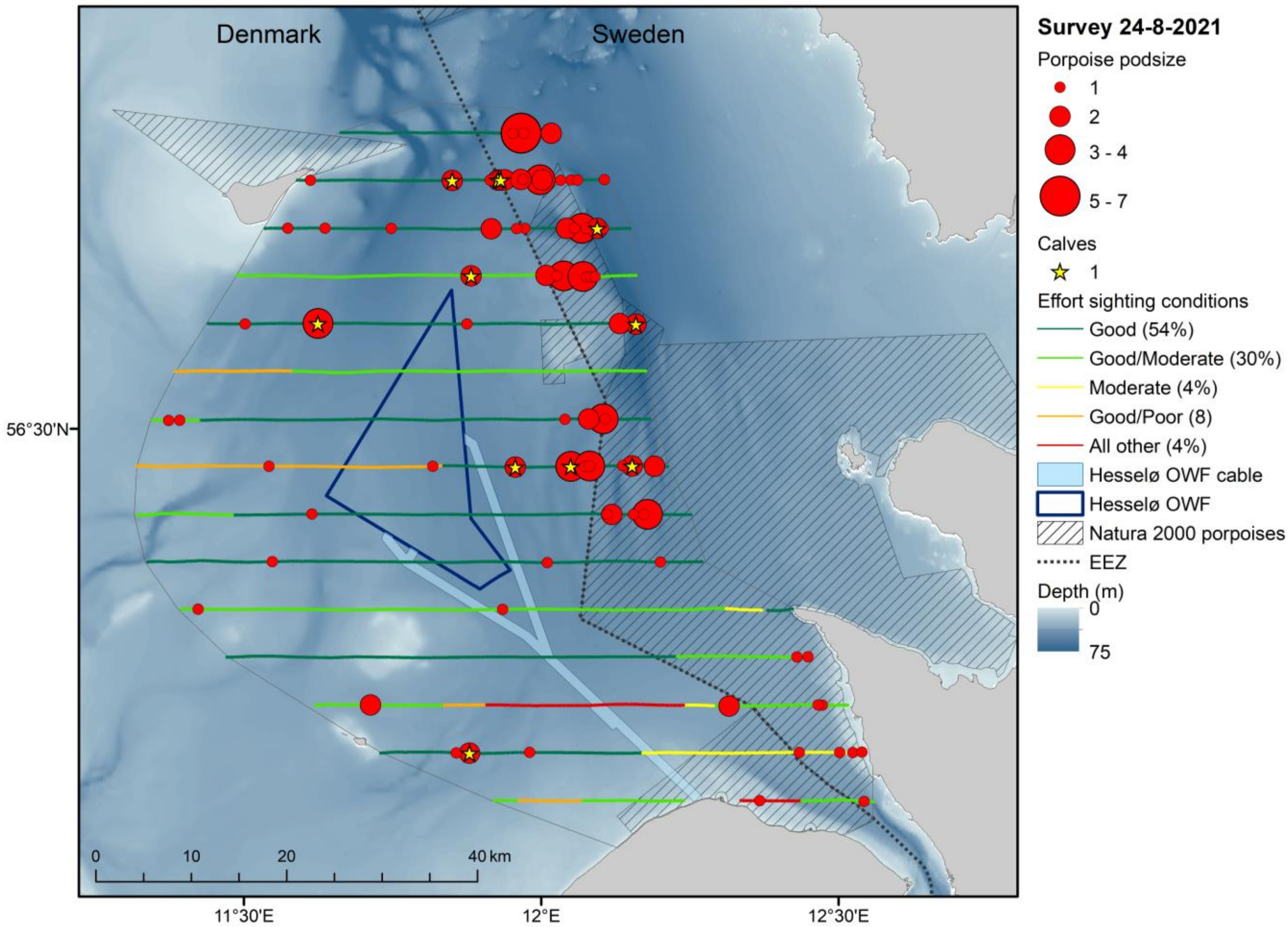

Figure 4-9 Harbour porpoise observations during the aerial survey the 24th August 2021. The size of the dot indicated the group size at each observation and a star indicate a porpoise calf. The observer assessed sightability are indicated as Good = both observers assessed the sightability to be good, Good/Moderate = one observer assessed good and the other assessed moderate and so forth. Natura 2000 sites for harbour porpoises are shown in shade.

To further assess the distribution of porpoises in and around the plan area for Hesselø OWF, porpoise observations from all three surveys were grouped and densities were illustrated by performing a Kernel density analysis in ArcGIS 10 (Figure 4.10). Kernel densities are used to illustrate clustering (densities) of observations. The darker the colour the higher the densities. The Kernel density numbers indicate the percentage of the total number of observations that were within that kernel category e.g. the darkest polygons show where 11.5% to 33.1 % of the observations were. The highest densities were located along the Swedish-Danish marine border. However, sporadic observations were found thoughout the survey area.

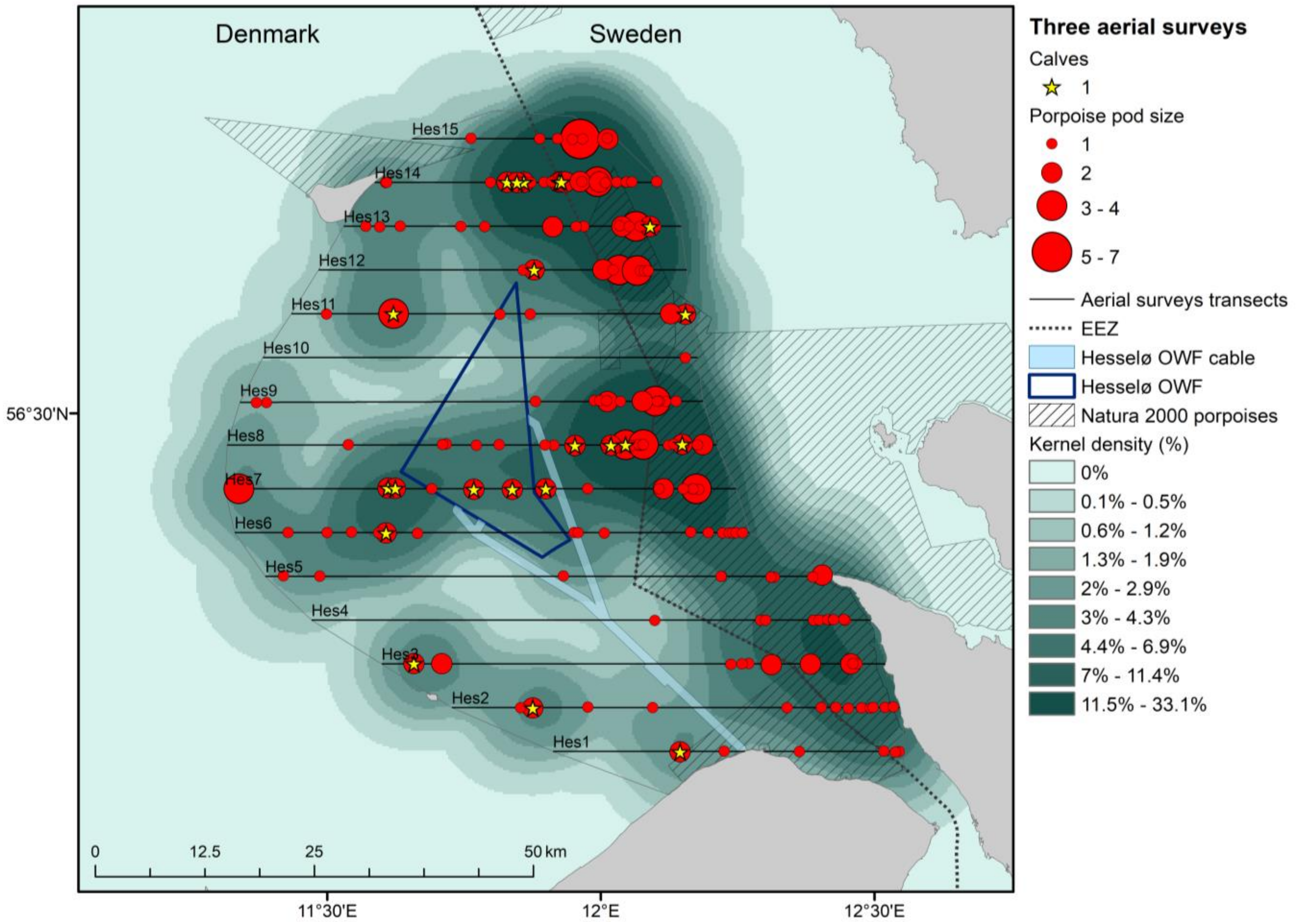

Figure 4-10 Observations from all three aerial surveys combined. Kernel density are displayed. The darker the colour the higher the densities. The Kernel density numbers indicate the percentage of the total number of observations that were within that kernel category e.g. the darkest polygons show where 11.5% to 33.1 % of the observations were.

4.2.2 Passive acoustic monitoring

Eight stations were deployed primo December 2020 and was serviced approx. every eight weeks until 29th December 2021. Each deployment period is marked with a letter beginning with A, i.e. the first deployment is called A the next B and so forth. Details for each deployment can be found in Table 4-3.

In total, of the 48 deployments (6 deployments of each 8 stations), 38 were re-covered as planned, 1 was lost and 9 were later recovered unplanned i.e. they had been trawled or lost somehow and later received by a fisherman or by a private person finding the equipment stranded on the beach.

Of the potential recordings, a total of 3144 recording days (8 stations*393 days (1/12/2020 – 29/12/2021) were conducted which resulted in a 90 % recording success (range 75-100%) (see Table 4-4). Station HES2 was missing during the first three service trips and consequently it was moved to station HES9. The northern part of the survey area was geographically covered by station HES1 and HES3 and the new HES9, and provided sufficient data for the baseline assessment of porpoise presence in the planning area. Furthermore, the missing equipment from station HES2 was laterretrieved and most of the data found to be usable.

Table 4-3 Overview of CPOD deployments, moorings and recovery at the Hesselø OWF area and the Gilbjerg cable corridor

