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THOR OFFSHORE WIND FARM
MARINE MAMMALS

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List of Abbreviations:	
Abbreviation	**Explanation**
Aerial Survey Area	Survey area covered by the observer- and digital flights, bigger than the gross area for Thor OWF
AIC	Akaikes Information Criterion
C-POD	Brand name of the porpoise detector
DEA	Danish Energy Agency
DPM	Detection Positive Minute
MW	Megawatt
ODAS	Offshore Data Acquisition System
PBR	Potential Biological Removal
PCOD	Modelling approach for Population Consequences Of Disturbance
Prediction Area	Area used for the modelling of marine mammal densities
R	Statistical Software
R2	Northern cable corridor
R3	Southern cable corridor
SCI/SPA	Site of Community Importance / Special Protection Area
SEA	Strategic Environmental Assessment
Thor OWF	Thor Offshore Wind Farm
The gross area for the Thor Offshore Wind Farm	The larger investigated area in this report of 440 km^2 within which the future Thor OWF will be placed
TSEG	Trilateral Seal Expert Group
TTS/PTS	Temporary Threshold Shift / Permanent Threshold Shift

1. INTRODUCTION

By adopting the Energy Agreement of June 2018, the Danish Parliament requested the construction of three additional Offshore Wind Farms (OWF) in Danish waters before 2030, setting the installed capacity at approximately 1000MW. In the scope of the Energy Agreement 2018 the grid connection of the additional OWFs was scheduled for 2024 to 2027. In February 2019, the Danish Energy Agency (DEA) initiated a screening study to identify potential development sites for large-scale (app. 1000MW) OWF in Danish waters. Based on this screening study the DEA declared an area in the North Sea 20 km off the coast of Thorsminde as a suitable development site for the Thor OWF (Figure 1-1). The gross area for Thor OWF, which is investigated covers approximately 440 km^2 of which the future OWF will take up approximately 220 km^2. The capacity of the Thor OWF is aimed at 800 – 1000 MW.

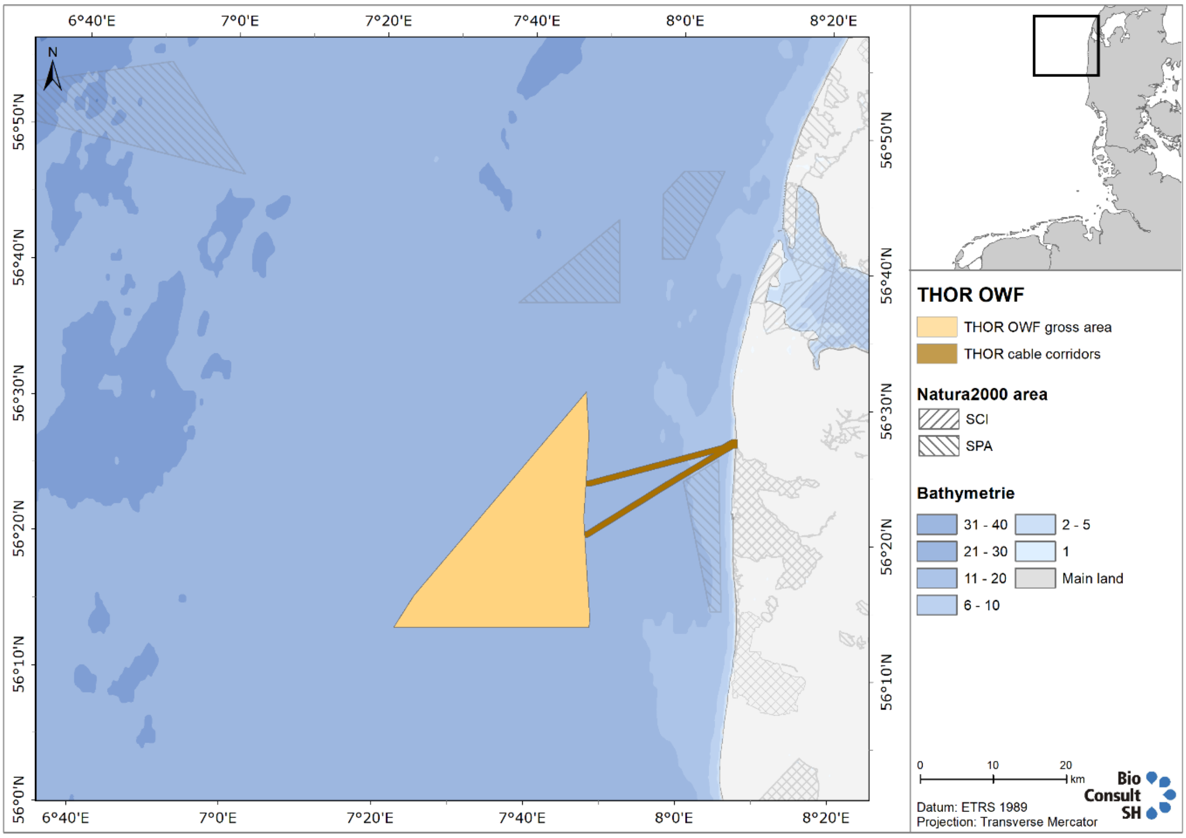

Figure 1-1 Location of the gross area screened for the potential location of the Thor OWF approx. 20 km west of the Jutland peninsula (including sites of Community Importance and Special Protected Areas).

1.1 Objectives

The purpose of this technical report is to document the baseline conditions of marine mammals in the gross area for Thor Offshore Windfarm, to provide a sensitivity analysis of marine mammals in the area and in relation to potential impacts of the planned Thor OWF on marine mammals in the area where relevant. To perform the analysis, existing literature and the investigations carried out in the gross area for Thor OWF (passive acoustic monitoring and aerial survey data from 2019 and 2020) were used.

The DEA requires the preparation of a Strategic Environmental Assessment (SEA) for the declared gross area, serving as a baseline to assess effects on environmental parameters and to identify potential conflicts between the project and the site and/or stakeholders. The SEA identifies suitable locations and potential conflicts supported by existing literature and technical reports on specific environmental subjects (e.g., benthic flora and fauna, fish and fisheries, marine mammals, etc.), and addresses potential impacts on the environment occurring either during the construction, operation or decommissioning of the Thor OWF. The SEA is consistent with the stipulations of the Energy Agreement 2018 and meets the required detailing level for an SEA under the EU Directive implemented in Denmark.

The present technical report focuses on marine mammals only, with specific focus on the potential exposure to underwater noise during the construction phase. Other impacts such as habitat loss, sediment spill, noise during operation, electromagnetic fields are considered minor or negligible (see chapter 6).

The area around the gross area for Thor OWF is known to be regularly visited by marine mammals. The most common species are the harbour porpoise (*Phocoena phocoena*) and the harbour and grey seal (*Phoca vitulina* and *Halichoerus grypus*).

The specific objectives of this baseline report and sensitivity analysis were thus to

- describe and evaluate the use of the gross area for Thor OWF by marine mammals.
- determine the potential effects of the installation, operation and decommissioning of the offshore elements of the proposed offshore wind farm Thor on the species and to predict the significance of those impacts in terms of a sensitivity analysis; The sensitivity analysis includes the ranges of disturbances and physical impacts of noise on marine mammals and the effects in the closest Natura 2000 sites.
- present a Habitats Regulations Assessment for the proposed development, including the Natura2000 screening process and an assessment of the conservation obligations for strictly protected species according to the Habitats Directive.

The construction of the offshore wind farm involves activities that produce underwater noise. Installation of monopiles into the seabed by means of impact pile driving is regarded the most significant noise source with the potential to harm marine mammals and fish in the area. Therefore, an Underwater Noise report (ITAP 2020) has been prepared and used as an initial assessment on the displacement effects on the marine mammals. Technical details (e.g., the precise size of the hammer etc.) will be decided for the specific Thor project, therefore this report is based on assumptions about the technical details of the future project.

2. PROJECT DESCRIPTION

The gross area for the location of the future Thor OWF is located in the Danish North Sea west of Nissum Fjord at least 20 km off the coast of Jutland (Denmark) (Figure 1-1). The water depth in the project area is between 24 m and 32 m (EMODnet), and within the gross area, the uppermost surface layer of the sediment consists of a mix of sand, gravel and clay (see the "Thor OWF Technical report – Benthic fauna and flora" for details).

At the current planning stage, the final layout and position of the OWF has not been defined yet and there are several possible configurations with regard to the total capacity of 800 – 1000 MW of the OWF, the number of turbines and the capacity of each individual turbine.

The plan for Thor OWF includes the following elements:

- the gross area for the Thor OWF within which the positioning of wind turbines will be specified at a later stage,
- the offshore substation (transformer platform),
- two alternative cable corridors (R2 – Northern cable corridor and R3 – Southern cable corridor) leading to one landfall on the north coast of Nissum Fjord. Either one or both cable corridors maybe used.
- an onshore substation located close to the landfall area of the export cables and onshore cables to the grid connection point at Idomlund, which is east of Nissum Fjord.

2.1 Turbines

Turbine capacity and thus turbine numbers have not been identified yet. However, a range between 8 - 15 MW power capacity is expected, corresponding to a minimum of 67 turbines and a maximum of 125 turbines (thus representing a total capacity of the wind farm of approximately 1000 MW). Due to the range of potential capacities the assessment is performed on a general level.

2.2 Foundations

The most likely construction method considering the water depths and the expected seabed conditions will be a pile-driven monopile. As alternatives, jacket-foundations and suction buckets are discussed in the assessment. However, the noise emissions used for the assessment of affected areas are based on the constraints given in the noise report (ITAP 2020 p. 2020) using as a base case a monopile with 13 m diameter. In an addition a scour protection is most likely needed, covering a radius of approximately 20 m around each foundation. With an erosion protection around each turbine of in total 20 m diameter the footprint of the 125 8 MW turbines is estimated to 0.039 km^2 and 0.021 km^2 for the 67 15 MW turbines. These assumptions are based on experience from other windfarm projects along the west coast of Jutland were scour protection is potentially done with stones placed with a diameter of 15-20 m around the foundation (*Vesterhav Nord vindmøllepark - Miljøkonsekvensrapport* 2020, *Vesterhav Syd vindmøllepark - Miljøkonsekvensrapport* 2020).

3. METHODS

The assessment of the marine mammal presence within and around the gross area for the Thor OWF is based on datasets collected during flight surveys as well as datasets from a passive acoustic monitoring.

3.1 Aerial surveys

The project-based flight surveys were planned as observer-based flights. Due to the COVID-19 restrictions in spring 2020 the first flight was changed to a digital flight on the same transect design to avoid the contact of crews and observers from German and Danish high-risk areas. Because the two methods monitor different strip width during the flight, digital and observer-based flights result in different counts of individuals. This is levelled during the later analysis when the counts are transformed into the index Individuals/km^2 (details see below).

Flights were performed during the months of April (digital flight on 18.04.2020), June (observer flight on 18.06.2020 and August 2020 (observer flight on 17.08.2020) with technical planning and long-term weather forecasting beginning in March 2020.

3.1.1 Digital flights

The HiDef system is comprised of four high-definition video cameras capturing a combined strip-width of 544 m at a survey altitude of 549 m (Figure 3-1). The resolution of 2 cm / pixel enables identification of most marine mammals to species level. Due to the similar appearance in water, harbour seals and grey seals are grouped under the clade pinnipeds/seals. All cameras changed their focus direction after each transect to avoid glare. GPS track, time and flight height are automatically stored with each picture for automatic georeferencing.

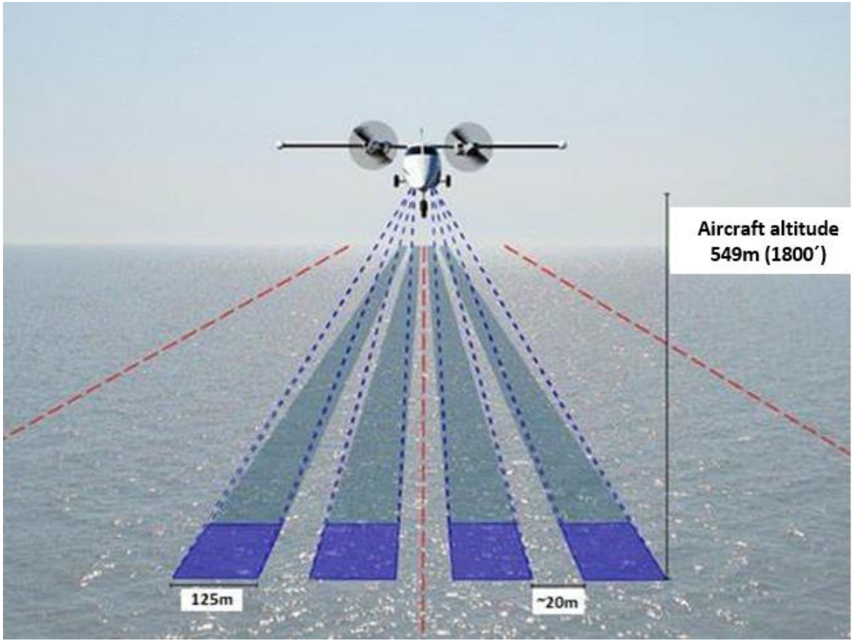

Figure 3-1 Technical layout of HiDef camera system.

3.1.2 Observer flights

Observer based flights takes place in 600 feet flight height using purpose build planes (twin-engined, high wing aircrafts e.g., Partenavia P-68 Observer or Britten Norman Islander BN-2, both with bubble windows and active collision warning power flarm). The crew includes two pilots and three trained marine mammal observers per survey. The flight speed is set to 100 kn. The observers record all sightings on dictaphones. Concurrently, time and GPS-Position for each observation are logged and a permanent GPS from the plane is synchronized. Recordings are transferred and georeferenced in the office and translated into ArcGis raw data.