Station	ID	Deployment position Latitude	Longitude	Mooring	Date deployed	Date recovery	Days deployed	Recovery status
HES1	A	56° 35.002'	11° 51.818'	AR	01/12/2020	17/12/2020	16	Unplanned
HES2	A	56° 30.287'	11° 47.092'	AR	01/12/2020	03/01/2021	33	Unplanned
HES3	A	56° 28.580'	11° 51.327'	AR	01/12/2020			LOST
HES4	A	56° 25.551'	11° 42.348'	AR	01/12/2020	15/12/2020	14	Unplanned
HES5	A	56° 25.383'	11° 48.188'	AR	01/12/2020	17/01/2021	47	Unplanned
HES6	A	56° 22.040'	11° 53.780'	AR	01/12/2020	07/12/2021	70	Unplanned
HES7	A	56° 08.888'	12° 14.386'	AR	02/12/2020	12/02/2021	72	Planned
HES8	A	56° 08.078'	12° 15.290'	AR	02/12/2020	12/02/2021	72	Planned
HES1new	B	56° 35.022'	11° 52.288'	AR & Bouy	12/02/2021	10/04/2021	57	Planned
HES2	B	56° 0.293'	11° 47.039'	AR & Bouy	12/02/2021	29/03/2021	45	Unplanned
HES3	B	56° 28.552'	11° 51.248'	AR & Bouy	12/02/2021	10/04/2021	57	Planned
HES4new	B	56° 25.558'	11° 42.748'	AR & Bouy	12/02/2021	11/04/2021	58	Planned
HES5new	B	56° 25.073'	11° 47.851'	AR & Bouy	12/02/2021	11/04/2021	58	Planned
HES6	B	56° 22.017'	11° 53.738'	AR & Bouy	12/02/2021	11/04/2021	58	Planned
HES7	B	56° 8.876'	12° 14.408'	AR	12/02/2021	11/04/2021	58	Planned
HES8	B	56° 8.069'	12° 15.326'	AR	12/02/2021	11/04/2021	58	Planned
HES1new	C	56° 35.014'	11° 52.324'	AR & Bouy	10/04/2021	01/06/2021	52	Planned
HES2	C	56° 30.274'	11° 47.058'	AR	10/04/2021	01/06/2021	52	Unplanned
HES3	C	56° 28.532'	11° 51.266'	AR & Bouy	10/04/2021	02/06/2021	53	Planned
HES4new	C	56° 25.592'	11° 42.759'	AR & Bouy	11/04/2021	22/06/2021	52	Unplanned
HES5new	C	56° 42.605'	12° 01.898'	AR & Bouy	11/04/2021	02/06/2021	52	Planned
HES6	C	56° 22.050'	11° 53.727'	AR & Bouy	11/04/2021	16/06/2021	66	Planned - recovered with Seamaster
HES7	C	56° 08.894'	12° 14.438'	AR	11/04/2021	02/06/2021	52	Planned
HES8	C	56° 08.087'	12° 15.356'	AR	11/04/2021	02/06/2021	52	Planned
HES1new	D	56° 35.039'	11° 52.274'	AR & Bouy	01/06/2021	04/08/2021	64	Planned
HES2								Not redeployed
HES3	D	56° 28.589'	11° 51.232'	AR & Bouy	02/06/2021	04/08/2021	63	Planned
HES4new	D	56° 25.564'	11° 42.774'	AR & Bouy	02/06/2021	04/08/2021	63	Planned
HES5new	D	56° 25.104'	11° 47.879'	AR & Bouy	02/06/2021	04/08/2021	63	Planned
HES6	D	56° 22.053'	11° 53.788'	AR & Bouy	02/06/2021	03/08/2021	62	Planned
HES7	D	56° 08.885'	12° 14.432'	AR	02/06/2021	03/08/2021	62	Planned
HES8	D	56° 08.068'	12° 15.346'	AR	02/06/2021	03/08/2021	62	Planned
HES9	D	56° 31.870'	11° 53.784'	AR	02/06/2021	03/08/2021	62	New deployment - relacement for HES2
HES1new	E	56° 34.984'	11° 52.298'	AR & Bouy	04/08/2021	05/10/2021	62	Planned
HES2								Not redeployed
HES3	E	56° 28.556'	11° 51.288'	AR & Bouy	04/08/2021	05/10/2021	62	Planned
HES4new	E	56° 25.565'	11° 42.716'	AR & Bouy	04/08/2021	06/09/2021	33	Unplanned
HES5new	E	56° 25.075'	11° 47.883'	AR & Bouy	04/08/2021	06/10/2021	63	Planned
HES6	E	56° 22.052'	11° 53.705'	AR & Bouy	03/08/2021	06/10/2021	64	Planned
HES7	E	56° 8.897'	12° 14.494'	AR	03/08/2021	06/10/2021	64	Planned
HES8	E	56° 8.116'	12° 15.385'	AR	03/08/2021	06/10/2021	64	Planned
HES9	E	56° 31.863'	11° 53.773'	AR	03/08/2021	05/10/2021	63	Planned
HES1new	F	56° 35.071'	11° 52.242'	AR & Bouy	05/10/2021	29/12/2021	85	Planned
HES2								Not redeployed
HES3	F	56° 28.559'	11° 51.245'	AR & Bouy	05/10/2021	29/12/2021	85	Planned
HES4new	F	56° 25.566'	11° 42.737'	AR & Bouy	06/10/2021	29/12/2021	84	Planned
HES5new	F	56° 25.093'	11° 47.899'	AR & Bouy	06/10/2021	29/12/2021	84	Planned
HES6	F	56° 22.041'	11° 53.786'	AR & Bouy	06/10/2021	29/12/2021	84	Planned
HES7	F	56° 08.890'	12° 14.483'	AR	06/10/2021	29/12/2021	84	Planned
HES8	F	56° 8.069'	12° 15.346'	AR	06/10/2021	29/12/2021	84	Planned
HES9	F	56° 31.881'	11° 53.792'	AR	05/10/2021	29/12/2021	85	Planned

Table 4-4 Overview of percentage successful recording days for each CPOD station for each deployment period (named A to F, deployed from 1/12/2020 – 6/10/2021) during the baseline study of harbour porpoises at the Hesselø OWF project area. The F deployment was retrieved 29th December 2021.

Station	A (Dec-Jan)	B (Feb-Mar)	C (Apr-May)	D (Jun-Jul)	E (Aug-Sep)	F (Oct-Dec)	Average
HES1	22	100	100	100	100	100	84
HES2	46	79	100	-	-	-	75
HES3	0	100	100	100	100	100	80
HES4	19	100	100	53	100	100	75
HES5	65	100	100	100	100	100	93
HES6	97	100	100	100	100	100	99
HES7	100	100	100	100	100	100	100
HES8	100	100	100	100	100	100	100
HES9	-	-	-	100	100	100	100

The results presented here cover the 13 months of deployments (December 2020 to December 2021) and show that porpoises are detected at the 9 stations on 96-100% of all recording days. This means that porpoises basically are present throughout the area everyday year round.

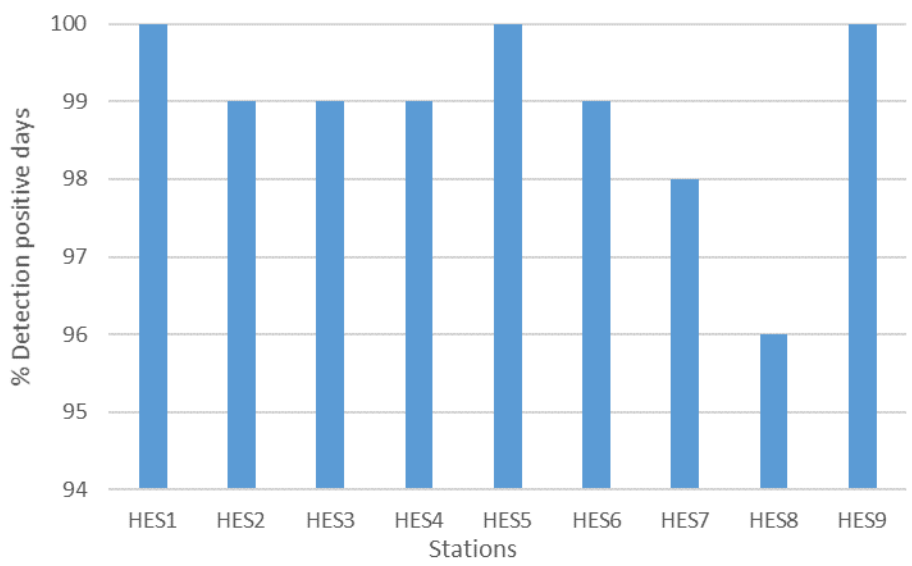

Figure 4-11 Percent detection positive Days at each passive acoustic station deployed at the Hesselø OWF planning area.

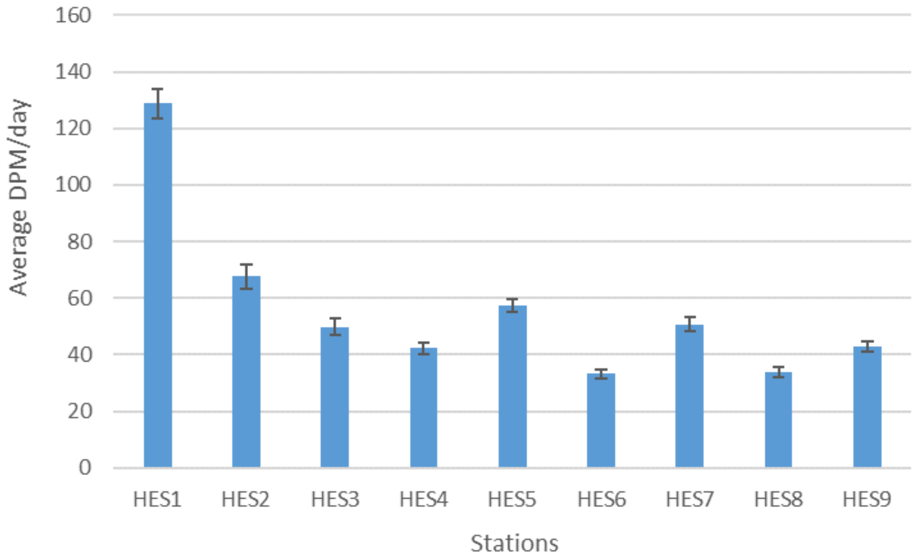

Figure 4-12 Average harbour porpoise detection positive minutes (DPM) per day during the 13 month of deployment of the 9 stations within the Hesselø OWF and the cable planning area. Error bars show standard error of mean.

In the Hesselø OWF area, the most northern station HES1 had the most detections with an average of approx. 130 detection positive minutes per day (Figure 4-12). The second highest detection rate is on station HES2 with 68 DPM / day. The lowest detection rates were observed at HES6 and HES8.
A similar pattern may be observed with HES1 having the most detections throughout the year except for the period from October to December (Figure 4-13). The detection rate is especially high during the summer in June and July. HES2 also have high levels of detections in April and May, but at the other stations the average daily detection positive minutes (DPM) per month varies from 14-90 across the year. There is no strong seasonal variation, but a slight increase in detections can be observed from May to July on most stations.

In the southern end of the Gilberg cable corridor near Gilleleje, the detections on the two stations show a more clear seasonal variation with very similar detection levels from February to December 2021. Both stations detect most porpoises from March to May 2020 and October to November and fewer in February and June to August. Only in December 2020 and January 2021 large differences are found with HES7 having a much higher detection rate than HES8. In general, the levels are low and comparable to the stations in the Hesselø OWF planning area. The low level of summer detections indicates that this southern part of the cable corridor is not an important breeding area, which is confirmed by the aerial surveys.

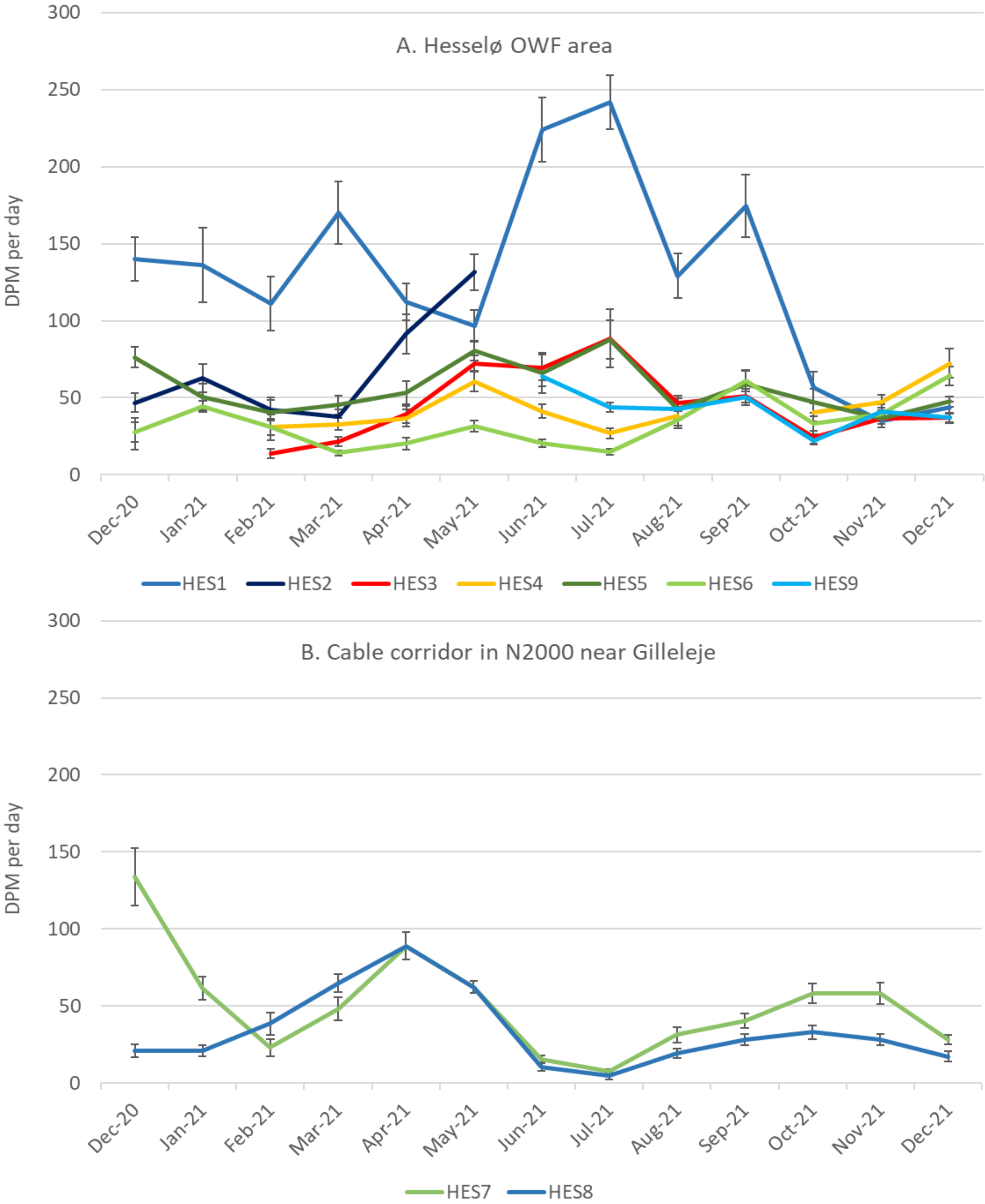
A. Hesselø OWF area
DPM per day
300
250
200
150
100
50
0
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Jun-21
Jul-21
Aug-21
Sep-21
Oct-21
Nov-21
Dec-21
HES1
HES2
HES3
HES4
HES5
HES6
HES9
B. Cable corridor in N2000 near Gilleleje
DPM per day
300
250
200
150
100
50
0
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Jun-21
Jul-21
Aug-21
Sep-21
Oct-21
Nov-21
Dec-21
HES7
HES8

Figure 4-13 Harbour porpoise detection positive minutes (DPM) detected by 6 CPODs deployed within Hesselø OWF (A, top panel) and by 2 CPODs deployed along the Gilberg Cable in the Natura2000 site near Gilleleje (B, lower panel). Error bars show standard error of mean.

4.2.3 Conclusions and perspectives for harbor porpoises (comparison with other areas in the Kattegat and inner Danish waters)

Harbour porpoise is the most common cetacean in Danish waters and some of the highest densities in Europe may be found at certain hot-spots in the inner Danish waters, such as the northern Sound, the Great Belt and Little Belt. Porpoises inhabiting the Kattegat, the Belt Seas and the western Baltic are identified by genetics, morphology and satellite tracking as a separate population called the Belt Sea population (Sveegaard, et al., 2015). The Belt Sea population have only limited geographical overlap with the two neighbouring populations in the North Sea and the Baltic Proper, respectively. The abundance of the Belt Sea population has been estimated in 1994, 2005, 2012, 2016 and 2020 (Unger, et al., 2021). The latest survey in 2020 estimated 17,301 harbour porpoises (95% CI = 11,695-25,688; CV = 0.20), with an average density of 0.41 individuals/km² (95% CI = 0.28-0.61). Since the geographical range of the estimates are not directly comparable, it is more appropriate to compare densities (Figure 4.12). The densities of the population have varied over the years, with the 2005 and the 2020 estimates as the lowest (Unger, et al., 2021).

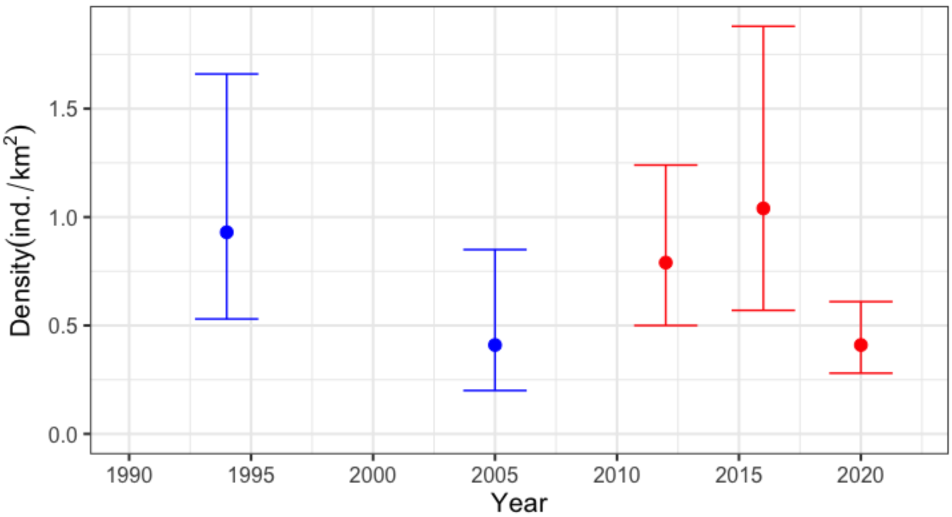

Figure 4-14 Time series of harbour porpoise mean density estimates for surveys in the Belt Sea population region. Surveys either covered solely the distribution range of the population (i.e., western Baltic Sea, Belt Sea, The Sound and Kattegat) (red) or covered a larger area, including the Skagerrak to different extents (blue). Figure from Unger et al. (2021).

The large-scale distribution of harbour porpoises is relatively well known in Kattegat, the Belt Seas and Skagerrak from the above mentioned surveys (Hammond, et al., 2013; Viquerat, et al., 2014), and satellite tracking (Sveegaard, et al., 2011). However, by deploying passive acoustic monitoring stations and conducting aerial surveys in the reproductive period, this project examined the harbour porpoise presence and distribution with and in the vicinity of the investigation area for Hesselø OWF and cable corridor.

The results of the aerial surveys are comparable to the aerial surveys conducted throughout the Kattegat, Belt Seas and western Baltic in June-July 2020, called MiniSCANS-II (Unger, et al., 2021) and the comparison indicate stability of porpoises in the area as well as porpoise presence within the Hesselø OWF area compared to surrounding areas, and this is conducted in the following: The MiniSCANS-II was aimed at estimating the total abundance of the Belt Sea population inhabiting these waters. The southern Kattegat including the plan area for Hesselø OWF were in 2020 covered by three separate survey strata; MSA, MSB and MSC (MS = MiniSCANS area A, B and C, Figure 5-11). The strata were geographically larger than the Hesselø aerial survey area, and so abundances cannot be directly compared, but densities can. The porpoise densities were very similar between 2020 (0.42 to 1.25 porpoises/km2) and 2021 (0.42-1.34 porpoises/km^2) and comparable to the density found during SCANS-III in 2016 where the average density for the Belt Sea population management area were estimated to be 1.03 porpoises per km^2 (Hammond et al. 2021). This indicate that porpoise densities are relatively stable in the southern Kattegat where the Hesselø OWF is located.

The calf ratio found in June (12%) and August (19%) in the Hesselø OWF survey area are higher than previous findings. During MiniSCANS-II in 2020, calves ratios in the three strata were 0-9.4% in June 2020 (Table 4-5). Even the highest ratio of 9.4% is less than half of the estimated ratio in the Hesselø OWF survey area in June 2021. This indicates that the plan area for Hesselø OWF (excluding the southern cable corridor) is a relatively important breeding site.

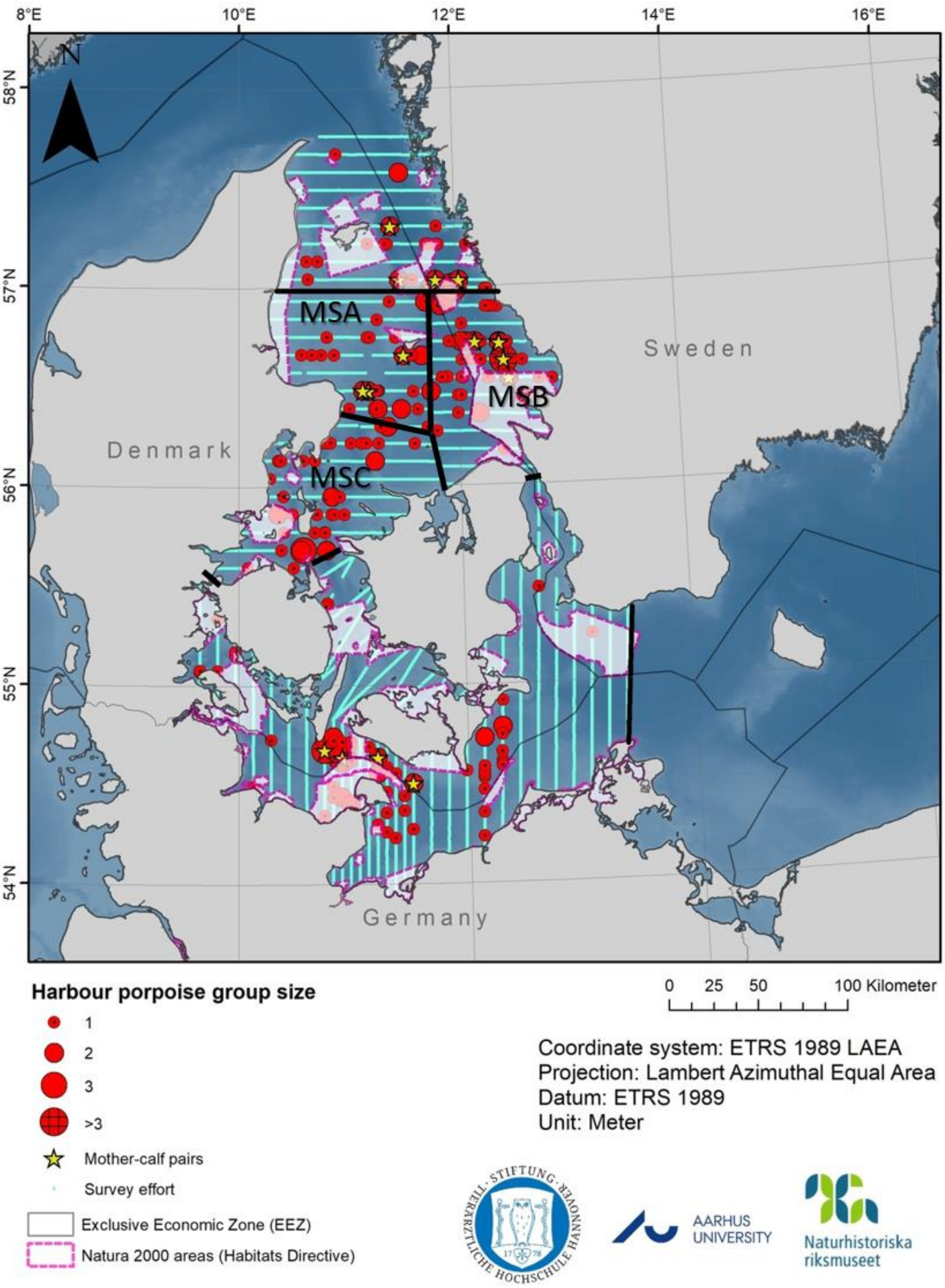

Figure 4-15 Survey effort and distribution of harbour porpoise sightings during aerial surveys (under good or moderate conditions) in the strata MSA-MSI and NK during the MiniSCANS-II survey. The map shows all Natura 2000 areas in the study area, where the harbour porpoise is listed as protected species. The outer thick black lines indicate the borders of the management area of the Belt Sea population (defined in Sveegaard et al., 2015). Figure modified from Unger et al 2021.

Table 4-5 Data and results from the three aerial surveys conducted in survey strata MSA, MSB and MBC (MiniSCANS-A, B and C) during the MiniSCANS-II survey in 2020. CV = Coefficient of Variation. From Unger et al. 2021.

Strata	Area	Stratum size (km2)	No. porpoises	No. calves	Calves ratio	Abundance	Density	CV	Date
MSA	Kattegat west	6177	43	3	7.0	2869	0.46	0.30	24.6.2020
MSB	Kattegat east	5842	85	8	9.4	7316	1.25	0.32	24.6.2020
MSC	Kattegat south	6073	42	0	0.0	2529	0.42	0.22	24.6.2020

For the passive acoustic monitoring, the densities found in this study are in general lower than CPOD studies in nearby waters. During the national monitoring of the Natura 2000 site in the Northern Sound "Gilleleje Flak og Tragten" in 2014 and 2015 average densities of up to 400 daily average DPM per month was found (Hansen, 2016). Furthermore, during one year of monitoring with 11 CPODs at the Store Middelgrund reef, higher detection rates were found during summer with a clear seasonal variation (Figure 4.14).

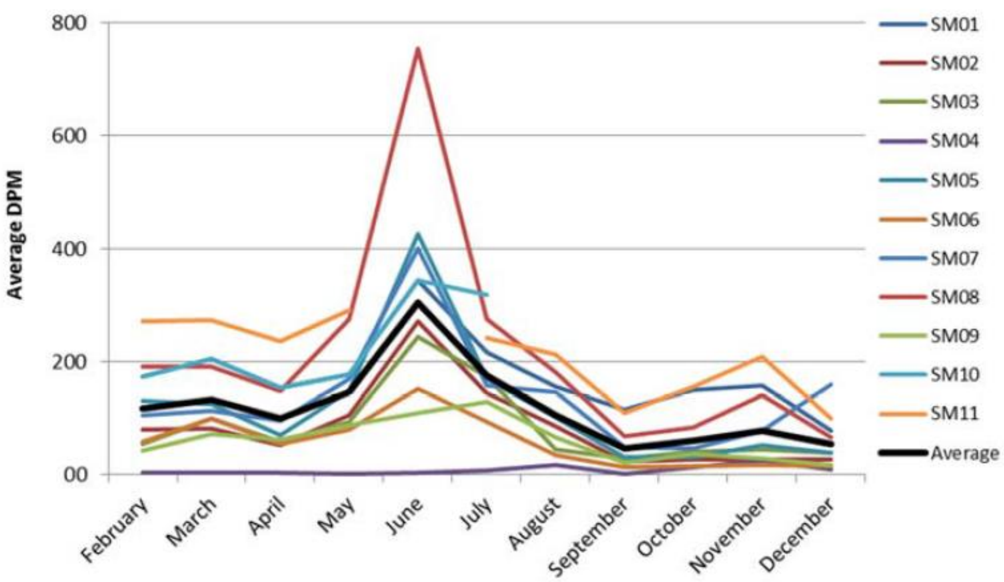

Figure 4-16 Average daily detection positive minutes (DPM) per month per station from February to December 2016 at the 11 CPODs deployed at and near St. Middelgrund (From (Sveegaard, et al., 2017)).