3.1.3 Study area

The flight transect design agreed with the client covers 2487,53 km² with twelve transects of approximately 48 km length and 5 kilometers spacing (see Figure 3-2). Transect layout was chosen as an east-west design to have transect lines horizontal to the main depth contours. This allows analysis of avoided areas in relation to water depth. Each transect line covers approximately 200 m of Danish onshore coastline to also monitor seals on land if present. The aerial survey area was defined to cover a substantial larger area as the gross area (covering 2487 km² compared to the Thor gross area of 440 km²). This was done to take into account that marine mammals are highly mobile and spatial patterns can be distributed over large areas. The chosen area of the aerial investigations allows to analyze if the gross area is of special importance to marine mammals in relation to the surrounding area and if regular spatial patterns occur.

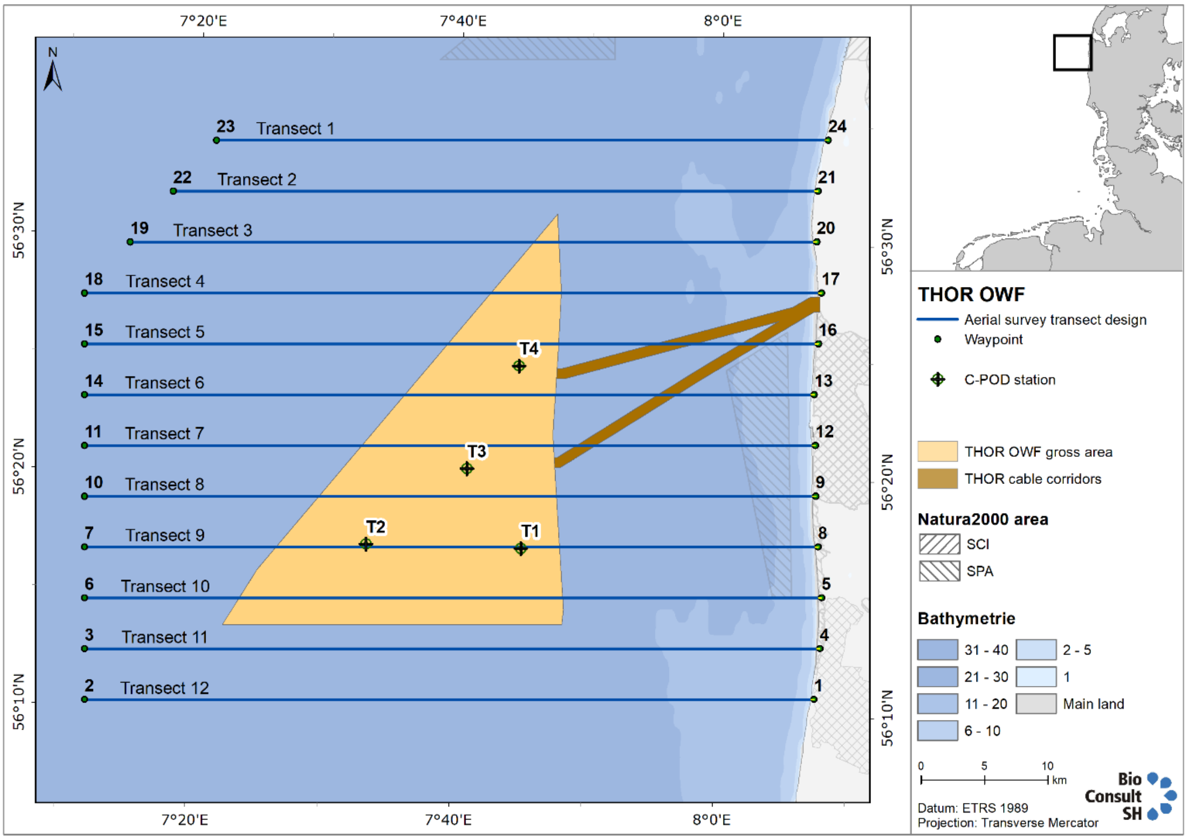

Figure 3-2 Flight transect design used during all three aerial surveys.

3.1.4 Data validation of observer and digital flights

Data from digital and observer-based flights yield comparable results and can be directly compared to each other. Though digital flights cover bigger areas and consequently identify more objects, the transformation into the index "individuals per km²" levels this initial difference. Data from digital flights however is less prone to assumptions and variations because no distance correction needs to be performed and thus the variation within data sets is usually lower. This change of methods has been done in most projects in the EU and has been documented for example for the FemarnBelt Fixed Link project and all offshore wind projects in Germany (documented in the Standard "Investigation of impacts of offshore wind turbines on the marine environment" (Bundesamt für Seeschifffahrt und Hydrographie 2013) and many in France (ongoing projects)). Main driver for the change of methods is the flight height, which can be realized with the digital method. Observer flights are conducted within rotor height and planes fly in a narrow corridor in operational wind farms. To avoid flights in rotor height of operational wind farms, digitals flights are performed much higher than the potential tip height of future rotors. Details of the comparison of both methods are discussed in peer reviewed publications (Žydelis et al. 2019, Bröker et al. 2019).

3.1.5 Data analysis

The flight data is stored on hard drives (thus raw data is reproducible at any time) and analysed in the office by a review and identification team. Raw data on hard drives can be handed to the client after a quality check.

For both methods (observer based and digital flight surveys), distributions and densities of marine mammals (harbour porpoises, harbour seals and grey seals) are calculated and plotted as density maps or point sightings maps.

Observer data requires distance sampling correction for adjusting the estimated total number of sightings (Buckland et al. 2001, Thomas et al. 2002). Distance sampling is a widely used methodology for estimating animal density or abundance. Its name derives from the fact that the information used for inference are the recorded distances to animals obtained by surveying lines. In observer-based surveys, the probability of detecting an animal decreases as its distance from the observer increases. Much of distance sampling methodology is concentrated on detection functions, which model the probability of detecting an animal, given its distance from the transect and the group size (which affects to the species detectability). For the investigation of the aerial survey area distance sampling analysis was performed using the software Distance 7.3 (Thomas et al. 2010).

3.1.6 Data modelling

Spatial modelling of aerial flight data is performed within a Bayesian framework making use of Latent Gaussian Models (LGMs) and the Integrated Nested Laplace Approximation (INLA; (Rue et al. 2009)) combined with the Stochastic Partial Differential Equation (SPDE) approach (Lindgren et al. 2011). This approach allows to implement spatial modelling for point process data, while accounting for spatial-temporal interdependence and autocorrelation in the data. As an advantage, Bayesian inference uses the Bayes' theorem to update the probability of a hypothesis after new data are obtained, where the Bayes' theorem describes the conditional probability of an event based on data as well as prior information or beliefs about the event or conditions related to the event (Kruschke 2014). The modelling includes the aerial survey area and some area around the transect lines, thus the prediction area for marine mammal densities is slightly bigger than the aerial survey area (3560 km^2). However, all modellings a carried out for the index Individuals/km^2 so the results are comparable at any time.

This modelling framework is designed not to make use of any covariates; however, it can optionally integrate environmental variables, multiple data sources or distance sampling methods, and it can deal with spatially varying detection probability. Therefore, it is an ideal method for quantifying animal distribution and abundance from aerial and boat-based surveys, while correctly considering predictive uncertainty.

Data modelling was performed using the R-package inlabru (Bachl et al. 2019) from the R statistical software (R Core Team 2020).

The availability bias was taken into consideration for calculation of the total abundance estimation. It depends on the proportion of time harbour porpoises spend in the upper water column where they can be seen from the airplane (down to 2 m below surface). TEILMANN et al. 2013 calculated the mean monthly percentage of 'near surface time' for harbour porpoises in the North Sea waters based on transmitter data (Figure 3-3), estimating it to be approximately 61% of the time during the month of April and a 52% during the month of August.

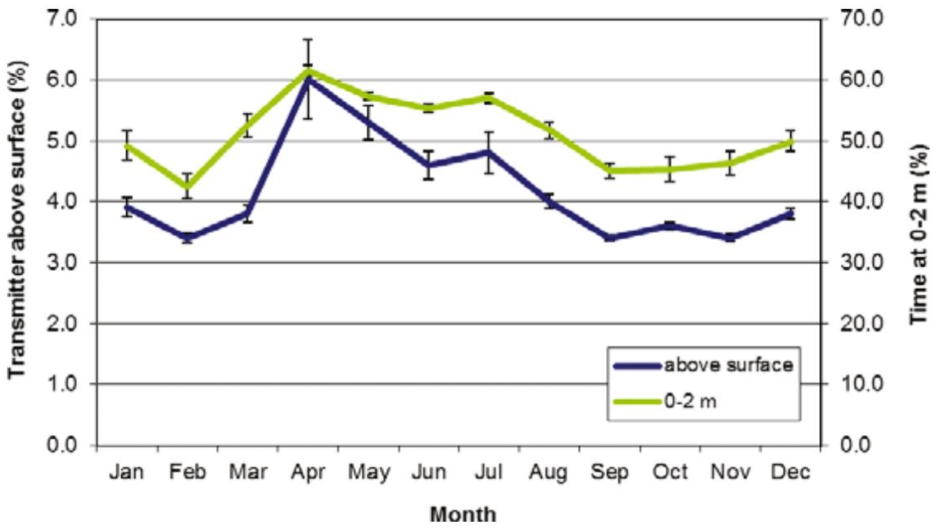

Figure 3-3 Monthly mean percentages of time spent near surface (0-2m depth) for harbour porpoise in the North Sea (from Teilmann et al. 2013)

Derived from the publication by Teilmann 2013 the following correction factors have been used for the specific flight month:

Table 3-1 Detection probability of harbour porpoises in the surface layer (0 to 2 m) following Teilmann et al. (2013b) depending on the month of data assessment.

Month	Detection probability (0 to 2 m)
January	0,492
February	0,425
March	0,525
April	0,615
May	0,573
June	0,553
July	0,570
August	0,517
September	0,450
October	0,453
November	0,463
December	0,499

3.2 Passive acoustic monitoring

Harbour porpoises orientate themselves by means of echolocation and therefore emit almost constantly high-frequency clicking sounds (Koschinski et al. 2008, Clausen et al. 2010). These can be recorded to gather information about the presence of harbour porpoises in an area. To gather long term data from specific areas, C-PODs are deployed over longer periods returning data on the presence of individuals on different time scales. To identify harbour porpoise dynamics in the gross area four stations with two C-PODs at each station have been deployed. However, C-PODs do not give an estimate of harbour porpoise densities and are thus to be combined with flight data.

3.2.1 Technical details, Deployment and recovery of C-PODs

A C-POD (Cetacean POrpoise Detector, Chelonia Ltd, UK; http://www.chelonia.co.uk; Figure 3-4) is a device that records the high-frequency echolocation calls of harbour porpoises using a built-in hydrophone up to a distance of approx. 300 m, with an almost 100 percent detection in a radius of 100 meters (http://www.cpodclickdetector.com). C-PODs consist of an 80 cm long plastic tube with the hydrophone at one end. Directly below are an amplifier and an electronic filter. The hydrophone records all sound events omnidirectionally in a frequency range from 20 to 160 kHz. Main frequency, frequency curve, loudness duration, intensity (in 8 bit steps), bandwidth and envelope of the frequency spectrum are stored for each individual click. A total of ten 1.5 Volt D batteries supply the device with enough voltage for at least six weeks. SD cards provide an easy-to-read memory unit of up to four GB. The devices are calibrated by the manufacturer to the main frequency of porpoise clicks (130 kHz) and set to the same hearing threshold (±3 dB). Applying various filters, a C-POD converts the sound waves into digital data and stores them on an SD card, allowing later evaluation of harbour porpoise presence. All C-PODs are calibrated every two years at the manufacturer. C-POD data are read out once off-shore, but the SD-card containing the original data will be stored until final data review in the office. All data are secured daily on two external servers according to the ISO and OHSAS standards.

Figure 3-4 C-PODs to investigate harbour porpoise presence

Mobilization for C-PODs survey has been in Esbjerg or Hvide Sande (DK) and at both locations storage for spare materials has been maintained. Vessels as the above proposed SKOVEN or of similar type and certification have been provided by FOGA APS. A survey to exchange C-PODs has been planned every eight to ten weeks and took place on the following days and with the vessels given in Table 3-2.

Table 3-2 Service plan for 2019/2020 C-POD Services.

Survey	Date	Vessel	Purpose
1	19.12.2019	Skoven	Deployment
2	26.02.2020	Skoven	Service & Repair
3	20.04.2020	Cecilie	Service and Repair
4	02.07.2020	Reykjanes	Service and Repair
5	27.08.2020	Reykjanes	Service and Repair
6	31.10.2020	Skoven	Service and Repair
7	28.11.2020	Skoven	Recovery

3.2.2 Moorings

As mooring for these stations, a combination of surface-markers (spar buoys), marker balls and anchor stones has been used. A C-POD station with surface markers is set-up according to the international guideline for off-shore data acquisition systems (ODAS) with 6 m spar-buoys with yellow 3NM flash-light, radar-reflector and yellow top-cross (see Figure 3-5).

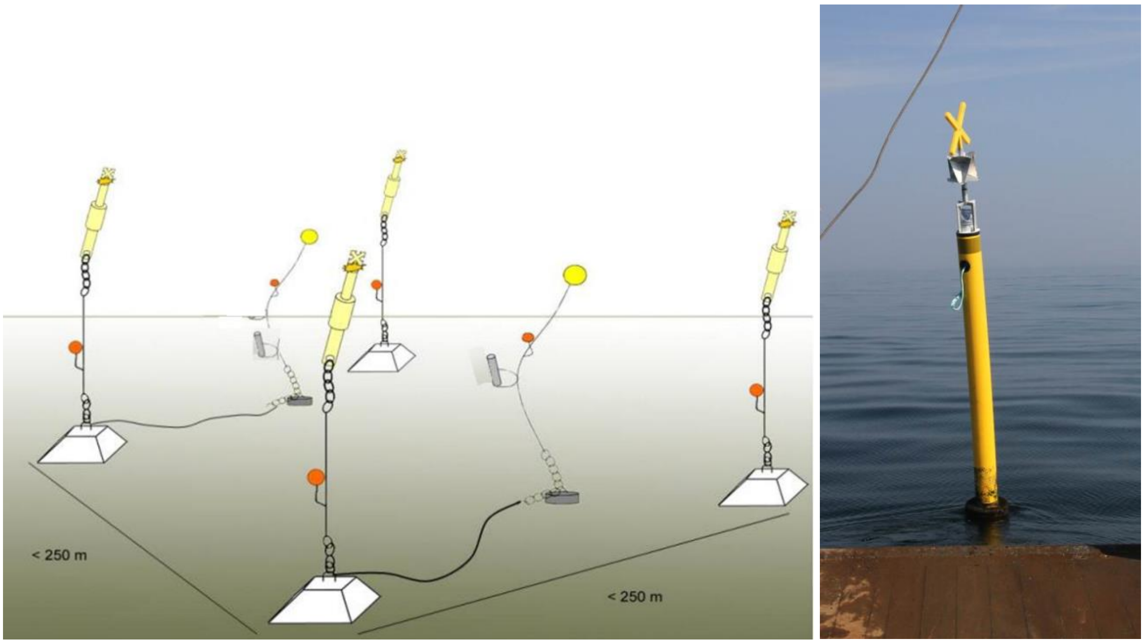

Figure 3-5 Design of a single C-POD station. Stations with two C-PODs or more follow the same design

For exchange of C-PODs only the small anchor-stone is lifted from the seabed. Spar-buoy and large anchor stone are serviced twice a year and are otherwise left untouched.

3.2.3 Parameters and definitions

The use of the area by harbour porpoises was assessed using the parameters *Detection-Positive 10 Minutes per day (DP10M/day)* and percentage *(DP10M/day; synonymously used %DP10M/day)*: number of blocks of ten minutes within a single day with at least one porpoise detection, in relation to the maximum of 144 10-minute intervals for a full day. Days when devices were exchanged and some hours without detection occurred were not taken into account. This daily measure was used for assessment of the harbour porpoise presence and dynamics (daily and seasonal variations in harbour porpoise presence = phenology). Similarly, days with an excess of noise were eliminated from analysis.

3.2.4 Phenologies

The shape of a phenology curve is usually more interesting than absolute numbers for certain days. Confidence intervals were not definable for comparisons of phenologies (*PP10M/day*) on a daily base. At this temporal resolution, analyses of phenologies had to be kept on a strictly explorative level. Phenology and 95% Interval Confidence intervals were calculated using a LOESS smooth function. Monthly detection rates (%DP10M/day) were aggregate by month for all stations to give an overall idea of the detection rates per month.

Significance of time series correlation among mooring stations were assessed by means of a hierarchical clustering technique via multiscale bootstrap resampling. For this task only full days with valid records in all stations simultaneously were used.

In addition, the potential interaction between day of the year and hour of the day was investigated by means of a Generalized Additive Model. And finally, C-POD data was compared with aerial flight data during the flight time period by means of a Pearson´s correlation index to assess for differences between C-POD detections and aerial sightings.

All maps by BioConsult SH are based on bathymetric data by GEBCO (The GEBCO_2014 Grid, version 20150318, http://www.gebco.net).

4. BASELINE SITUATION

4.1 Biology and distribution of the harbour porpoise

Harbour porpoises are one of the smallest European cetaceans, belonging to the toothed whales and reaching a length of up to 1.85 m, very rarely even 2 m. On average, however, they are only 1.60 m long. The weight of the adult harbor porpoise varies between approx. 40 and 90 kg. Females generally become larger and heavier than their male counterparts(Bjørge & Tolley 2009). Harbor porpoises have a life expectancy of up to 22 years (Benke & Siebert 1994, Bjørge & Tolley 2009). However, they often only reach an age of around 12 years. The males become sexually mature at 2 to 3 years of age, whereas the females only reach sexual maturity at an age of 3 to 4 years. The mating season is from mid-July to the end of August, leading to a calving season in the Danish North Sea around July of each year with the calving season spreading between May and August of each year (Bjørge & Tolley 2009). Porpoises usually swim alone or in pairs (mother/calf groups). Bigger groups can occur occasionally, but these small whales are seldom found in schools of more than 7 animals. Their average swimming speed is around 2-7 km/h. This swimming speed differs greatly between travelling, feeding or even fleeing activities. In experimental setups the swimming speed of a captive harbour porpoise was around 4.3 km/h in a baseline measurement reaching 7.1 km/h during playback of simulated piling noise (Kastelein et al. 2018). This marine mammal species can only be found in the northern hemisphere, preferring waters close to coasts such as shallow seas, fjords, sounds, bays and estuaries, feeding on fish living on the seabed as well as schooling fish. These include the goby, the lesser sand eel and the eel mother, the herring, the sprat, the cod, the whiting, the mackerel and the horse mackerel (Aarefjord et al. 1995, Börjesson et al. 2003, Santos & Pierce 2003). Occasionally, octopuses, crustaceans, snails and bristle worms are found in stomach content analyses. Prey species of Harbour porpoise are generally no larger than 30 cm.

Harbor porpoises can be diurnal as well as nocturnal (Williamson et al. 2017), sometimes adapting their activity rhythms to prey availability, season or daylength. In adapting to their habitat, the porpoises have developed a bio-sonar as an orientation aid. With the so-called "phonic lips", an organ similar to the vocal folds, the animals produce short, high-frequency clicks. Porpoises can orient themselves in their environment, communicate with conspecifics and catch prey in complete darkness or in high turbidity waters and adopt their vocalization patterns to specific tasks (Koschinski et al. 2008, Clausen et al. 2010, Brandt 2016). The hearing abilities of harbour porpoises have been an object of intensive research due to the fact, that harbour porpoises rely on their auditory system to search for prey. Thus, any impairments of the auditory system can lead to starvation. Studies on the hearing abilities of harbour porpoises showed in audiograms, that harbour porpoises have the best hearing abilities between 16 and 140 kHz with a lower threshold around 40-60 dB re 1µPa (Kastelein et al. 2002, 2010, Lucke et al. 2008, 2009, Lee A. Miller & Magnus Wahlberg 2013). This corresponds to the frequencies harbour porpoises emit clicks, which usually lies between 100 and 140 kHz.

In the North Sea the total harbour porpoise abundance is estimated to be 466,569 individuals (with a range between the low and high confidence intervals (CI) of 345,306 – 630,417 individuals)(Hammond et al. 2017), but abundances vary greatly as well between years as between areas of the North Sea, depending on seasonal migration and food availability. The calculation of the most recent abundances in Hammond et al (2017) is based on flight surveys covering large areas including the coasts of Spain, Portugal and additional data sets from the North Atlantic Sighting Survey and the Irish Observer project. But to define the biogeographical population relevant for projects in the Danish EEZ the ICES assessment unit “North Sea” is used (ICES 2014), describing the animals distribution from the English Channel up to the Norwegian coast (Figure 4-1). Thus the estimated population size as part of the total population (pink in

Figure 4-1), relevant for the impact assessment, is assumed to be 345,373 animals with an lower and upper confidence interval of 246,526 and 495,752 individuals (Hammond et al. 2017).

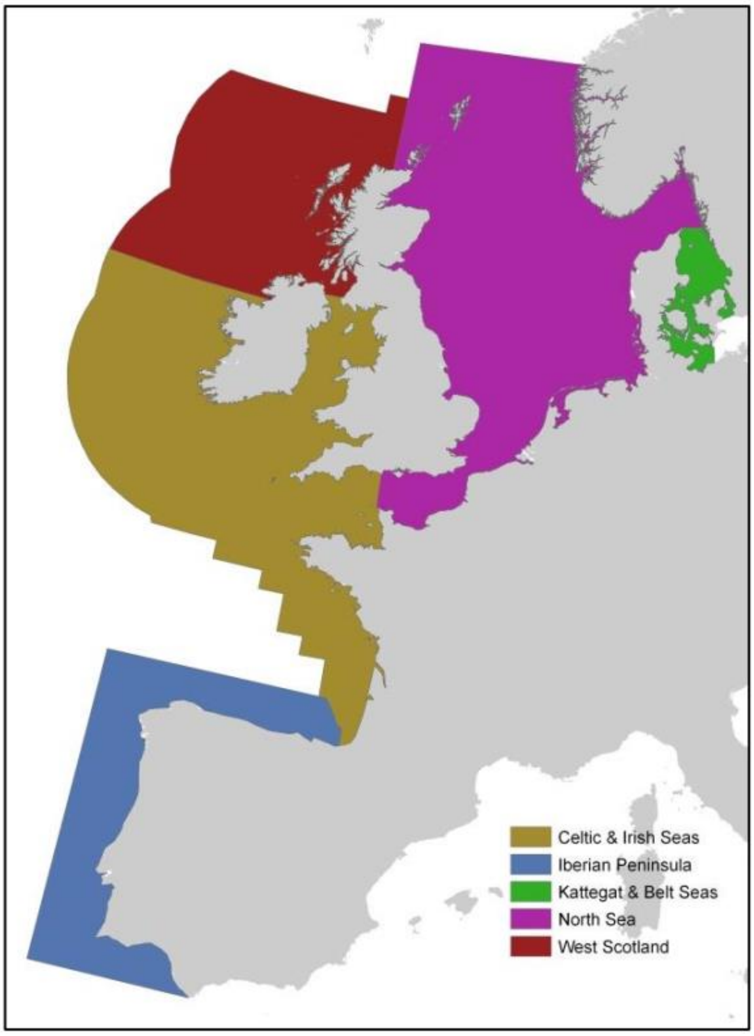

Figure 4-1 Harbour porpoise assessment units as proposed for OSPAR (ICES 2014). The North Sea population (pink) is used as reference population in this report.

The gross area for the Thor OWF is located north of the investigation area of yearly flights in the Danish Southern North Sea (DCE 2011 – 2019), providing comparable results and investigation areas (Figure 4-2) to assess the importance of the area and the reliability of the data.

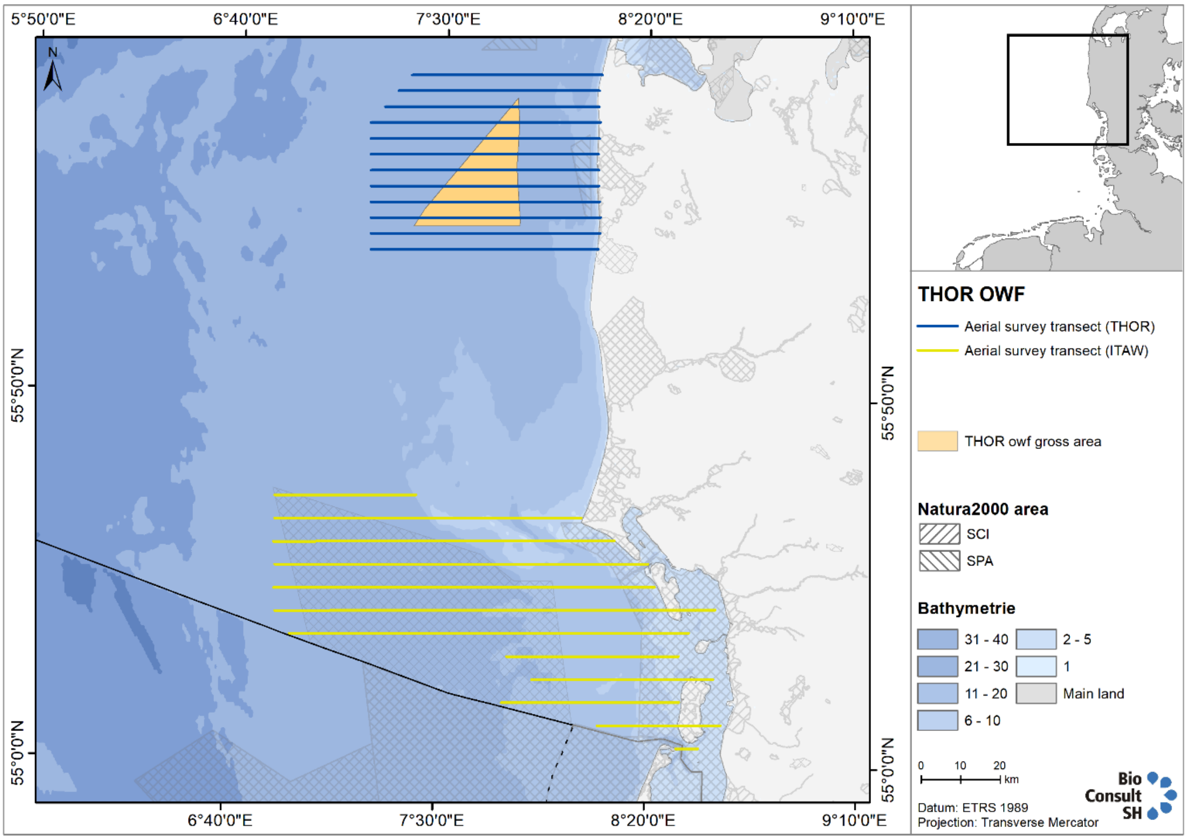

Figure 4-2 Investigation area for the Southern Danish North Sea from 2011 to 2019 in spatial relation to the gross area of Thor OWF.