Even the highest detections at HES1 are relatively low in comparison, which indicates that the Hessel OWF site examined by CPODs cannot be considered to be an area of high porpoise density.

Aarhus University has been tagging harbour porpoises in Danish waters since 1997 which over the years amount to approx. 150 individually tagged porpoises (with satellite transmitters). Kernel density analysis of the data were conducted in Sveegaard et al. (2018) (Figure 4.15). When looking closely at these data from 2007 to 2016, a similar pattern as the one found in this study, appear: In the southern Kattegat, the densities are highest along the Danish-Swedish border and in the northern part near Anholt. These data are not meant for detailed studies of smaller areas, because the approx. 100 tagged porpoises included may not represent all of the population, but the fact that the data still shows similarities, support our results during the Hesselø OWF studies and indicate a rather stable distribution.

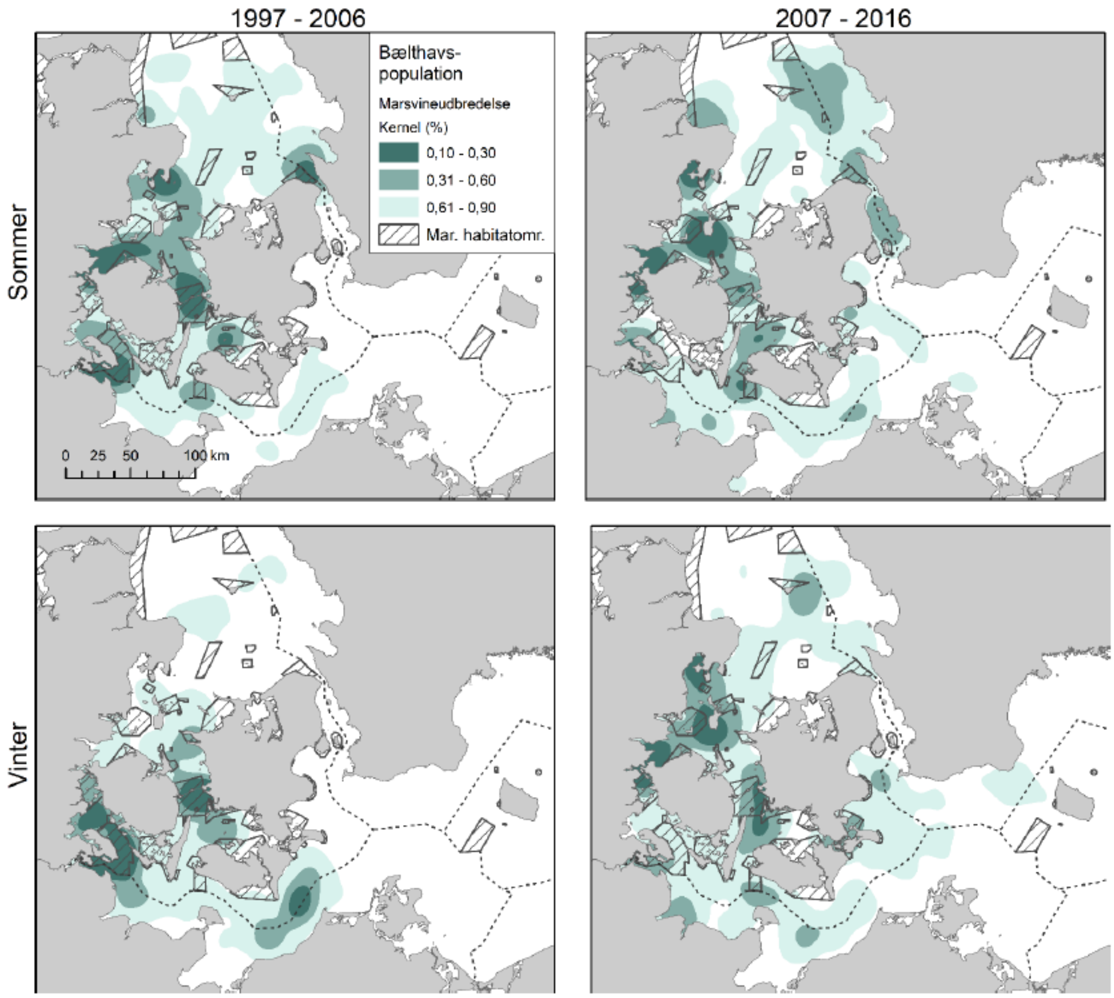

Figure 4-17 Distribution of satellite tracked porpoises in the Belt Sea management unit analysed as Kernel densities (the darker the colour the higher the density) divided in 10 year periods and two seasons (Summer: Apr-Sep, Winter: Oct-Mar). The Kernel-categories are defined as high (contain 30% of all positions from porpoises on the smallest possible area), Medium (31-60%) and low (61-90%). Number of porpoises and positions of porpoises and positions per analysis: 1997-2006, Summer: 18 animals/906 pos., 1997-2006, Winter: 32 animals/817 pos., 2007-2016, Summer: 27 animals/799 pos., 2007-2016, Winter: 28 animals/1004 pos. From Sveegaard et al. 2018.

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In conclusion, harbour porpoises in the examined Hesselø OWF study area are present every day and all year throughout the area. The density is however relatively low in most of the area compared to nearby hot-spots at Store Middelgrund and in the northern Sound. The highest densities are found in the eastern part along the Danish-Swedish border and in the northern part of the plan area for Hesselø OWF. The area is utilised by mother-calves pair in a relatively high ratio throughout the reproductive period but especially from June to August.

5 Sensitivity

The method behind the sensitivity analysis provided in this technical report is based on the Marine Evidence-based Sensitivity Assessment (MarESA) methodology (Tyler-Walters, et al., 2018). The MarESA method is a systematic approach to determine the sensitivity of species and habitats to external impacts. The approach was developed for application on especially benthic organisms and habitats, so for the purpose of this report, modifications to the method have been made in order to make it applicable on marine mammals. The sensitivity score classification system used in the MarESA method, as well as similar approaches, have recently been applied in technical reports or environmental impact assessments in relation to establishment of offshore wind farms, e.g. Hornsea 4 (Ørsted, 2019) and Moray Offshore Windfarm (Moray Offshore Windfarm (West) Limited, 2018), as well as the Fehmarnbelt tunnel in the Baltic Sea connecting Denmark and Germany (FEMA, 2013a) (FEMA, 2013b). These examples have applied the method in relation to assessments of benthic communities, and this report will extend the application of the method in order to assess sensitivity of marine mammals in relation to the planned establishment of Hesselø Offshore Wind Farm.

In biology and ecology, sensitivity analysis is applied in order to assess how sensitive a species, population, community or habitat is towards environmental change caused by external, human-mediated activities. In the following section the methodology behind the sensitivity analysis is described including the modifications to the MarESA method in order to make it applicable on marine mammals. The sensitivity analysis of marine mammals is performed in relation to the planned establishment of Hesselø Offshore Wind Farm.

5.1 Method description

The sensitivity of a receptor (individual or population of relevant marine mammal species) is defined as a product of:

- intolerance to changes due to an external pressure (resistance) *and*
- time taken for subsequent recovery (recoverability)

Expanding on these terms, where resistance to a particular pressure is high, a receptor can absorb or tolerate disturbance or stress without changing character; conversely, receptors with low resistance are more readily affected by the same external pressure. Recoverability, or resilience, describes the ability to return to a previous state once the pressure is removed.

Pressures are mechanisms through which an activity has an effect on receptors, and can be of physical, chemical or biological character. Different activities (e.g. cable laying and foundation construction) can cause a similar pressure (e.g. habitat change), but different pressures (e.g. habitat change and increased underwater noise) can also result in similar effects (e.g. avoidance response) (Figure 5.1). The MarESA method includes a classification of potential pressures, which has been reviewed to identify those that are relevant to the activities associated with the proposed development. The standard pressure descriptions within the MarESA methods have also been adapted so that they relate directly to the Hesselø OWF.

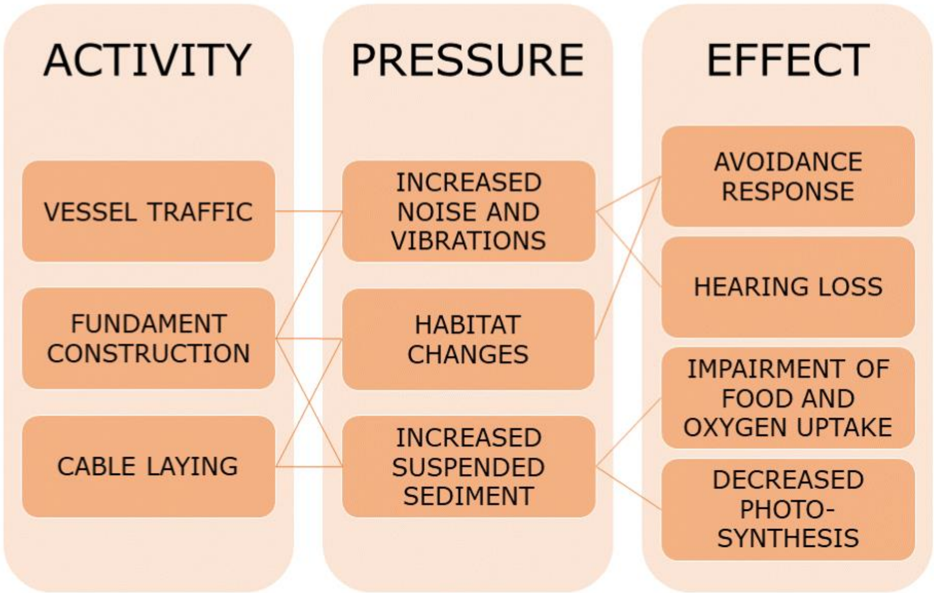


Figure 5.1: Overview of some of the relationships between activity, pressure and effect including examples relating to establishment of offshore wind farms.

Where appropriate, pressures can be described in terms of intensity (force of pressure, quantitative where possible), duration (timespan of pressure) and range (spatial extent of pressure). In the case of Hesselø Offshore Wind Farm, which is not a defined project, these pressure descriptors will be determined on the basis of professional experience and general knowledge on offshore wind farms.

The resistance of a receptor is scored using a scale of none, low, medium and high resistance, which are defined either quantitatively or qualitatively (Tyler-Walters, et al., 2018) (Figure 5.1). Various criteria are used to determine the sensitivity including, among others resistance to change, adaptability, rarity, diversity, value to other resources/receptor and whether a resource/receptor is actually present during the active phase of the project. When assessing sensitivity of marine mammals in relation to the type of impact, the main focus has been on biology (physiological impact), population conservation status, abundance, vulnerable periods (e.g. breeding or moulting season), protection status and distribution (their presence during the impact).

Table 5-1: Scale for scoring resistance to a pressure. Modified from (Tyler-Walters, et al., 2018).One or more of the bullets in the quantitative descriptions has to be fulfilled for the relevant resistance score.

Resistance	Qualitative description	Quantitative description
None	Severe change	1) Impact area widely exceeding the project area. 2) The impacted area has an above-average densities of the species. 3) The impacted area has an important ecological function for the species (breeding, migration ect.). 4) Disturbance (e.g. behavioural avoidance response) occur over a period of time long enough to have significant impact on fitness and survival.
Low	Significant change	1) Impact area exceeding the project area. 2) The impacted area has an average densities of the marine mammal species. 3) The impacted area has an average important ecological function for the species. 5) Disturbance occur over an extended time period long enough to have significant impact on fitness and survival.
Medium	Some change	1) Impact area limited to the project area and immediate surroundings. 2) The impacted area has an average or below-average densities of the species. 3) The impacted areas has an average or below-average ecological function for the species. 4) Disturbance occur over a short time period.
High	No change	1) Impact area limited to the project area or a fraction of it. 2) Below-average densities of the species. 3) Below-average ecological function for the species. 4) Disturbance occur over a very short time period.

The recoverability of a receptor is scored using a scale of very low, low, medium and high recoverability (Tyler-Walters, et al., 2018) (Table 5-2). Recoverability assumes that the pressure is relieved or stopped, and that the receptor experiences the conditions that existed prior to the pressure.

Table 5-2: Scale for scoring recoverability after a pressure has been relieved. Modified from (Tyler-Walters, et al., 2018).