This data can be used to compare the abundances in the gross area between 2011 and 2019 with data from surveys for the Thor OWF in 2020 and get a reliable baseline estimate. The assessment area investigated by ITAW between 2011 and 2019 covered about 5342 km^2. The calculated abundances in this area south of the Thor gross area vary between the years starting with 4828 estimated animals in 2011, followed by lower numbers in 2013, 2015, 2017 and 2018 (lowest estimate with on 978 animals in 2015). In 2014 6531 individuals were registered in the ITAW investigation area (Figure 4-3). Accordingly, the number of individuals can vary greatly in the area from year to year and shows large confidence intervals due to variation in conditions during data acquisition and between years. Nevertheless an overall negative tendency towards a decrease in animals numbers in the area is observed in the period from 2011 to 2019(Hansen & Høgslund 2019).

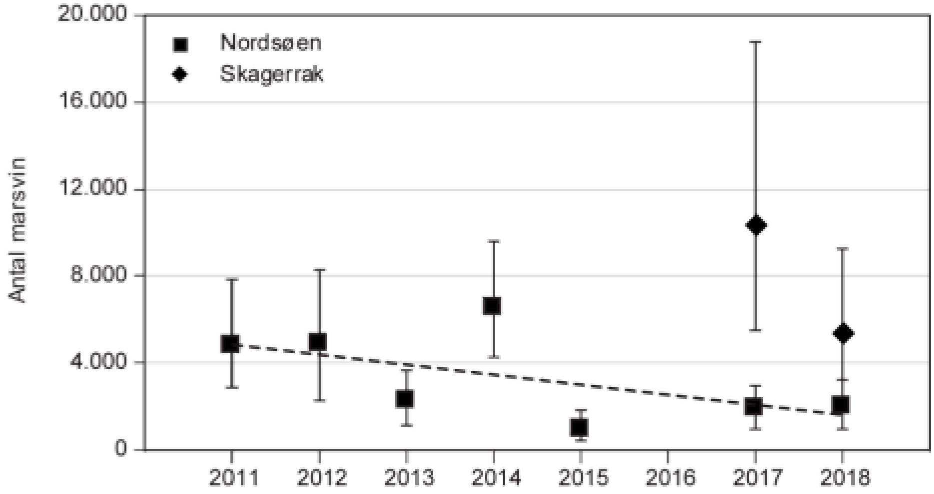

Figure 4-3 Abundances in the area of yearly flight survey of the Danish southern North Sea for 2011 to 2018 (Hansen & Høgslund 2019) The data relates to an area south of the gross area for Thor OWF (Figure 5-19**).**

4.2 Biology and distribution of the harbour seal

Harbour Seals (*Phoca vitulina*) are the most widely distributed species of all seals. Adult harbour seals reach a length of 180 cm and can weight up to 170 kg, though most specimen are smaller and reach approximately 100 kg of body mass with females being about twenty percent smaller and lighter (Reijnders 1992). Harbour seals feed on a great variety of prey, depending on location, water depth, and individual prey abundance. Thus these opportunistic feeders share their prey preferences with harbour porpoises and grey seals, including sand eel (*Ammodytes spec*), cod (*Gadus morhua*) and whiting (*Merlangius merlangus*) but also other bottom dwelling fish as flounders and mobile fish such as sprat (*Sprattus sprattus*) (Hall et al. 1998, Tollit et al. 1998, Hansen & Harding 2006, Andersen et al. 2007).

Harbour seals can be found on many marine coastlines of the northern hemisphere and can be distinguished into genetical different sub-populations (Andersen & Olsen 2010). Among these sub-population the Danish based populations located at Limfjorden, Skagerrak, Kattegat and the West Baltic Proper and the Wadden sea (including the Wadden Sea areas of all three Wadden Sea nations, Denmark, Germany and the Netherlands) form individual clusters and individuals from these locations may occur in the gross area for Thor OWF. Though the Wadden Sea haul out sites are more than 100 km away, it has been shown that seals travel these distances on multi-week foraging trips to the north-west of their haul out sand banks (Tougaard et al. 2003). The 2016 NAMMCO report stated an abundance of 1000 animals in the Limfjorden population, and another 16.000 individuals in the Skagerrak and Kattegat area (North Atlantic Marine Mammal Commission (NAMMCO) 2016). For all populations a positive trend of an increasing population size of up to 6% per year was predicted after a massive reduction due to the Phocine Distemper Virus (PDV) breakouts in 1988 and 2002. However, the annual growth of the Wadden Sea subpopulations between 2012 and 2019 has shown a stabilizing trend of +0,4% p.a. New data from 2018 and 2019 harbour seal surveys showed an increase of harbour seal pups in the Danish Wadden Sea of approximately 64%. In the trilateral moult counts in August 2019 in all 27.763 harbour seals were counted in the Wadden Sea countries, representing the highest count up to date (Galatius et al. 2019) (Figure 4-4). Of these 2.676 adult seals were counted in the Danish Wadden Sea.

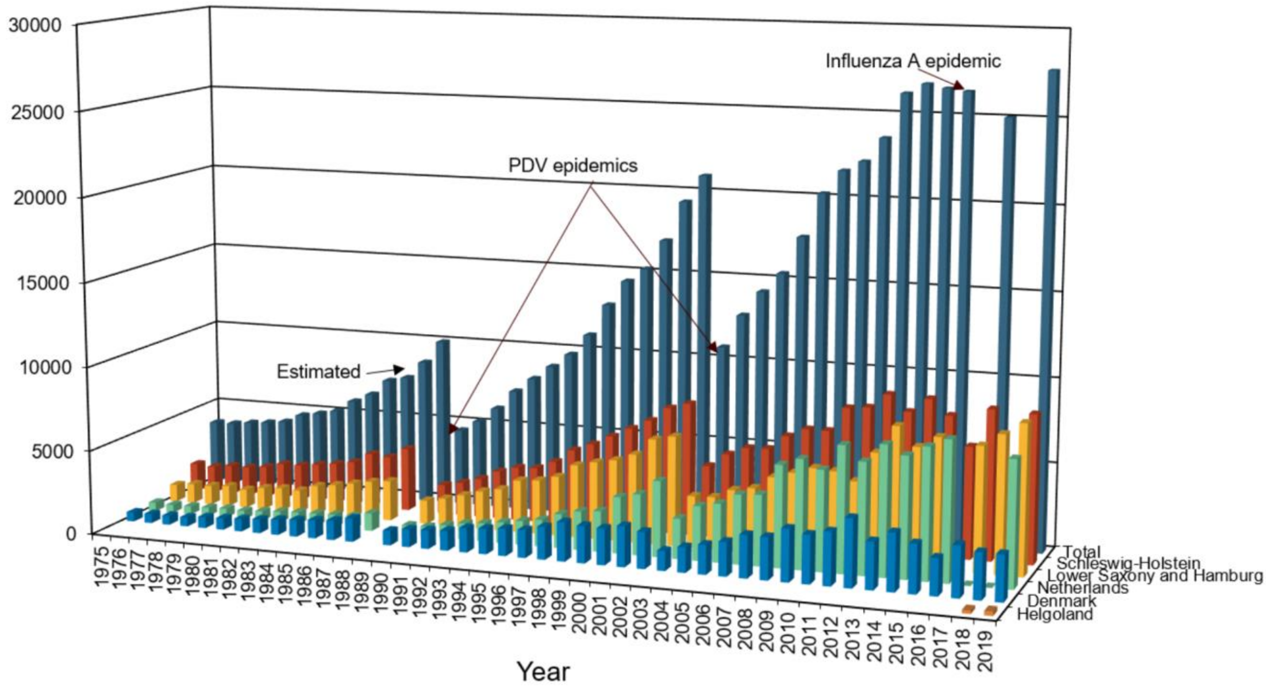

Figure 4-4 Total number of harbour seals counted between 1975 and 2019 in the Wadden Sea areas (source:(Galatius et al. 2019)).

Counts vary greatly between different years and haul out sites, indicating that there is a regular exchange and movement of seals between all Wadden Sea areas, thus this population can be regarded as a single population without distinct subpopulations (Galatius et al. 2019). Combining the counts of the Wadden Sea and the Danish Waters of the Limfjorden and Skagerrak and Kattegat leads to an population estimate of about 40,000 – 45,000 individuals for the Danish North Sea.

4.3 Biology and distribution of the grey seal

The grey seal (*Halichoerus grypus*) is a large seal species which can be found on most coasts of the western Atlantic and in distinct more or less isolated sub-populations e.g., in the North Sea or the Baltic Sea (Klimova et al. 2014, Fietz et al. 2016). Grey seal is, thus a potential visitor in the gross area investigated for the Thor OWF. Adult males reach up to 300 kg body weight and a body length of 2.5 m, while females stay slightly smaller (up to two meters body length) and a maximum of around 190 kg. Grey seals are opportunistic feeders with a wide range of prey species which often includes seabirds as well as harbour porpoises (Jauniaux et al. 2014, Leopold et al. 2015). The fish species which are preyed on include a similar range as that of harbour seals with main contributions of sand eels, flounder, herring and cod, depending on location and season (Thompson et al. 1991, 1996). Grey seals show distinct movement patterns around their haul-out sites but are also capable of long distance trips of up to 2000 km (McConnell et al. 1999). However, this species occurrence in danish waters along the west coast of Jutland is limited to a few individuals, for example a single pup has been documented in 2015 (Jensen et al. 2015). The 2020 grey seals report on the trilateral Wadden Sea counts (cooperation between Denmark, Germany and the Netherlands) reported one pup and 267 adult grey seals in the Danish Wadden Sea (Brasseur et al. 2020). As some individuals of the Wadden Sea population are deemed to be visitors from UK-based populations (Brasseur et al. 2015), and genetic studies show a mixed population of all haul out sites around the North Sea, (Fietz et al. 2016) the Wadden Sea population is not regarded as a separate individual population.

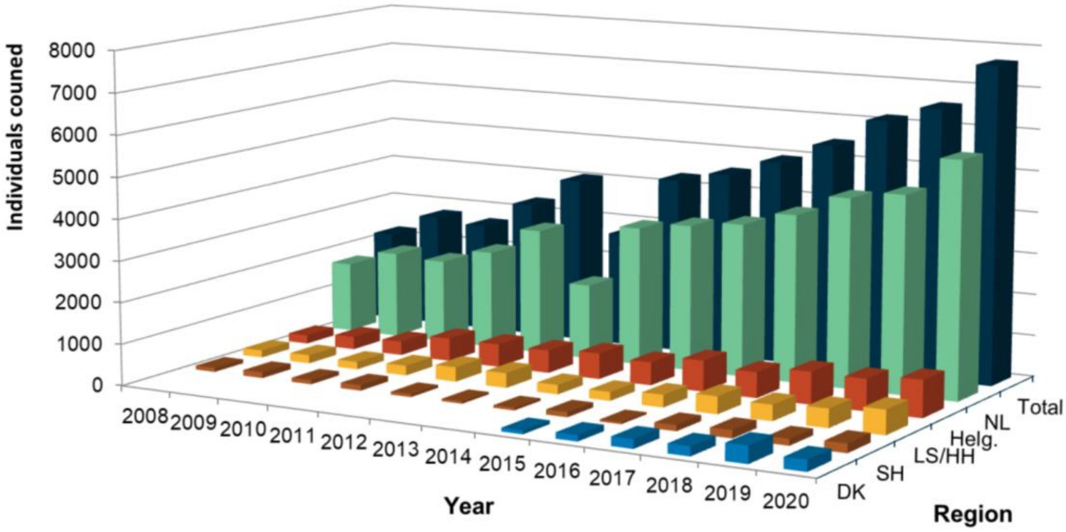

Figure 4-5 Total number of grey seals counted between 2008 and 2020 in the Wadden Sea region of Germany, Denmark and the Netherlands (Brasseur et al. 2020).

5. RESULTS

5.1 Aerial data analysis

5.1.1 Digital flight

During the first flight survey on 18.04.2020, 112 individuals of harbour porpoise were spotted (Figure 5-1). The total abundance in the aerial survey area for the Thor OWF covered by the flight transects was estimated to be 1664 individuals (95% credible intervals at 1299 – 2149 individuals) leading to a mean density of 0.47 individuals/km^2. Population estimated within the boundaries of the gross area for Thor OWF (440 km^2) was estimated to be 463 individuals (95% credible intervals at 357 – 598 individuals) with a slightly higher mean density within the gross area of 1.05 individuals/km^2. Two areas with higher numbers of animals were identified within the gross area of Thor OWF (Figure 5-2).