Recoverability	Description
Very low	Negligible or prolonged recovery possible; more than one year to recover. The marine mammal species is highly sensitive to the pressure. Significant effect, likely to have negative consequences for the long time development of the population, or potentially lethal impact on individuals.
Low	Full recovery within 7 to 12 months. The marine mammal species is moderately sensitive to the pressure. Significant, but non-lethal effect on individuals, unlikely to have negative consequences for the long time development of the population.
Medium	Full recovery within 1 to 6 months. The biology of the marine mammal species is little sensitive to the pressure. Insignificant effect on individuals, unlikely to have any negative consequences for the long time survival of the individual or the development of the population.
High	Full recovery within less than one month. The marine mammals species is not sensitive to the pressure i.e. their biology is not or only temporarily affected by the pressure. Possible short-duration, but insignificant effect on individual animals, without long-term consequences for the population.

The combination of a receptor's resistance and recoverability scores gives the overall sensitivity score of the receptor, which can be categorized as not sensitive, low, medium or high sensitivity (Tyler-Walters, et al., 2018) (Table 5-3).

Table 5-3: The combination of resistance and recoverability scores to categorize sensitivity (Tyler-Walters, et al., 2018).

		Resistance			
		None	Low	Medium	High
Recoverability	Very low	High	High	Medium	Low
	Low	High	High	Medium	Low
	Medium	Medium	Medium	Medium	Low
	High	Medium	Low	Low	Not sensitive

In cases where a sensitivity analysis is not possible, the following terms can be used:

- Not relevant. Recorded where the evidence suggests unlikely or no direct interaction between pressure and receptor.
- No evidence. Recorded where there is not enough evidence to assess the sensitivity.

At this stage of the assessment process (sensitivity determination) it is important to note the following:

- The duration (length of time) of an impact is not a factor in determining receptor sensitivity. For example, if a pressure (e.g. 'habitat change') is permanent, receptor recoverability following theoretical reinstatement of the original conditions is evaluated.
- Sensitivity is a key element of the future impact assessment process, but not in itself necessarily an indicator of impact importance (significance). The future impact assessment will consider other factors including the duration and magnitude of pressures.

The sensitivity analysis of marine mammals provided here is composed of the following parts:

- A summarized baseline description of marine mammals as **receptors** occurring in and around the plan area for Hesselø Offshore Wind Farm, including an evaluation of the importance of the areas for marine mammals
- A list and description of possible **activities** during construction, operation and decommissioning of Hesselø OWF that may cause **pressures** with **effects** relevant for marine mammals (physiological and behavioural impacts). As Hesselø OWF is not a defined project, the description of pressures will be determined on the basis of professional experience and general knowledge on establishment and operation of offshore wind farms.
- Scoring of **resistance** and **recoverability** of marine mammals to relevant pressures based on knowledge from existing literature and professional experience.
- Scoring of **sensitivity** of marine mammals to relevant pressures caused by possible activities during construction, operation and decommission of Hesselø OWF.

5.2 Sensitivity analysis

In the following, a sensitivity analysis for marine mammals is performed based on descriptions in chapter 4, information on activities, pressures and effects arising from establishment of Hesselø OWF as well as existing knowledge on marine mammal species in relation to resistance and recovery time.

5.2.1 Receptors

This section summarizes main conclusions from chapter 4 on baseline description of marine mammal species occurring in and around the plan area for Hesselø OWF, including the area's importance to marine mammals. The baseline description is based on existing knowledge and the result of marine mammal field surveys undertaken in this project. Finally, a description of hearing in seals and harbour porpoise is included in this section, as the information is highly relevant to assess the sensitivity of marine mammals towards underwater noise.

5.2.1.1 Harbour seal

Harbour seals in and around the investigation area for Hesselø OWF are part of the Kattegat population, which is shared between Denmark and Sweden. In 2020, 8,000 harbour seals were counted during the moulting season, not including seals at sea during the surveys. Using the correction factor of Härkönen et al. (Härkönen, et al., 1999), this corresponds to a population abundance of approx. 14,000 seals. The investigation area is located approx. 20 km from three important haul-outs for harbour seals; Anholt, Hesselø and Hallands Väderö. Counts of harbour seals from previous surveys as well as aerial counts conducted in 2021 in relation to investigations for this technical report show that fewest seals are registered in winter and spring and the counts peaks in August with 2,700 harbour seals (coinciding with their moulting period). In the time period 2016-2020, 28% of the observations of the harbour seal Kattegat population were at the haul-outs close to the plan area for Hesselø OWF. Together with Anholt (Totten), Hesselø is one of the most important haul-out sites for harbour seals in Kattegat with more than a hundred pups annually at both haul-out sites. Harbour seals are considered to be at favorable conservation status according to the EU Habitats Directive (Fredshavn, et al., 2019)

It is concluded that the plan area for Hesselø OWF is used by harbour seal. Based on the knowledge on the distribution of harbour seals in this part of Kattegat, the plan area is considered to be of medium/high importance for harbour seal due to the short distance to important haul-out sites for the Kattegat population.

The most vulnerable period for harbour seals is around the breeding and moulting seasons (June- August).

5.2.1.2 Grey seals

Grey seals move over much larger distances than harbour seals, and in consequence, grey seal populations cover much larger areas. In Kattegat, grey seals from two distinct populations occur, namely the greater North Sea population and the Baltic population. The observations during 2021 indicate that the majority of the grey seals in the study area originate from the Baltic population. In this population 40,000 individuals were counted in 2020 (ICES 2021), this count does not include animals at sea during the survey. There is no correction factor available for Baltic grey seals, but based on data from other species, the total abundance is likely at least 25% higher than the count. The highest number counted at the four surveyed haul-outs was 50 in June (coinciding with the Baltic grey seal moulting period). Grey seals breed sporadically in Kattegat, with pups recorded at Bosserne near Samsø, Borfeld near Læsø and at Anholt in recent years. During the aerial surveys conducted in 2021 there were no registrations of pups on the four haul-out sites in the study area.

It is concluded that the plan area for Hesselø OWF is used by grey seal, however, based on the knowledge on the distribution of grey seals in this part of Kattegat, the plan area is considered to be of low importance for grey seal due to the low counts of grey seal at the four nearest haul-out sites. However, the grey seal was historically the most abundant seal species in the area, and is currently recovering from local extinction in Denmark in the early 20th century (Olsen et al. 2018). Grey seals are considered to be at unfavourable conservation status according to the EU

Habitats Directive (Fredshavn, et al., 2019), and conditions in an area that was historically important for the species are likely important for the recovery of the species in Denmark.

The most vulnerable periods are around pupping (December-January for North Sea grey seals, February-March for Baltic seals) and moulting seasons (March-April for North Sea and May-June for Baltic Sea) and grey seals are likely more vulnerable than harbour seals during the pupping season as their pups are born in lanugo fur and cannot swim from birth.

5.2.1.3 Harbour porpoise

Specific breeding grounds for harbour porpoise in Kattegat are unknown, however based on observations of mother-calf pair in connection with the aerial surveys in the plan area for Hesselø OWF, the plan area could be an important area for harbour porpoise during the breeding season (especially from June to August). This is supported by data from the PAM study, where the highest detection of harbour porpoises are from the summer months. Passive acoustic monitoring (PAM) of harbour porpoises within the plan area for Hesselø OWF, show that porpoises are present in the area every day. The density is, however, relatively low in most of the area compared to nearby hot-spots at Store Middelgrund and in the northern Sound. Based on three aerial surveys conducted in the summer 2021 in and around the plan area, the highest densities were found in the eastern part along the Danish-Swedish border (mainly outside the OWF planning area) and in the northern part of the plan area for Hesselø OWF.
The Belt Sea population of harbour porpoises are considered to be at favorable conservation status according to the EU Habitats Directive (Fredshavn, et al., 2019).

It is concluded that the plan area for Hesselø OWF is used by harbour porpoise and the investigation area is considered to be of medium importance for harbour porpoise, however in the breeding season, a high calves ratio is observed in the plan area indicating that the plan area for Hesselø OWF could be a relatively important breeding site.

5.2.1.4 Hearing in seals and harbour porpoises

As seals are adapted to life both in water and on land, their hearing ability, like their vision, has adapted to function in both air and water (Møhl, 1968; Reichmuth, et al., 2013). Seals produce a wide variety of communication calls both in air and in water, e.g., in connection with mating behavior and defense of territory (Bjørgesæter, 2004). It is believed that the hearing of seals in air functions in the same way as in terrestrial mammals. How the seal ear functions in water is not completely clear, but the seals' outer ear canal closes when they dive (Møhl, 1967), and it is believed that they hear through "bone conduction" in water (Hemilä, et al., 2006; Kastelein, et al., 2008).

A number of studies have been performed on hearing ability in harbour seals in water (primarily behavioral studies) (Kastak & Schusterman, 1998; Møhl, 1968; Terhune, 1988; Reichmuth, et al., 2013; Kastelein, et al., 2008) and in water (Reichmuth, et al., 2013; Kastak & Schusterman, 1998; Møhl, 1968). Figure summarizes the results for the different studies, both in air (left) and in water (right).

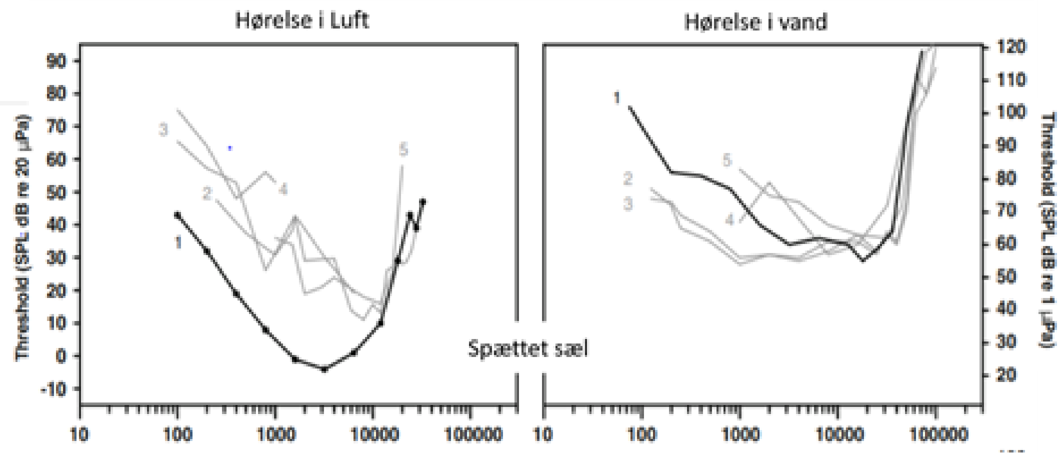


Figure 5.2: Audiogram of harbour seals in air (left) and in water (right). Modified after (Reichmuth, et al., 2013).

Hearing is important for harbour porpoises, as they, like other toothed whales, actively use sound to navigate and find prey as well as to communicate with conspecifics. Harbour porpoises use echolocation, where they emit high-frequency sounds (peak frequency of 130 kHz) and listens for reflected echoes (Møhl & Andersen, 1973; Miller, 2010; Wisniewska, et al., 2016; Villadsgaard, et al., 2007). The use of echolocation to find prey enables harbour porpoises to forage both at day and night (Akamatsu, et al., 2005; Wisniewska, et al., 2016).

Several studies have tested the hearing ability of harbour porpoises, and all studies show that harbour porpoises have a keen hearing and can hear sounds over a wide frequency spectrum (Andersen, 1970; Kastelein, et al., 2002; Kastelein, et al., 2010). Mammals, including harbour porpoises, do not hear equally well at all frequencies. Harbour porpoises hear well in the frequency range 10-140 kHz, but are most sensitive in the frequency range from 90-140 kHz, with a hearing threshold of approx. 40-60 dB re 1 µPa (Kastelein, et al., 2002). This coincides with the frequency range at which the main energy in their echolocation signals is found (Møhl & Andersen, 1973; Villadsgaard, et al., 2007). Harbour porpoises also hear sounds at frequencies below 10 kHz, but with decreasing sensitivity toward to the lower frequencies. Above 140 kHz there is a sharp drop in sensitivity toward higher frequencies (Figure 5.3).

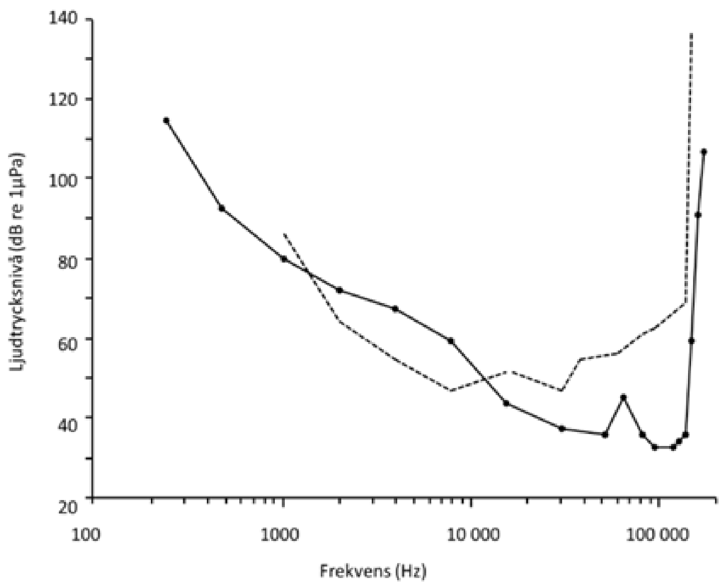


Figure 5.3: Audiogram for harbour porpoises modified after Kastelein et al. (2010) (solid line) and Andersen (1970) (dotted line). The frequency range with best sensitive is between 10-140 kHz.

5.2.2 Activities, pressures and potential effects

This section describes possible activities during construction, operation and decommissioning of Hesselø Offshore Wind Farm that may cause pressures relevant for marine mammals, as well as the potential effects of these pressures on marine mammals. An overview of possible activities from establishment of Hesselø OWF and the related pressures and effects relevant for marine mammals is provided in Table 5-4.

In the following, each pressure and resulting effect(s) are described, including their relevance to marine mammals.

Table 5-4: Overview of activities during construction, operation and decommission of Hesselø OWF and the relating possible pressures and effects for marine mammals.

Receptor	Activity	Pressure	Effect
CONSTRUCTION			
Harbour porpoise, harbour seal and grey seal	Pile driving	Increased underwater noise	Masking of communication and echolocation signals Avoidance response and temporary habitat loss Temporary or permanent hearing loss
	Cable laying, gravitation foundations installation	Sediment spillage	Decreased visibility Indirect changes in prey abundance
	Vessel traffic	Increased underwater noise	Avoidance response
Harbour seal and grey seal	Pile driving	Increased airborne noise	Avoidance response of seals at their haul-out sites
OPERATION			
Harbour porpoise, harbour seal and grey seal	Operating turbines	Increased underwater noise	Avoidance response
	Vessel traffic	Increased underwater noise	Avoidance response
	Fundament presence	Permanent habitat changes	Introduction of hard substrate material (reef effect)
	Cable operation (power transmission)	Electromagnetic fields	Local electric field of 1V/m. Local magnetic field of 10μT
DECOMMISSION			
Harbour porpoise, harbour seal and grey seal	Decommissioning work	Increased underwater noise	Avoidance response Temporary or permanent hearing loss
	Decommissioning work	Sedimentation Suspended sediment	Decreased visibility Indirect changes in prey abundance

5.2.2.1 Underwater noise from monopile driving

Underwater noise from pile driving is the most disturbing effect on marine mammals during the installation of offshore wind farms (Madsen, et al., 2006) as the unmitigated pile driving noise can reach levels that at close distance can cause severe negative impact on marine mammals. Steel monopiles are one of the most common foundation designs in offshore wind farm construction due to their ease of installation in shallow to medium depths of water. The dominant method used to drive monopiles into the seabed is by hydraulic impact piling (hammering), which generates intense underwater noise levels, characterized as being of short duration and with a steep rise in energy level (Madsen, et al., 2006; Bellmann, et al., 2020). The frequency content of the underwater noise is important when assessing the impact on the different species of marine mammals as they do not hear equally well at all frequencies. The main energy of pile driving noise is below a few kHz, where especially porpoises have a poor hearing. Because of the very high energy level of pile driving noise, there is still some energy at higher frequencies, where both seals and porpoises have good hearing. This can potentially lead to negative impacts on marine mammals near the pile driving site. The underwater noise from pile driving can cause masking of the animals' communication and echolocation signals, behavioural avoidance responses, temporary threshold shift (TTS) and permanent threshold shift (PTS).

Auditory threshold shift (TTS and PTS)

Pile driving noise exposure can result in a decrease in hearing sensitivity either permanently or temporarily, termed threshold shift. If hearing returns to normal after a recovery time, the effect is a temporary threshold shift (TTS);

otherwise, it is a permanent threshold shift (PTS). TTS is considered auditory fatigue, whereas PTS is considered injury (Southall, et al., 2007). Sound intensity, frequency, and duration of exposure are important factors for the degree and magnitude of hearing loss, as well as the length of the recovery time (Popov, et al., 2011). Recovery from small amounts of TTS is fast (minutes to hours) and complete, whereas large prolonged exposures to noise, where the ear is re-exposed to TTS inducing sound pressure levels before it has had time to recover from previous TTS, may result in a building TTS, that can result in permanent threshold shift (PTS) (Ketten, 2012).

TTS has been studied in both harbour porpoises and seals (see reviews from (Southall, et al., 2007; Southall, et al., 2019)). TTS is in general localized to frequencies around and immediately above the frequency range of the noise inducing the TTS. TTS induced by low frequency noise typically affects the hearing at lower frequencies (Kastelein, et al., 2013c). However, at higher noise levels TTS can also be measured several octaves beyond the center frequency of the noise (Kastelein, et al., 2015; Kastelein, et al., 2016).

PTS in cetaceans has not been documented, however a very strong TTS of 44 dB was accidentally induced in a Yangtze finless porpoise (*Neophocaena asiaeorientalis*) (Popov, et al., 2011). PTS thresholds are estimated by extrapolation from TTS thresholds and a noise exposure that induces 40-50 dB of TTS will most likely induce PTS (Southall, et al., 2019).

TTS in a harbour seal exposed to longer duration noise has been investigated twice (Kastak, et al., 2005; Kastelein, et al., 2012b). Kastak et al. (2005) were able to induce 6 dB TTS after 25 min exposure to 152 dB re 1 µPa using octave band noise centered at 2.5 kHz. Kastelein et al. (2012b) found that TTS of approximately 6 dB was induced after 60 min exposure to 136 dB re 1 µPa octave band noise centered around 4 kHz.

PTS was accidentally induced in a harbour seal by Kastak et al. (2008), where the seal was exposed to a 60 s tone at 4.1 kHz at a total SEL of 202 dB re. 1 μPa^2s. A second experiment produced a very strong TTS at 44 dB (considered to be very close to PTS), also by accident, by exposure to 60 minutes of 4 kHz octave band noise at a SEL of 199 dB re. 1 μPa^2s (Kastelein, et al., 2013b).

As described above, the underwater noise from pile driving can lead to TTS and PTS in the frequency range where the energy of the signal is located. PTS serves as a well-defined and precautionary criterion for injury in porpoises and seals. There is very limited knowledge on both the short-term and long-term consequences of TTS in marine mammals. Tougaard and Mikaelsen (2020) concluded that the consequences for a porpoise suffering of a small elevation in hearing threshold at low frequencies, which recovers completely within a few hours at most (Popov, et al., 2011), are likely to be very low. TTS induced by pile driving noise occurs at very low frequencies, well outside the frequencies used for echolocation and communication (Kastelein, et al., 2015). Therefore, it is plausible that neither echolocation, nor communication between mother and calf will be affected by TTS induced by pile driving noise. The overall effect of inducing small amounts of TTS in porpoises because of pile driving will most likely not cause a reduction in long-term survival and reproduction of the animal, because of the short duration of the effect.

Behavioural effect of pile driving noise

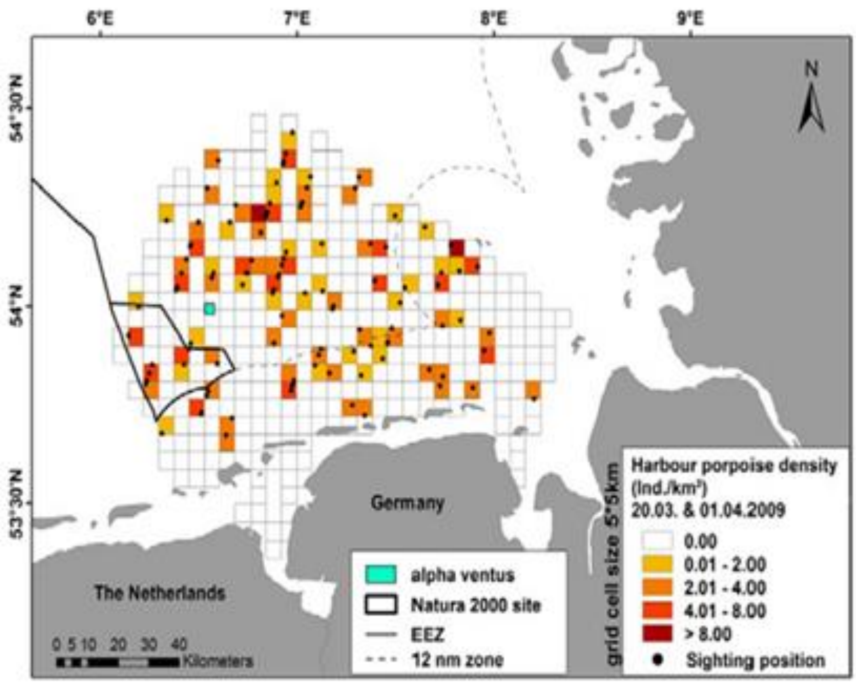
Behavioural responses of marine mammals can vary significantly from small changes in behaviour, e.g., increase in swimming speed or a short interruption in feeding behaviour (Dyndo, et al., 2015) to more severe behavioral changes like panic or fleeing responses. In worst-case situations a fleeing response can increase the risk of mortality due to bycatch in gill nets or separation of calves from mothers. Severe behavioural reaction could therefore have implications for the long-term survival and reproductive success of individual marine mammals. Furthermore, repeated pile driving noise in one area (where several offshore wind farms are installed) may cause long-term effects if pile driving events are occurring frequently (Rose, et al., 2019). All individuals might not return to the area after being displaced by multiple events and are therefore deterred from a specific area. Multiple disturbances may reduce fitness, and consequently affect the population level over several years. The Gescha 2 project analyzed the "long term trends" of impact on harbour porpoise densities during and after the construction of eleven offshore wind farms and offshore convert platforms built in the German North Sea and adjacent Dutch waters in the period 2010-2016. The project did not find a negative impact on the porpoise activity in the area related to the installation of several adjacent offshore wind farms (Rose, et al., 2019).

The knowledge of avoidance reactions of harbour porpoises to pile driving noise during construction has increased during the last ten years. The studies cover both installations with unmitigated pile driving (Tougaard, et al., 2009; Brandt, et al., 2011; Dähne, et al., 2013) and installation where mitigation measures have been applied (e.g. the use of air bubble curtains) (Dähne, et al., 2017; Nehls & Bellmann, 2016; Rose, et al., 2019; Brandt, et al., 2018). A single illustrative example, from the German wind farm Alpha Ventus, is shown in Figure 5.4.

For unmitigated pile driving installations, the results showed displacement and/or disturbance of the behaviour of porpoises out to distances of 15-34 km from the piling site during pile driving (Tougaard, et al., 2009; Brandt, et al., 2011; Dähne, et al., 2013; Rose, et al., 2019). The duration of deterrence/disturbance appears to be in the range of some hours to at most a day after end of pile driving (Brandt et al. 2011, Dähne et al. 2013, Brandt et al. 2018). The behavioural reaction of porpoises appears to be graduated with distance from the pile driving site, such that fewer animals respond and/or the response of the individual animals becomes less severe, the further from the pile driving site (e.g. Dähne et al. 2013). A recent study by Graham et al. 2019 examined the behavioural responses of harbour porpoises during the 10 months installation period of the Beatrice offshore wind farm in the North Sea in 2017 at 84 wind turbine locations using 2.2-meter steel piles. Each steel pile was hammered into the seabed. The passive acoustic monitoring of porpoises showed a 50% probability of response within 7.4 km at the first location piled, decreasing to 1.3 km by the final location. Thus, this study shows there is a clear tendency for habituation in the behavioural responses of harbour porpoises (Graham, et al., 2019).

Application of mitigation measures cause a marked reduction in impact ranges compared to installation without mitigation measures. Pile driving using mitigation measures caused impact ranges of 10-15 km (Dähne et al 2017; Rose et al 2019).

There are only a few studies addressing the avoidance behaviour and impact ranges of seals exposed to pile driving noise. During construction of offshore wind farms in The Wash, south-east England in 2012, harbour seals were equipped with satellite transmitters and the results showed that seal usage (abundance) was significantly reduced up to 25 km from the pile driving site during unmitigated pile driving and within 25 km of the centre of the wind farm, there was a 19 to 83% decrease in usage compared to during breaks in piling (Russell, et al., 2016). Based on the results Russell et al. (2016) suggested that the reaction distance for harbour seals to unabated pile driving was comparable to that of porpoises. On the other hand Blackwell et al. (2004) studied the reaction of ringed seals (*Pusa hispida*) to pile driving on an artificial island in the arctic and saw limited reactions to the noise.