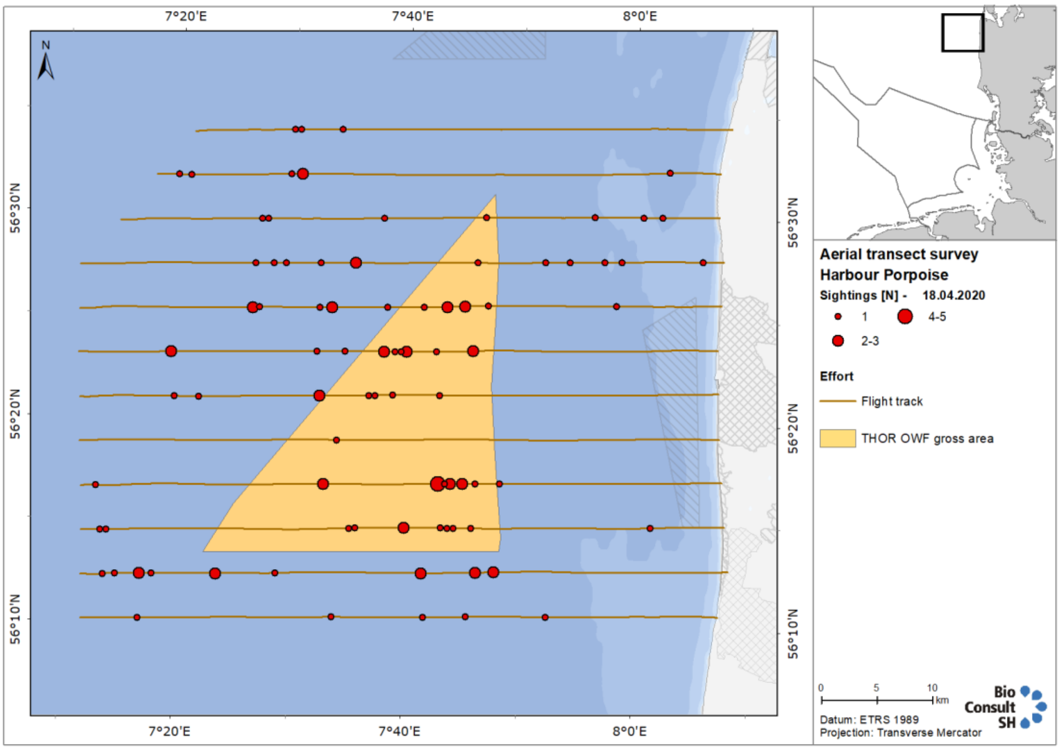

Figure 5-1 Sightings of harbour porpoise during the HiDef flight performed on 18.04.2020. Size of the point indicates size of the group.

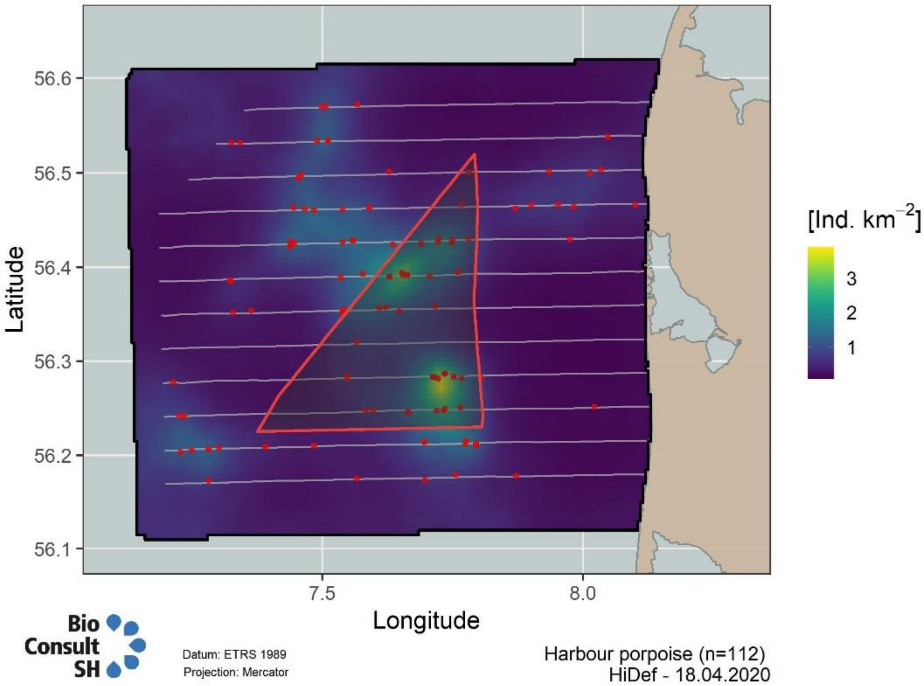

Figure 5-2 Spatial distribution of harbour porpoise showed by the predictive model from the digital flight performed on 18.04.2020. Red dots indicate sighting locations, grey lines indicate flight transects. Red polygon shows the extension of the gross area.

Regarding seals, 3 harbour seals and 18 unidentified seals were observed (Grey/Harbour Seals), and therefore, all sightings were merged into a single category for modelling.

Abundance of seals within the complete prediction area of 3560 km^2 was estimated to be 193 individuals (95% credible intervals at 44 – 285 individuals) and a mean density of 0.05 individuals/km^2. The stimated number of indiviudals within the boundaries of the gross area for Thor OWF was 26 individuals (95% credible intervals at 16 – 41 individuals) with a mean density of 0.06 individuals/km^2 (Figure 5-3 and Figure 5-4). Animals were relatively evenly distributed throughout the aerial survey area. Although slightly higher densities were observed in shallow waters, no significant relationship was found between seal distribution and depth.

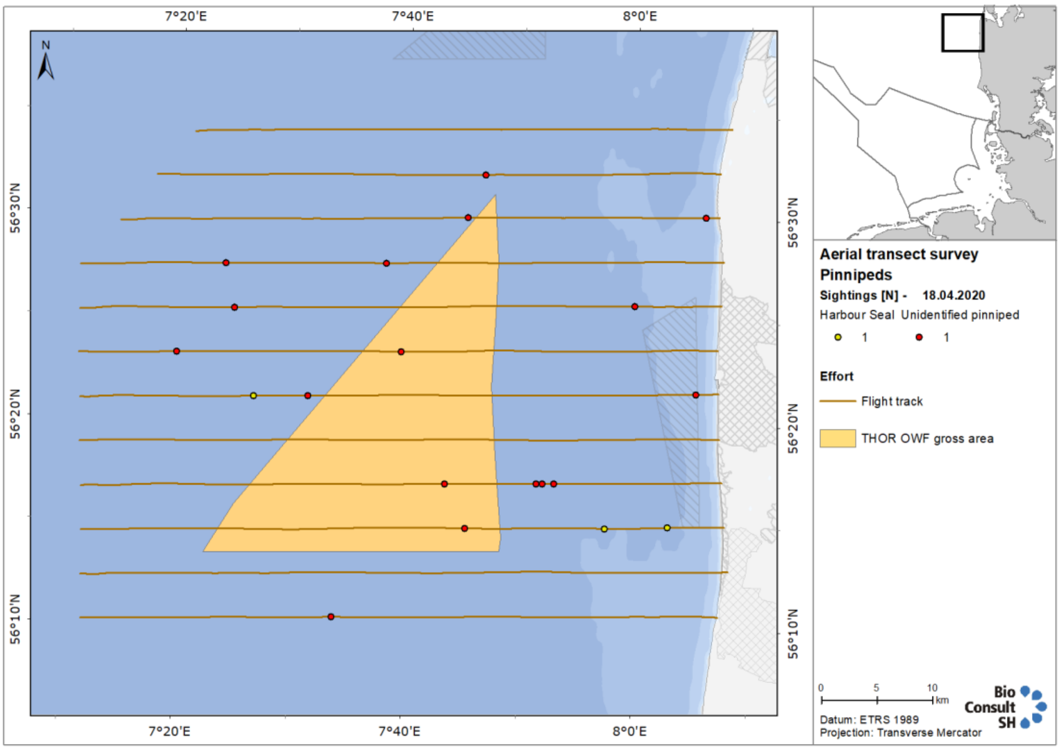

Figure 5-3 Sightings of seals during the HiDef flight performed on 18.04.2020. Only single individuals were observed.

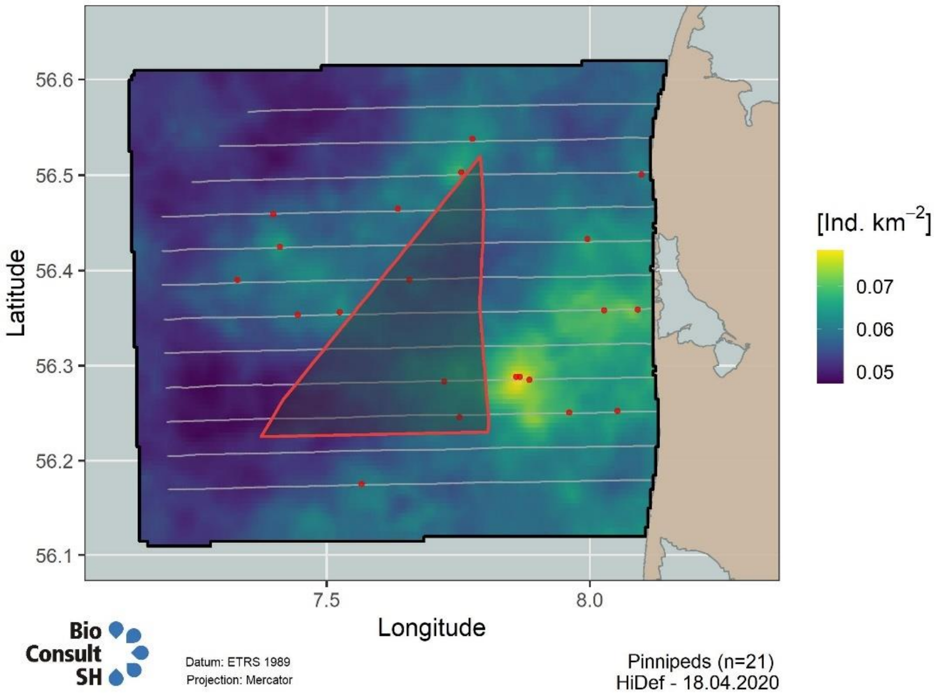

Figure 5-4 Spatial distribution of seal showed by the predictive model from the HiDef flight performed on 18.04.2020. Red dots indicate sighting locations and grey lines indicate flight transects. Black outlines show the prediction area included in the modelling.

5.1.2 Aerial observer data analysis

Observer data was corrected using the distance sampling technique and the half-normal detection function was selected based on AIC (Figure 5-5). The corrections are applied to account for the lower detection probability of individuals which are far away from the orthogonal transect line. The bigger the distance between the transect line and the observation area gets, the lower are the chances to detect an animal. This correction function can be calculated for each flight or for a set of data. Sighting rate was calculated based on detections of the third observer and group size was integrated into the calculations.

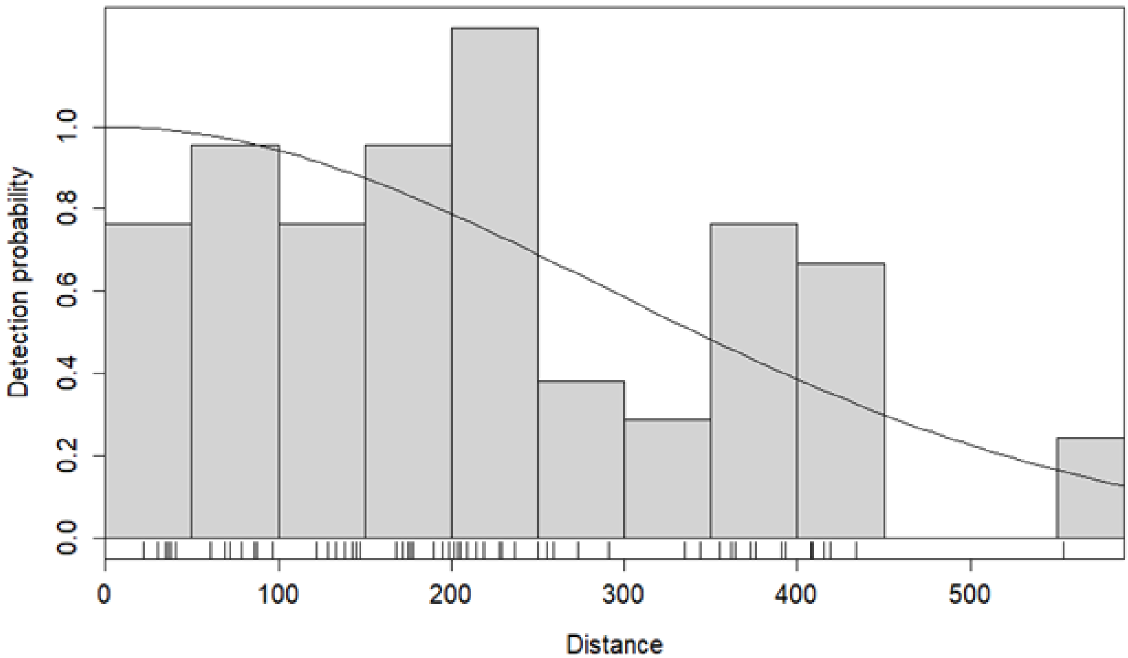

Figure 5-5 **Half-normal detection function calculated for the observer flights.**

A total of 75 porpoises were encountered during the two aerial observer flights by observer one and two under valid conditions (Seastate <3, glare = 0). 40 animals were observed on the flight on the 18.06.2020 and 35 individuals on the 17.08.2020 (Figure 5-6 and Figure 5-7). Individuals were distributed throughout the sampling area with mostly counts of single individuals but also smaller groups of four to seven animals (Figure 5-8). On the first flight in June 2020 five juvenile harbour porpoises were identified and six juveniles on the second flight in August 2020. After applying the availability bias and correction for distance sampling, abundance within the prediction area was estimated to be 1419 individuals on average of both flights (95% credible intervals at 1028 – 2146 individuals). A mean density of 0.41 individuals/km^2 was calculated.