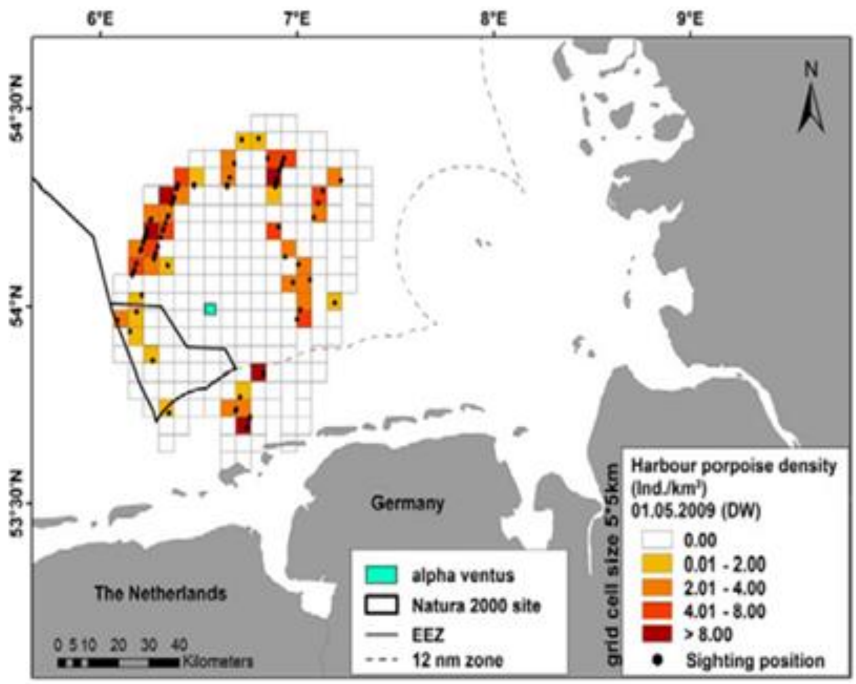


Figure 5.4: Porpoise observed from aerial survey before (top) and during (bottom) pile driving at the German offshore wind farm Alpha Ventus. The turquoise indicate the position of the pile driving position (Dähne, et al., 2013).

In addition to the use of abatement systems, such as bubble curtains, pingers and seals scarers are regularly used as deterring devices before the soft start procedure is initiated. Pingers are designed specifically to scare harbour porpoises away from fishing nets and there are different devices on the market. Pingers scare harbour porpoise out to distances of 100-300 meters depending on the used type (Kindt-Larsen, et al., u.d.; Omeyer, et al., 2020). Seal scarers are more powerful underwater sound emitters and deter seals out to a distance of some hundred meters (Mikkelsen, et al., 2017b). They are even more effective in deterring harbour porpoises out to at least 1300 meters (Mikkelsen, et al., 2017a) and can cause behavioural responses as far away as 10-12 km (Dähne, et al., 2017), and can thereby cause a significant disturbance of porpoises in itself. Dahne et al. (2017) describe the use of an acoustic deterrent device to protect harbour porpoises from losing their hearing due to pile-driving noise. The authors noted strong reaction to the seal scarer and raised concern that it may surpass the reactions to the pile-driving noise itself when operating with bubble curtains. This suggests that there are grounds for a re-evaluation of the specifications of such acoustic deterrent devices (European Commission, 2020). Acoustic deterrent devices do not reduce behavioural effects, but only reduce the directly physical effects. Seal scarers should therefore only be used to the extent it can aid in mitigating more serious effects, such as hearing loss.

Masking

Masking occurs when a sound or noise signal eliminates or reduces an animal's ability to detect or identify other sounds such as communication signals, echolocation, predator and prey signals, and environmental signals. Masking depends on the spectral and temporal characteristics of signal and noise (Erbe, et al., 2019).

Compensation mechanisms to overcome masking of communication signals have been described in several marine mammal species either increasing the amplitude of their signal or shifting the frequency of the signal (Holt, et al., 2009; Parks, et al., 2011). Masking can also be overcome by increasing the call duration or call rate making it more probable that a signal is detected or by waiting for the noise to cease (Brumm & Slabbekoorn, 2005).

Porpoises rely heavily on acoustic signals (echolocation) for all aspects of foraging, navigation, sexual displays and in communication between the mother and the calf (Clausen, et al., 2010). However, the emitted signals are in the ultrasonic frequency range between 129-145 kHz (Villadsgaard, et al., 2007), well above the frequency of the main energy in the pile driving and it is therefore unlikely that pile driving noise would mask communication or echolocation in porpoises. Underwater signals are particularly important in courtship and mating behaviour in seals (Van Parijs, 2003). The communication signals of seals are in the low-frequency range and masking from the pile driving noise may occur. However, harbour seals and grey seals are not known to vocalize outside the context of mating and this takes place close to the haul-out sites. Thus, pile driving close to a seal haul out can mask the communication signals whereas pile driving occurring far offshore, appears unlikely to have any potential to interfere with communication during mating displays.

Passive listening by both seals and porpoises could potentially be masked by pile driving noise. However, pile driving is an impulsive noise source and the duty cycle of a pile driving signal is relatively low, which leaves large gaps in between pulses, where signals can be detected. It is thus difficult to imagine a complete masking of passive listening by pile driving noise.

Resistance and recoverability – PTS and TTS

The long-term effects of various degrees of temporary or permanent hearing loss on survival and reproductive success of individual marine mammals is unknown. It is thus difficult to assess how these impacts may affect the population of seals and porpoises. Severe permanent hearing damage (strong PTS) will inevitable affect the ability of the animal to carry out its normal range of behaviours leading to a decrease in fitness. Although this may not cause directly death of the individual, it may reduce the life span and reproductive success of the animal. Thus PTS serves as a well-defined and precautionary criterion for injury in porpoises and seals.

The consequences for a marine mammal exposed to a small temporary elevation in hearing threshold at low frequencies, which recovers completely within a few hours at most, are likely to be very low. TTS induced by pile driving noise occurs at very low frequencies, well outside the frequencies used for echolocation and communication. The overall effect of inducing small amounts of TTS in marine mammals as a consequence of pile driving is thus assessed to be insignificant for the long-term survival and reproduction of the animal, and thus in turn also without any effects at the level of the population.

Thus, the resistance for PTS is ranked as ***none*** and the resistance for TTS is ranked as ***low*** for harbour porpoises as the plan area for Hesselø OWF is considered to be of medium importance for harbour porpoise outside their breeding season but as of high importance in the breeding season (as a precautionary approach).

For harbour seals the resistance for PTS is ranked as none and the resistance for TTS as ***low***, as the plan area is considered to be of medium/high importance for harbour seal due to the short distance to import haul-out sites for the Kattegat population of harbour seals.

For grey seals the resistance PTS is ranked as non and the resistance for TTS is ranked as ***low***, because of the unfavourable conservation status of grey seals in the area and because the area was historically important for the grey seals and are likely important for the recovery of the species in Denmark.

For both harbour porpoise, grey seals and harbour seals the recoverability of PTS is ranked as ***very low (not existing)*** and for TTS is ranked as ***medium*** as full recovery is expected to occur within a few weeks.

Resistance and recoverability – Behavioural avoidance response

As unmitigated pile driving noise can cause impact range out to 34 km (worst case) it is a significant part of the harbour porpoise population from the Belt Sea, that can experience underwater noise levels above the threshold for avoidance responses. A simple calculation indicate that between 9-30% of the Belt Sea population can be impacted of unmitigated underwater noise[1], which is a significant part of the population. Thus, the resistance is ranked as ***none***.

For harbour seals the resistance for behavioural responses is ranked as ***low***, as the plan area for Hesselø OWF is located with short distance to important haul-out sites for the Kattegat population of harbour seals (approximately 20 km), and it is expected that the unmitigated underwater noise can cause an impact on seals near to their important haul out sites.

For grey seals the resistance for behavioural responses is also ranked as ***low***, because of the unfavourable conservation status of grey seals in the area and because the area was historically important for the grey seals and are likely important for the recovery of the species in Denmark.

For harbour porpoise the recoverability of avoidance responses is ranked as ***low*** as a precautionary approach, because the plan area for Hesselø OWF may be an important area for calves and can have a negative impact on the calves (in a worst case). For harbour and grey seal the recoverability of avoidance responses is ranked as ***medium*** as a precautionary approach because of the potential impact on pups at the nearby important haul out sites.

Resistance and recoverability – Masking

As masking of harbour porpoise communication and echolocation signals by piledriving noise is unlikely the resistance and recoverability is both ranked as ***high*** on both individual level as well as on population level.

[1] Impact ranges of 34 km can cause impact areas of 3.632 km^2, leading to the between 1.525-5.194 porpoises can be impacted. Based om the density estimates in and near the plan area (0.41-1.43 porpoises (km^2) this would correspond to the 9-30% of the population is impacted.

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The nearest haul-outs for both harbour and grey seals are located at 20 km from the plan area for Hesselø OWF and as communication occur close to the haul-out site, masking is considered to be unlikely and the resistance and recoverability is both ranked as ***high*** on both individual level as well as on population level.

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5.2.2.2 Airborne noise from monopile driving

Pile driving does not only generate underwater noise, but also airborne noise. Harbour porpoises will not be affected by the airborne noise, as they spend their entire life submerged and only go to the surface to breathe. Seals on the other hand are adapted for a life in both water and on land. It is especially at their resting and breeding grounds on land, that seals can be disturbed by airborne noise.

Resistance and recoverability

The likelihood of disturbance from airborne noise is negligible as the nearest seal haul-out site is located more than 20 km from the plan area for Hesselø OWF and the airborne noise level is not expected to reach a level at the haul-out sites where it cause disturbance of seals. Thus, the resistance and recoverability is both ranked as ***high*** on both individual level as well as on population level.

5.2.2.3 Sediment spillage

During the construction phase, periods of increased amounts of suspended material in the water column (and subsequently increased sedimentation) will occur in connection with the installation of foundations, inter array cables as well as the export cables. The increased amounts of suspended material in the water column can reduce the visibility.

Harbour porpoises are adapted to life in the coastal waters, where visibility is often limited due to natural turbidity. Like other toothed whales, harbour porpoises use echolocation to navigate and the find prey. Echolocation is an active process, where the porpoise emits high-frequency sounds and listens for reflected echoes from prey or obstacles in the surroundings (Miller, 2010). Verfuß et al. (2009) tested the ability of harbour porpoises to navigate and find prey after their eyes had been covered. By using echolocation alone, porpoises could navigate and find prey with the same success rate as when their vision was unimpeded.. Other studies have found that harbour porpoises forage both during day and night (Wisniewska, et al., 2016; Kyhn, et al., 2018), which supports the observation that vision is not essential for harbour porpoises to find and catch prey. It is therefore not expected that harbour porpoises will be directly affected by suspended sediment in the water column.

Indirectly, however, harbour porpoises can be negatively affected by suspended sediment, if fish and benthic fauna are negatively affected by an increased amount of suspended sediment and subsequent sedimentation, as it could lead to a reduction in the amount of prey in and around the plan area for Hesselø OWF, at least for a limited time period. The impact of this effect will rely on the spatial and temporal extend of the spill and the amount of dissolved sediment in the water.

Both harbour seals and grey seals, are (like harbour porpoise) adapted to life in coastal waters, where they are often exposed to murky water due to suspended sediment in the water column after e.g., a storm. Unlike harbour porpoises, seals do not use echolocation to find and catch prey, but studies of harbour seals have shown that they use their vibrissae to find prey in water with low visibility (Dehnhardt, et al., 2001). These tactile sensory organs can - in addition to sensing the prey by direct contact - also detect prey at distances of up to 40 meters by detecting the wake of a swimming fish in the water (Dehnhardt, et al., 2001). This sense together with their hearing ability makes it possible to find prey in water with low visibility, where the use of vision is impeded. Grey seals, like harbour seals, have vibrissae, and it is expected that they also use these in water with low visibility to locate and catch prey. It is therefore expected that seals are only lightly and temporarily affected by suspended sediment. However, as mentioned for harbour porpoises, the seals can be indirectly affected by suspended sediment, if fish and benthic fauna are affected by the increased amount of suspended sediment and subsequent sedimentation.

Resistance and recoverability

The resistance is ranked as ***high*** for both harbour porpoises and seals as they can still hunt in turbid waters. The effect is considered to be local as it is mainly the area around the installation that is affected by sediment spill. In areas further away the suspended sediment is diluted by the currents and settlement of suspended sediments is expected to be marginal. Most of the suspended sediment will settle within a short time (few days), the recoverability is therefore considered ***high*** on both individual level as well as on population level.

5.2.2.4 Underwater noise from vessels

During construction, an increase in ship traffic is expected within and near the plan area for Hesselø OWF. In connection with the maintenance of the wind farm during the operational phase, there will be shipping activity in the area of the wind farm.