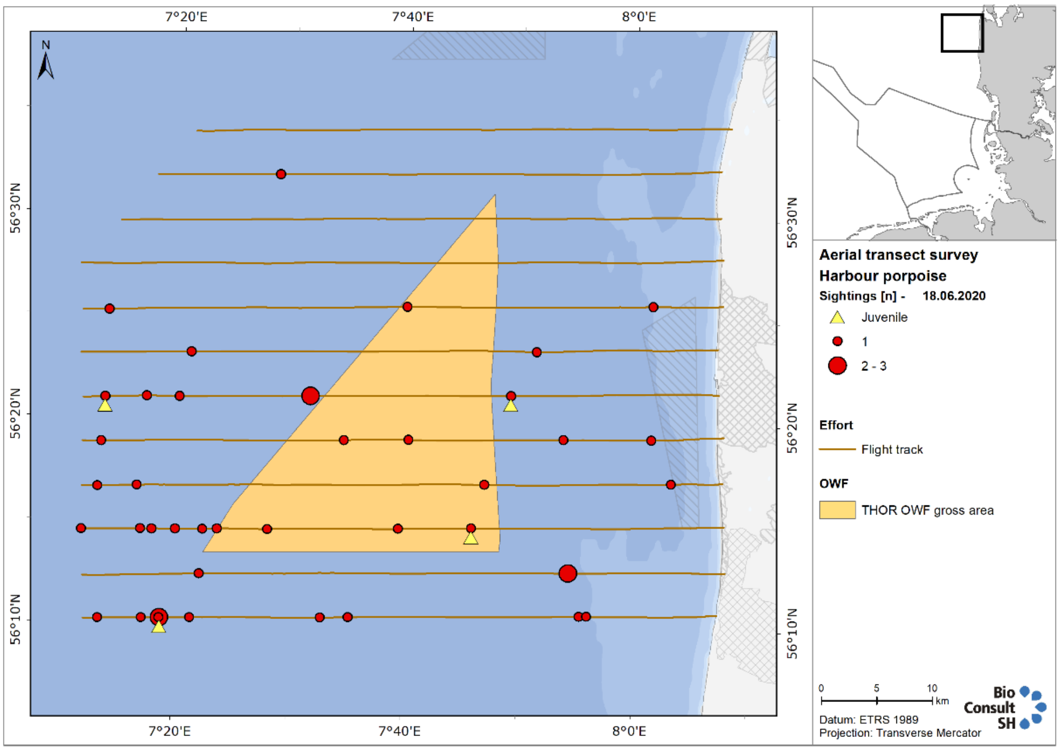

Figure 5-6 Sightings of harbour porpoise during the Observer flight performed on 18.06.2020. Size of the point indicates size of the group.

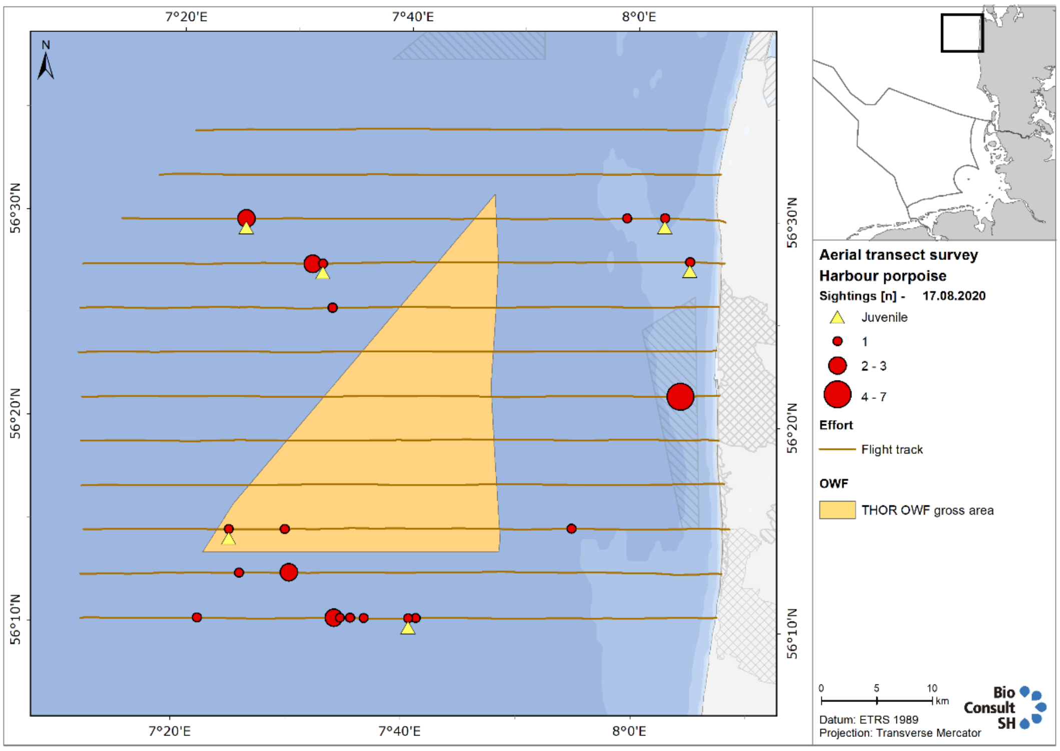

Figure 5-7 Sightings of harbour porpoise during the Observer flight performed on 17.08.2020. Size of the point indicates size of the group.

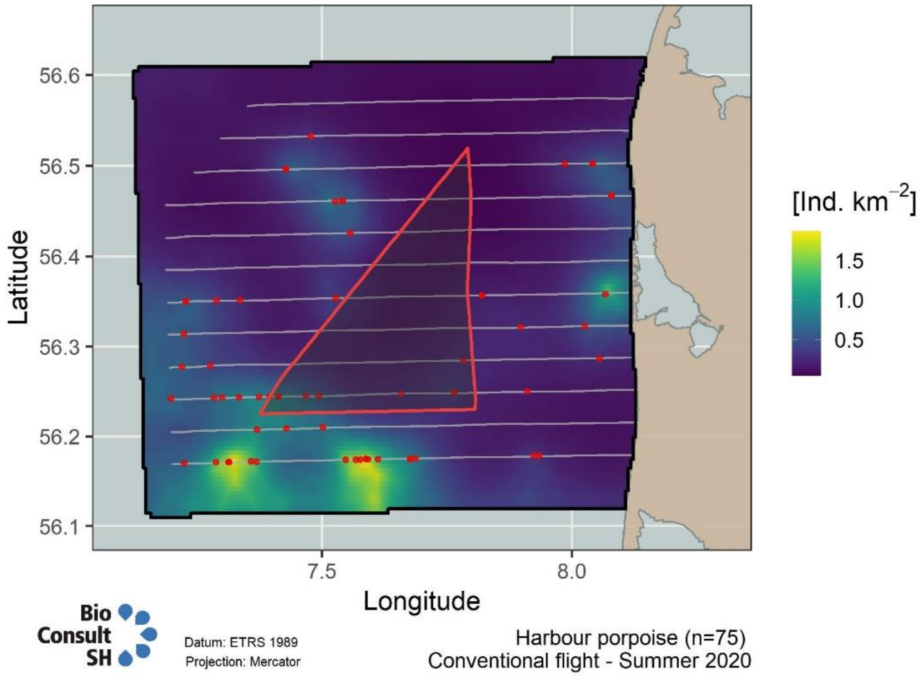

Figure 5-8 Spatial distribution of harbour porpoise showed by the predictive model for the combined data from the two observer flights performed during summer 2020. Red dots indicate sighting locations and grey lines indicate flight transects and grey lines indicate flight transects.

Regarding seals, only 2 individuals were observed under valid conditions, on each flight one individual was observed east of the gross area for the Thor OWF (Figure 5-9, Figure 5-10 and Figure 5-11). Abundance within the prediction area was estimated to 11 individuals on the flight on the 18.06.2020 and 9 individuals on the flight on the 17.08.2020. A mean density of 0.005 individuals/km^2 for the first flight was calculated and 0.003 individuals/km^2 for the second flight.

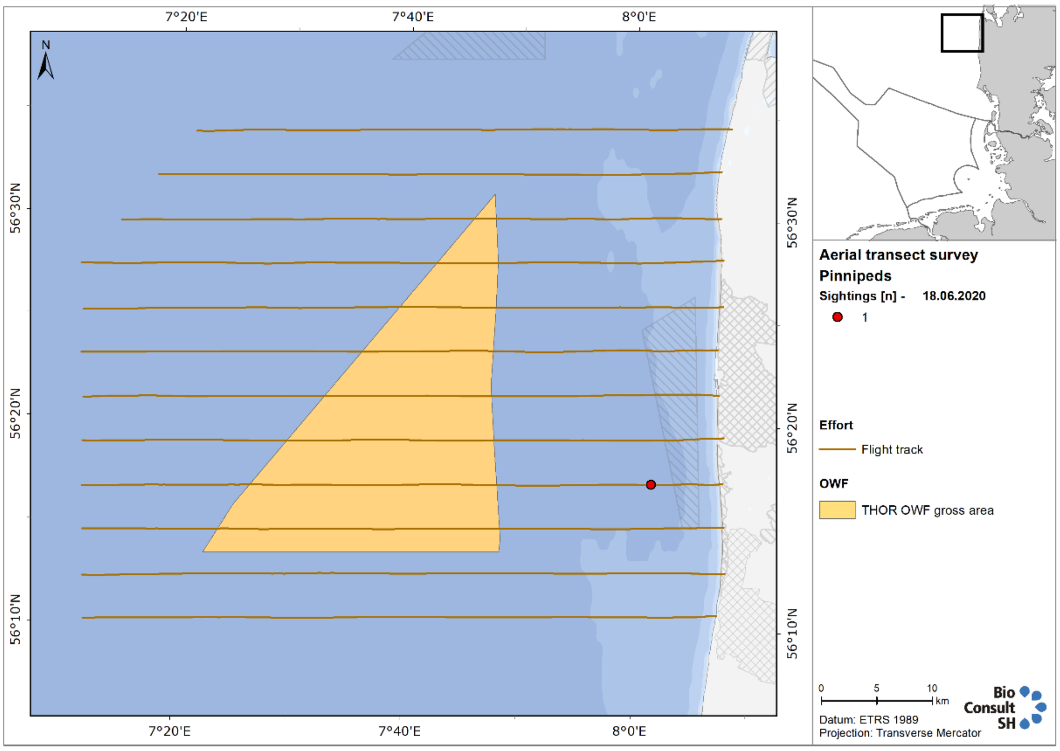

Figure 5-9 Sightings of seals during the Observer flight performed on 18.06.2020. Size of the point indicates size of the group.

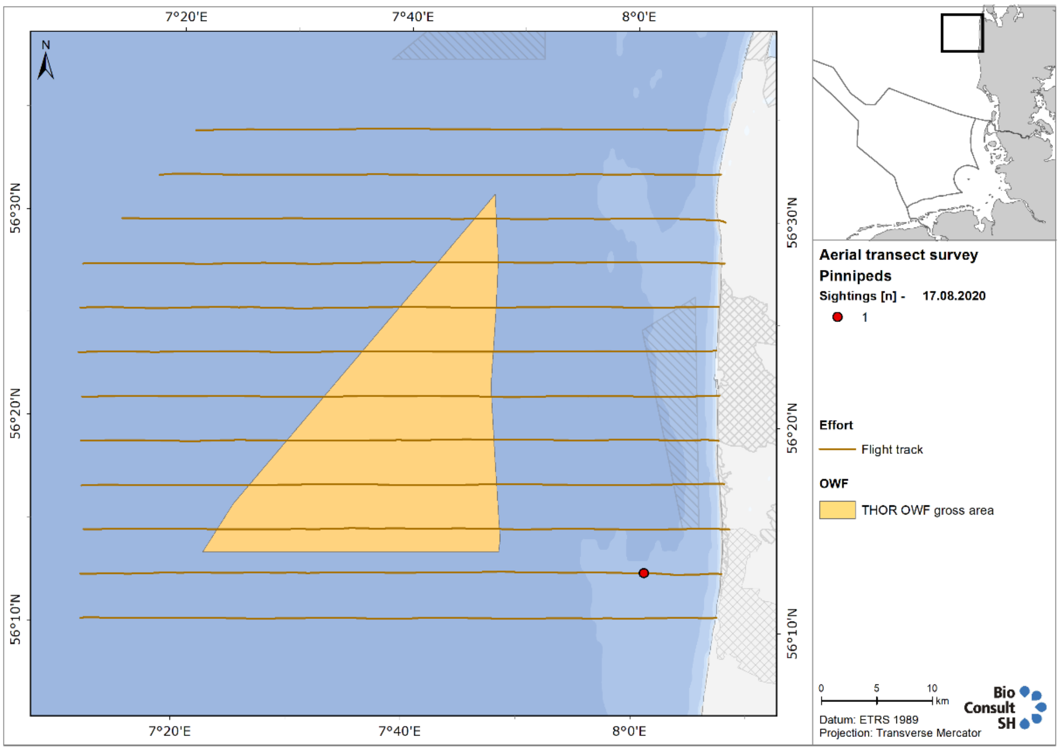

Figure 5-10 Sightings of seals during the Observer flight performed on 17.08.2020. Size of the point indicates size of the group.