It is expected that both small and fast boats as well as larger, slower moving vessels will be used during the construction and maintenance work. Underwater noise from smaller boats has a noise level of between 130-160 dB re 1 µPa@1meter (Erbe, 2013; Erbe, et al., 2016), while the underwater noise levels from larger vessels is up to 200 dB re 1 µPa@1 meter (Erbe & Farmer, 2000; Simard, et al., 2016; Gassmann, et al., 2017). Most of the underwater noise is generated by the motion of the ship's propeller causing cavitation (Ross, 1976), where "clouds" of gas bubbles formed behind the rotating propeller collapse. This generates broadband underwater noise with energy at frequencies from a few Hz to 100 kHz (Ross, 1976). Studies show that the underwater noise levels increase when the ship is maneuvered, such as when the ship backs, or thrusters are used to hold the ship at a certain position (Thiele, 1988). In a recent Danish study, the underwater noise from several different types of ships was measured. The study found that the frequency content was broadband from 0.025 to 160 kHz, which is in a frequency range where it can potentially have a negative effect on marine mammals (Hermannsen, et al., 2014). However, the main energy is at low frequencies (>1 kHz) (Erbe, et al., 2019), where especially porpoises have poor hearing.

There is limited knowledge about how marine mammals are affected by ship noise. The largest impact of ship noise, however, is likely to be from masking of the marine mammals' communication signals as well as potential behavioral changes e.g., changes in their foraging pattern (Richardson, et al., 1995; Wisniewska, et al., 2016).

A study examining the relationship between ship noise and harbour porpoise hunting behaviour found initial signs of short-term behavioural changes because of the ship noise (Wisniewska, et al., 2016). Dyndo et al. (2015) concluded that ship noise can lead to avoidance responses in harbour porpoise up to a distance of over 1 km. Another study conducted on Black Sea harbour porpoises in the Istanbul Strait examined changes in behaviour caused by different types of ship traffic (cargos, speed boats, fishing boats and vessels, ferries and research boats). The study found that the speed of the ship and distance to the porpoise have a significant effect on the probability of response of the porpoises (Bas, et al., 2017). Porpoises are more likely to change behaviour if ships are within a 400 m radius of the porpoise. The higher the speed, the higher probability of a response. This study indicates that ships disturb animals at close range, but the study found no overall significant effect of the disturbance on the animals' cumulative (diel) behavioural budget (i.e. total amount of time spent on the different types of behaviour) (Bas, et al., 2017). Overall, the studies currently available do not provide a clear picture of how and when harbour porpoises react to noise from ships, but the EU Horizon 2020 SATURN project, which uses tags on harbour porpoises and harbour seals to investigate effects of shipping noise on individuals (https://www.saturnh2020.eu/) may provide more information in the future.

As disturbance by vessel traffic can have a negative effect on marine mammals, especially on harbour porpoises, vessel traffic should be carefully assessed and managed, and measure taken e.g., to reduce vessel speed or channel the traffic on regular lanes.

Resistance and recoverability

The plan area for Hesselø OWF is located in an area with substantial ship traffic and is located in close vicinity to the main ship routes in the central part of Kattegat. The area is therefore expected to be dominated by low-frequency ship noise already and the marine mammals occurring in the area are likely adapted to a certain degree of ship noise. Thus, the resistance and recoverability is ranked as ***medium*** for harbour porpoises and as ***high/medium*** for seals and the recoverability is ranked as ***high*** for both harbour porpoises and seals.

5.2.2.5 Habitat change

The bottom substrate in the plan area for Hesselø OWF plan is dominated by soft bottom substrate. The wind turbine foundations and erosion protection will cause a reduction in the naturally occurring soft bottom substrate that will be replaced with introduced hard bottom substrates in the form of concrete, rock formations and steel. The changes in the habitat could lead to a change in the composition of the prey items in the plan area for Hesselø OWF immediately around the foundations as soft bottom species will be replaced with species that live on hard bottom substrates.

It is expected that after a period of time, the foundations and erosion protection will function as so-called artificial reefs. The new hard bottom substrate at the wind turbine foundations will after some time be overgrown with algae and become a habitat for a fauna consisting of a large number of epibentic invertebrates (bottom-dwelling invertebrates) (Gutow, et al., 2014). This could attract fish, which in turn could mean increased feeding opportunities for the marine mammals and thus could potentially have a positive effect on the marine mammals as all three species of marine mammals are opportunistic feeders.

Studies on the impact of an operating wind farm on harbour porpoises, has predominantly shown that harbour porpoises return in the same or higher numbers after the wind farm has been build (Scheidat, et al., 2011)Like harbour porpoises, seals too could be affected by operating wind farms. In study, harbour seals were tagged with high resolution GPS tags in the Netherlands and in Great Britain The data showed that the seals moved and foraged inside the wind farm area and that they systematically searched the wind turbines foundations for food (Russell, et al., 2014).

Resistance and recoverability

As the habitat change is consider to have limited or positive impact on harbour porpoise and seals the resistance and recoverability is ranked as ***high*** for all three marine mammals species.

5.2.2.6 Operational underwater noise

Underwater noise from operating turbines in a future wind farm at Hesselø cannot be accurately predicted. However, by comparison with available measurements on existing wind turbines, it appears likely that noise levels will be low and unlikely to affect marine mammals beyond some few hundred meters in worst case. For a more detailed description see "Hesselø Offshore Wind Farm. Underwater noise. Technical report" (NIRAS, 2021).

Resistance and recoverability

As the operational noise is considered to cause a limited pressure on harbour porpoise and seals the resistance and recoverability is ranked as *high* for all three marine mammals species on both individual level as well as on population level.

5.2.2.7 Electromagnetic fields

Localized electric and magnetic fields are associated with operational power cables. Such cables may generate electric and magnetic fields that could alter the behaviour or development of sensitive species. Limited information is available on the potential effects associated with this pressure for marine mammals. Magnetic anomalies have been sought linked to an increase in the likelihood of strandings (Kirschvink, 1990), but it is still unclear how electromagnetic fields might contribute to strandings. Potential magnetic orientation in cetaceans is still not completely understood, and the underlying sensory systems are therefore not known. As there is no evidence that seals use magnetic fields, assessments of possible effects on pinnipeds are equally speculative. Field studies have shown that seals exhibit avoidance response to low intensity electric fields and has been used to deters seals form fresh water systems (Thompson, et al., 2020). The inter array cables are expected to be operated at voltage levels of 66 and the export cables between 220 - 345 kV. The strength of electromagnetic fields decreases rapidly with the distance from the source. Therefore, it is assumed that the effect (if any) is very localized at the cables to only a few meters.

Resistance and recoverability

As the electromagnetic fields are consider cause a limited pressure on harbour porpoise and seals the resistance and recoverability is ranked as *high* for all three marine mammals species on both individual level as well as on population level.

5.2.2.8 Decommissioning work

During decommissioning of the offshore wind farm, pressures on marine mammals are expected to be less than those of the construction phase of the wind farm. This includes underwater noise emission due to decommissioning work and increased ship traffic in the plan area for Hesselø OWF. As the decommissioning procedure is not known and there is limited experience from decommissioning of other offshore wind farms, the impact on marine mammals caused by underwater noise during the decommissioning phase is difficult to predict. However, it is expected that the underwater noise will be less intense compared to the construction phase, as there will be no pile driving activities.

There will be no risk of permanent hearing damage but in the event of persistent noise in connection to the decommissioning work, TTS-inducing noise levels may occur in the nearfield of the decommissioning position. Behavioral responses can also occur.

Resistance and recoverability

Underwater noise from decommissioning work is expected to cause a minor pressure on harbour porpoise and seals and the resistance is ranked as ***medium*** for harbour porpoise, harbour seals and grey seals whereas the recoverability is ranked as ***high*** for all three marine mammals species on both individual level as well as on population level.

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5.2.3 Sensitivity of receptors

As explained in Section 5.1 (Table 5-3), sensitivity is determined by the resistance and recoverability attributes of each receptor. Sensitivity scores for harbour seal, grey seal and harbour porpoise are listed for each pressure in Table 5.7

Table 5.7 Resistance, recoverability and resultant sensitivity ratings for identified hard bottom benthic receptors.

Pressure	Harbour porpoise			Harbour seal			Grey seal		
	Resistance	Recoverability	Sensitivity	Resistanc	Recoverability	Sensitivity	Resistance	Recoverability	Sensitivity
Increased underwater noise from unmitigated pile driving: PTS	None	Very low	High*	None	Very low	High**	None	Very low	High**
Increased underwater noise from unmitigated pile driving: TTS	Low	Medium	Medium*	Low	Medium	Medium**	Low	Medium	Medium**
Increased underwater noise from unmitigated pile driving: Avoidance response	None	Low	High*	Low	Medium	Medium**	Low	Medium	Medium**
Increased underwater noise from unmitigated pile driving: Masking	High	High	Not Sensitive	High	High	Not Sensitive	High	High	Not Sensitive
Increased airborne noise: Avoidance response	n/a	n/a	n/a	High	High	Not Sensitive	High	High	Not Sensitive
Sediment spillage: Avoidance response	High	High	Not Sensitive	High	High	Not Sensitive	High	High	Not Sensitive
Increased underwater noise from vessels: Avoidance response	Medium	High	Low	High/medium	High	Not Sensitive /Low	High	High/medium	Not Sensitive Low
Increased underwater noise from operation: Avoidance response	High	High	Not Sensitive	High	High	Not Sensitive	High	High	Not Sensitive
Habitat change	High	High	Not Sensitive	High	High	Not Sensitive	High	High	Not Sensitive
Electromagnetic fields	Limited evidence (assessed as Low Sensitivity)			Limited evidence (assessed as Low Sensitivity)			Limited evidence (assessed as Low Sensitivity)		
Increased underwater noise decommissioning work Avoidance response	Medium	High	Low	Medium	High	Low	Medium	High	Low
Sediment spillage from decommissioning work: Avoidance response	High	High	Not Sensitive	High	High	Not Sensitive	High	High	Not Sensitive

** If pile driving is conducted with application of mitigation system and is conducted outside the breeding season (May to August) for harbour porpoises, the magnitude of the effect can be considerably reduced and it is possible that the sensitivity is reduced to low for harbour porpoises (see "Miljøvurdering af Planen for Hesselø - delrapport 2" as an example).*

***If pile driving is conducted with application of mitigation system, the magnitude of the effect can be considerably reduced and it is possible that the sensitivity is reduced to low for seals (see "Miljøvurdering af Planen for Hesselø - delrapport 2" as an example).*

Unmitigated underwater noise from pile driving is the most disturbing effect on marine mammals during the installation of offshore wind farms. Sensitivity to PTS is high for all three marine mammal species and TTS is medium for all three receptors/marine mammals species for the unmitigated underwater piledriving noise. In addition, underwater noise from pile driving may cause behavioural avoidance responses in all three receptors/marine mammals species and the sensitivity for harbour porpoises is ranked as high because of the long impact ranged for the unmitigated underwater noise from pile driving and because the area may be important during the breeding season, whereas the sensitivity outside the breeding season is considered to be lower. For harbour seal the sensitivity for avoidance responses is medium because of the high number of pups at the nearest haul-out sites, whereas the sensitivity outside the pupping season is considered to be lower. For grey seal the sensitivity for avoidance responses is low, because of the low number of grey seal in the plan area all year round. However, grey seals are currently recolonising Kattegat as a breeding species, and it is not known if substantial noise during the breeding season may delay this process.

The impact distance of underwater noise from pile driving can be considerably reduced with application of abatement systems as discussed in section 5.2.2.1.3 as well as with application of a soft start procedure where onset of the piling process are conducted with low energy. The energy per stroke then increases gradually until full energy per stroke is applied. With increasing amount of energy, the emitted noise increases as well, allowing the marine mammals to move out away from the construction site before the noise becomes physically dangerous to them.
There are different noise abatement systems available. The most frequently applied technique uses bubble curtains, where air is pumped into a hose system positioned around the pile installation at the bottom of the sea. The hoses are perforated and air bubbles leak and rise toward the surface. This forms a curtain through the entire water column from seabed to sea surface. Due to the change in sound speed in the water-air-water bubble interface, a significant part of the outgoing noise is reflected backwards and kept near the pile, while the remaining noise energy going through the bubble curtain is greatly attenuated (Tsouvalas, 2020). The effect of bubble curtains can be increased further if a second bubble curtain is installed even further from the installation, thereby forming a Double Big Bubble Curtain (DBBC).

If pile driving is conducted with application of mitigation system and outside the breeding season May to August) for harbour porpoises, the magnitude of the effect can be considerably reduced and it is possible that the sensitivity is reduced to *low* for all three marine mammal species (see "Miljøvurdering af Planen for Hesselø - delrapport 2" as an example).

For all three receptors/marine mammal species, sensitivity to other pressures (sediment spillage, habitat change, increased underwater noise from vessels and electromagnetic fields) is ranked as low or not sensitive.

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