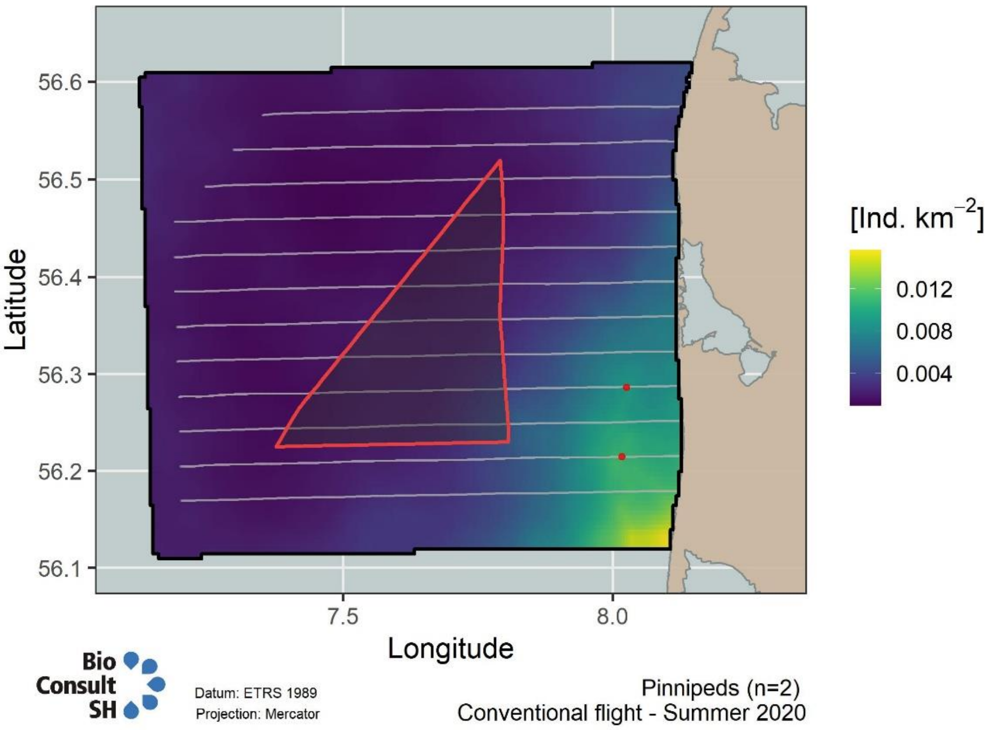

Figure 5-11 Spatial distribution of seals showed by the predictive model for the combined data from the two observer flights performed during summer 2020. Red dots indicate sighting locations and grey lines indicate flight transects, black lines outline the prediction area.

5.2 Passive Acoustic Monitoring (PAM) data analysis

5.2.1 Data exploration

C-POD stations were deployed within the boundaries of the gross area for Thor OWF. Each substation was collecting data during a period of 253 days in average. Overall, each of the 4 C-POD stations was collecting data during the entire period, although some data gaps due to environmental noise were found particularly during the winter season and when vessel activity was high, for example during explorative survey campaigns (Table 5-1 and Figure 5-13). In total, 82.4% of the days were valid and could be used for analysis.

Table 5-1 Deployment and termination dates and number of days in operation by substation.

Station	Substation	Deployment	Termination	Number of days of deployment	Number of valid days
T1	T1_1	20.12.2019	28.11.2020	345	**281**
	T1_2	20.12.2019	28.11.2020	347	**287**
T2	T2_1	27.02.2020	27.11.2020	275	**250**
	T2_2	20.12.2019	27.11.2020	344	**262**
T3	T3_1	20.12.2019	27.11.2020	263	**180**
	T3_2	20.12.2019	31.10.2020	264	**255**
T4	T4_1	20.12.2019	27.11.2020	344	**318**
	T4_2	**27.02.2020**	**27.11.2020**	**275**	**194**

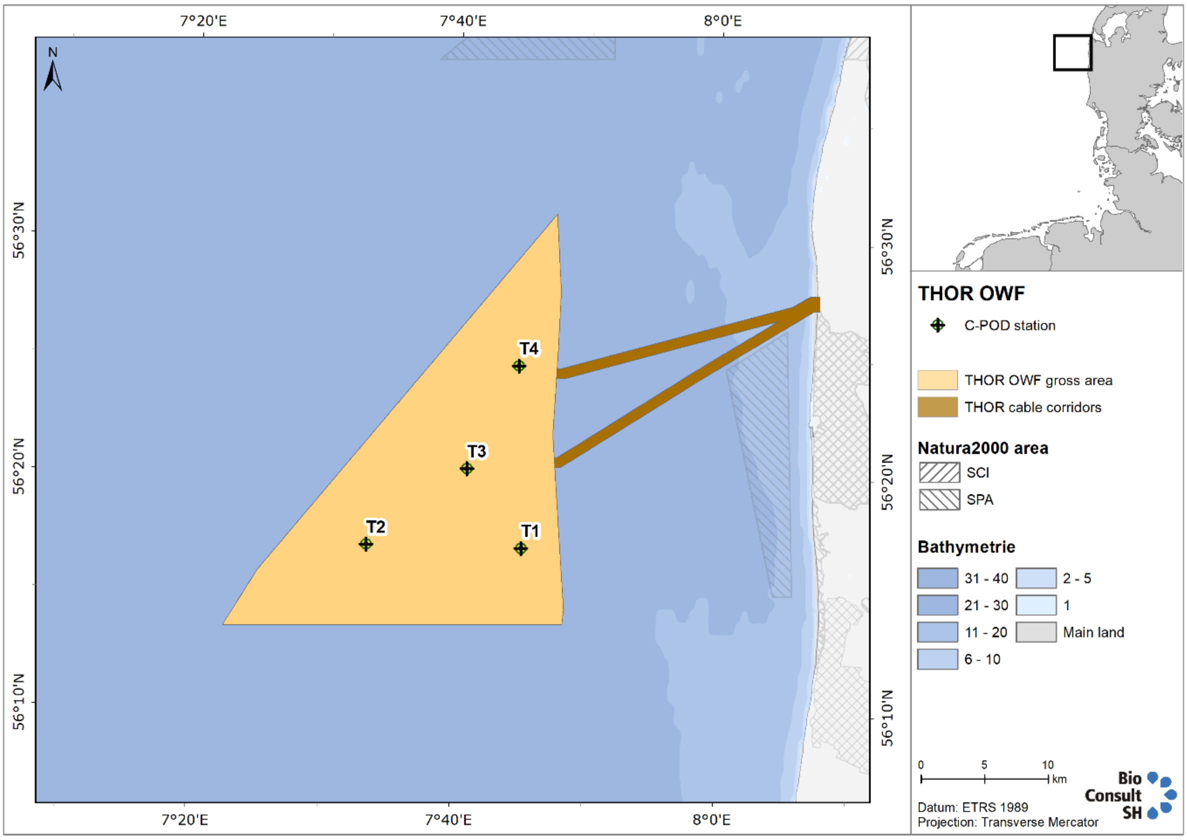

Figure 5-12 Location of the C-PODs stations during the field campaign.

Missing data due to a very noisy environment is presented in Figure 5-13 as black lines, whereas each line represents a single minute which could not be used for analysis. The C-POD stores signals including environmental noise (e.g. ship noise, shifting sediment) in units of single minutes. If the storage for a single minute is full of background noise, the C-POD stops recording for this minute and restarts with the next minute. Thus, times which are very noisy (because e.g., ships are near) cannot be evaluated and have to be excluded from further analysis.

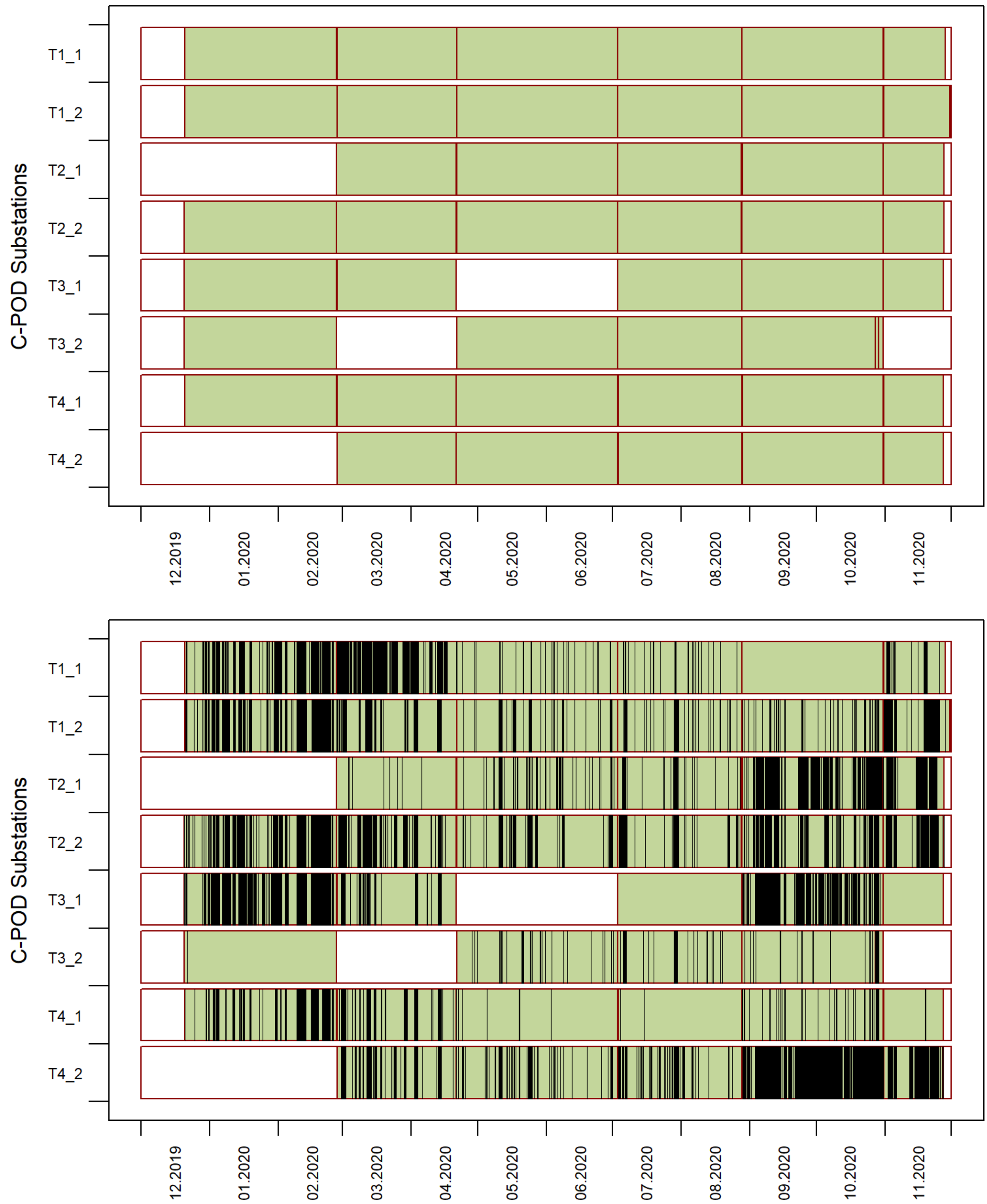

Figure 5-13 Data gaps in the C-POD data due to missing C-PODs (top graph in white) and due to noisy environmental conditions (bottom graph in black).

In average, detection rate (as %DP10M/day) was very similar per station, reaching 7.95% of "detection positive 10-minutes per day" (%DP10M/day Figure 5-14).

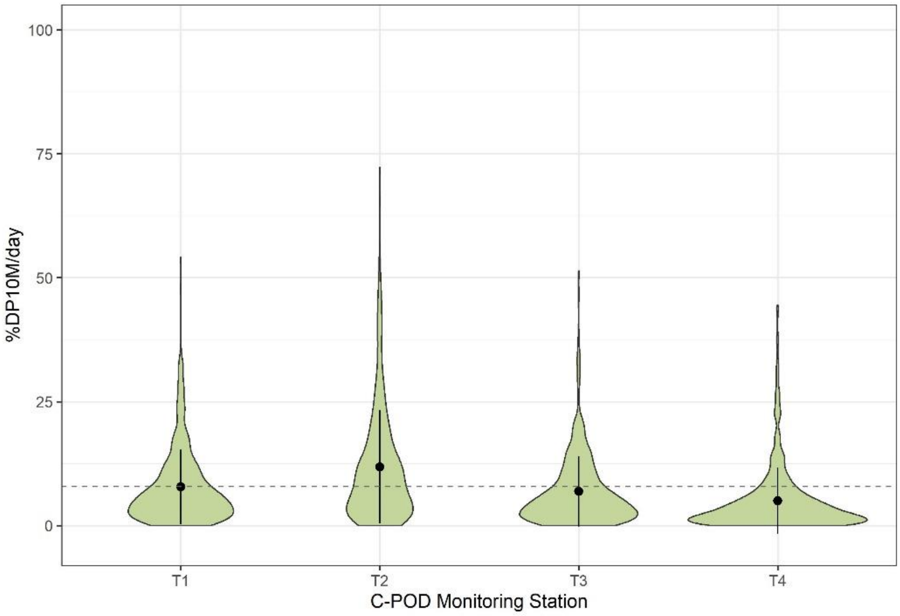

Figure 5-14 **Violin plot showing the distribution of the detection rate (y-axis) per station (x-axis). Detection rate is represented as percentage of positive 10 minutes per day.**

5.2.2 Phenology

Phenology only shows an increase in the detection rate (%DP10M/day) during the spring season in station 2. The rest of the stations show a relatively continuous trend (Figure 5-15) with a permanent by relatively low presence of harbour porpoises. This indicates, that in the south-western part of the area a slightly elevated harbour porpoise activity occurs.

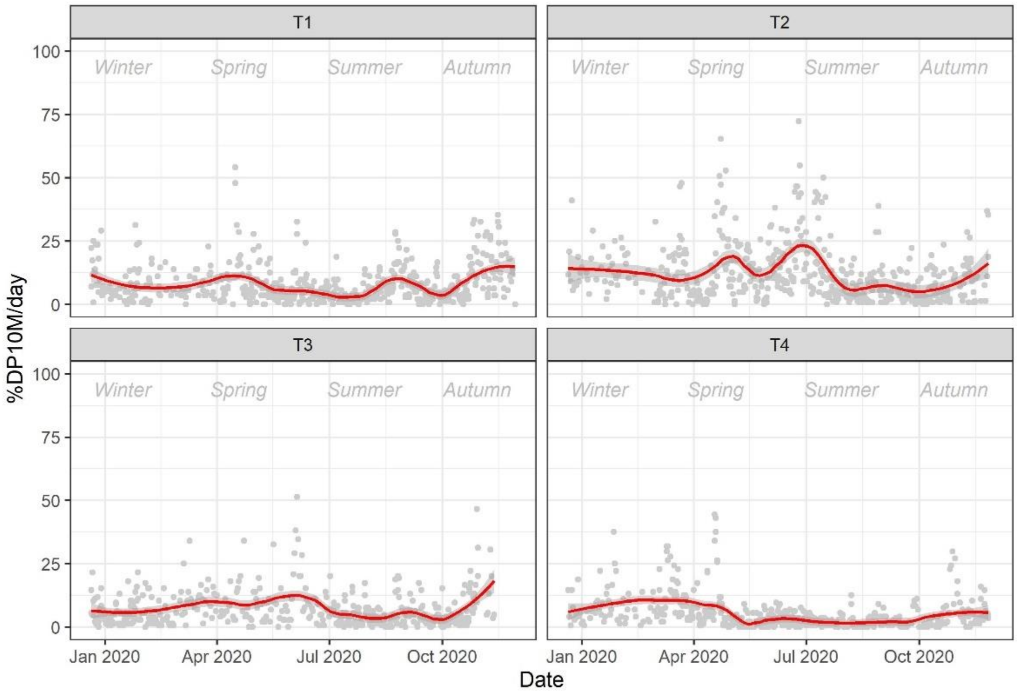

Figure 5-15 **Phenology of the detection rate per station during the full deployment time period of the CPODs obtained by the LOESS method. 95% Interval confidence bands are shown in grey. Detection rate is represented as percentage of positive 10 minutes per day.**

The monthly boxplot shows a relatively even use of the area across the year without distinct peaks or strong seasonal variations (Figure 5-15).

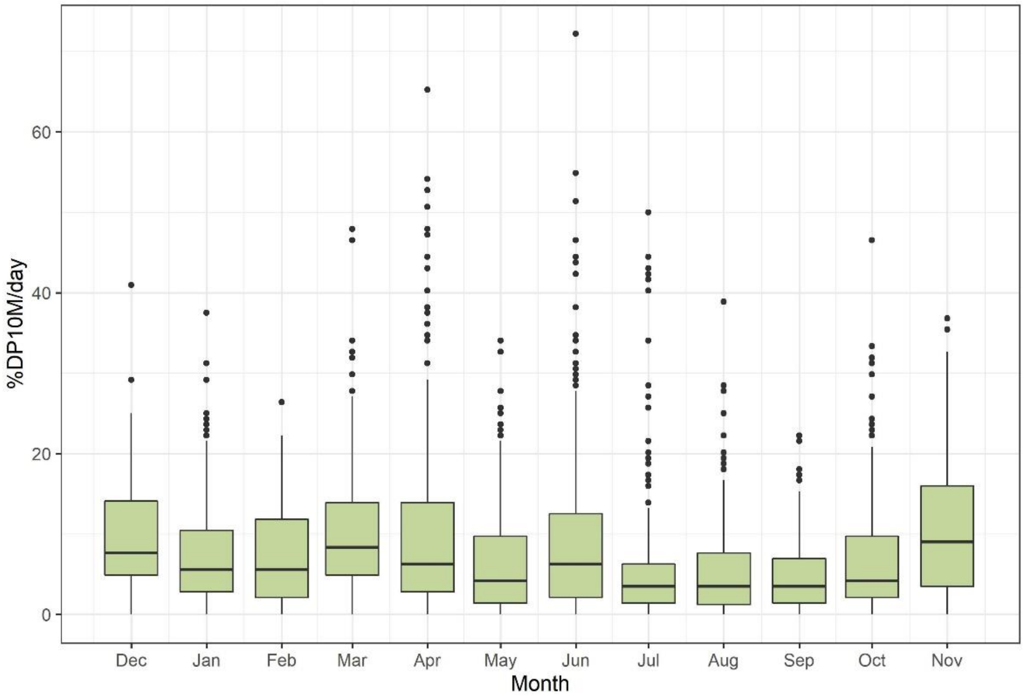

Figure 5-16 Monthly boxplot of harbour porpoise presence in the gross area for Thor OWF.

5.2.3 Interaction between Time of the day and Day of the year

The Gam model shows the relationship between detection rate (%DP10M/day) and the J-day (Julian day, where the first deployment day 20/12-2019 equals day number 1) and time of the day (0-24h) in the period where the C-PODs have been deployed. The colour-scale range from lower-than-average detection rates in blue to higher than average detection rates in yellow (Figure 5-17). The figure illustrates that the time of the day had very little importance, whereas day of the year was of greater importance showing blue zone with few detections in summer and autumn 2020.

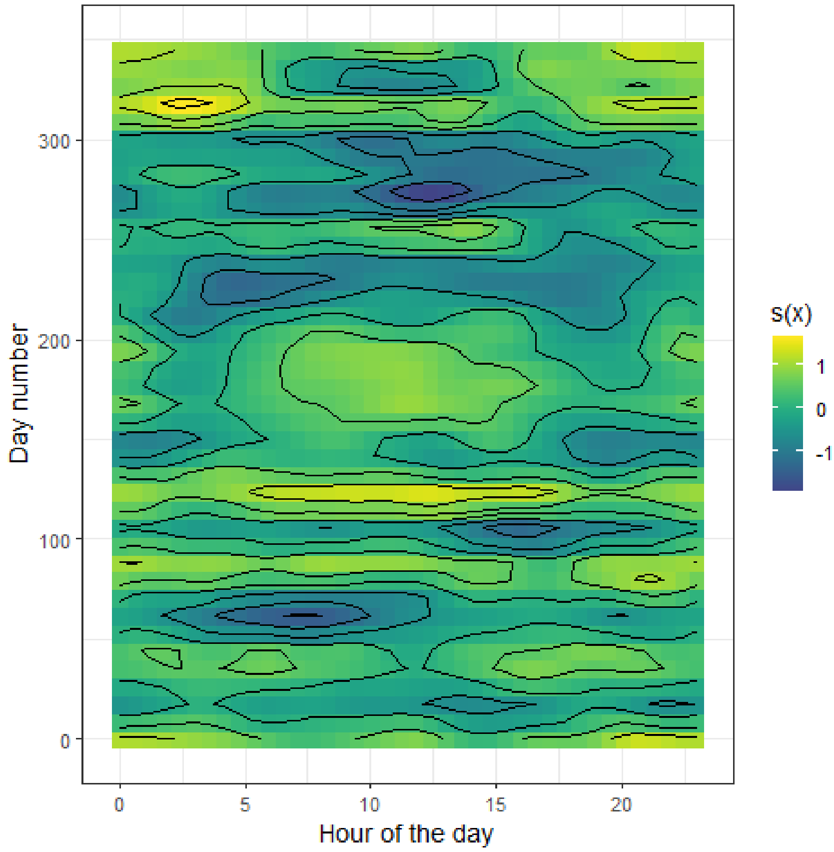

Figure 5-17 Interaction plot from the GAM model between day (counted from the start of the C-POD survey in December 2019) in the y-axis, and hour of the day (x-axis). Yellow shows higher than average detection rates (%DP10M/day) while blue shows lower than average detection rates.

5.2.4 Time series correlation

In total, 272 days met the requirements to perform a time series analysis (complete days with all four stations collecting valid data). Cluster dendrogram calculated from the detection rate time series per station shows significant similar trends for stations T1, T3 and T4, while station T2 exhibits a more independent behaviour (Figure 5-18). This goes along with the above findings, that station 2 shows more activity and more variation throughout the year.

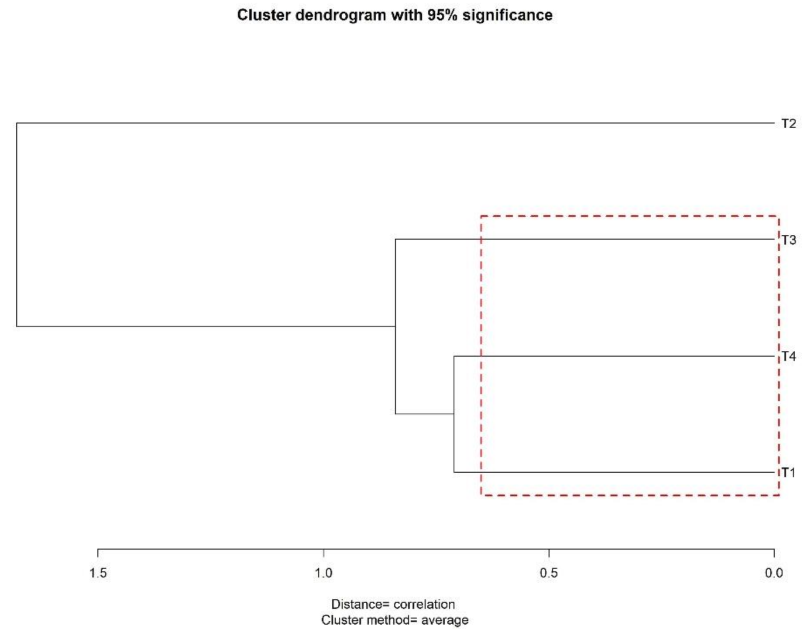

Figure 5-18 Cluster dendrogram showing the significance of the correlation between the temporal trends for each CPOD station. Dashed red line indicates significant (95% significance) clusters.

5.3 Summary

Spatial distribution of porpoises in the survey area did not show any particular spatial pattern or relevant relation with bathymetry based on the data of the three flights. The results are comparable with previous studies performed in the area (Hansen & Høgslund 2019) though densities are in part slightly higher than in earlier findings. The densities of harbour porpoises calculated for the investigation area are between 0.47 individuals per km^2 in April 2020 and a mean of 0,41 individuals per km^2 in June 2020 and August 2020. This is slightly higher compared to the densities found in 2017 and 2018 (2018: 0,38 individuals per km^2 in the Danish stratum Sothern North Sea in late August 2018 (Hansen & Høgslund 2019)) and also higher than densities calculated for the block M during the scans III flight surveys (0,277 Ind/km^2 (Hammond et al. 2017)). The Block M of the scans III surveys covers the area of the Danish and German EEZ and thus the gross area for Thor OWF, but also offshore area with greater water depths and lower harbour porpoise densities. However, the calculated numbers from the surveys of the gross area for Thor OWF lie within the range found in the area between 2011 and 2018. Considering the smaller investigation area compared to the flights by DCE, the estimated number of animals of approximately 1300 in the 2020 survey are still lower compared to the numbers documented in 2014 (08.2020: 1306 individuals in 2488 km^2 compared to 07.2014: 6531 Individuals in 5342 km^2) but higher than in other years. However, the results also suggest a frequent use of the area earlier in the year (including the presence of mother/calf groups e.g., in June 2020).

The spatial distribution derived from the digital and observer's flights show an apparently random and even distribution throughout the surveyed area, with few numerous groups and numerous individual sightings. Results do not allow to infer any spatial pattern or a dependency on an abiotic environmental parameter.

It is worth mentioning that the number of sightings performed by the observer flights is less than those made during the HiDef flight. This is due to the methodological approach in which the digital flights cover a larger area and thus count more individuals. But the resulting densities show comparable animals per km^2 in spring and in summer, as would be expected from published migration dynamics and modelling (Gilles et al. 2016). In addition, the detection rate obtained from the C-POD data does not suggest a lower use of the area during the summer season.

In a similar way, for seals, even if the number of detections was very low (21 sightings during the HiDef flight and 2 combined sightings during the observer flights) and densities are slightly higher in shallower waters, there is not enough evidence to conclude that the species distribution is driven by the bathymetry or marine traffic.

These observations seem to be confirmed by the temporal series of detection rate provided by the four C-POD stations placed within the gross area for Thor OWF. Excluding station T2, the rest of stations did not show any remarkable temporal pattern. On the other hand, station T2 showed an increase in detections during the spring season and an overall slightly elevated activity level. However, elevated vessel traffic for ground investigation in the gross area of the Thor OWF and in parts very close to the C-POD-Stations may be the reason for a temporarily low presence of marine mammals in the assessment area.

Average detection rates (%DP10M/day) among all stations of 9.75% is similar to those found by previous studies in near areas like Horns Rev 3 (Nehls et al. 2014) and slightly higher than found for example during the investigations for the OWF Vesterhav Syd (with an average of 6.74% of detection positive 10-minute intervals or OWF Vesterhav Nord (with 5.97% 10-minute-intervals with harbour porpoise detections (*Vesterhav Nord. EIA - backgound report. ATR09 marine mammals* 2015, *Vesterhav Syd. EIA - background Report. ATR09 marine mammals* 2015). In addition, C-POD data did not show any diurnal trend of the detection rate, although higher positive rates could be observed during the spring season. These findings in combination with findings of previous studies and large scale modelling of the reference population (Figure 5-19 an e.g. Gilles et al. (2016)) indicate a low to moderate importance of the area for harbour porpoises and a very low importance of the area for seals.

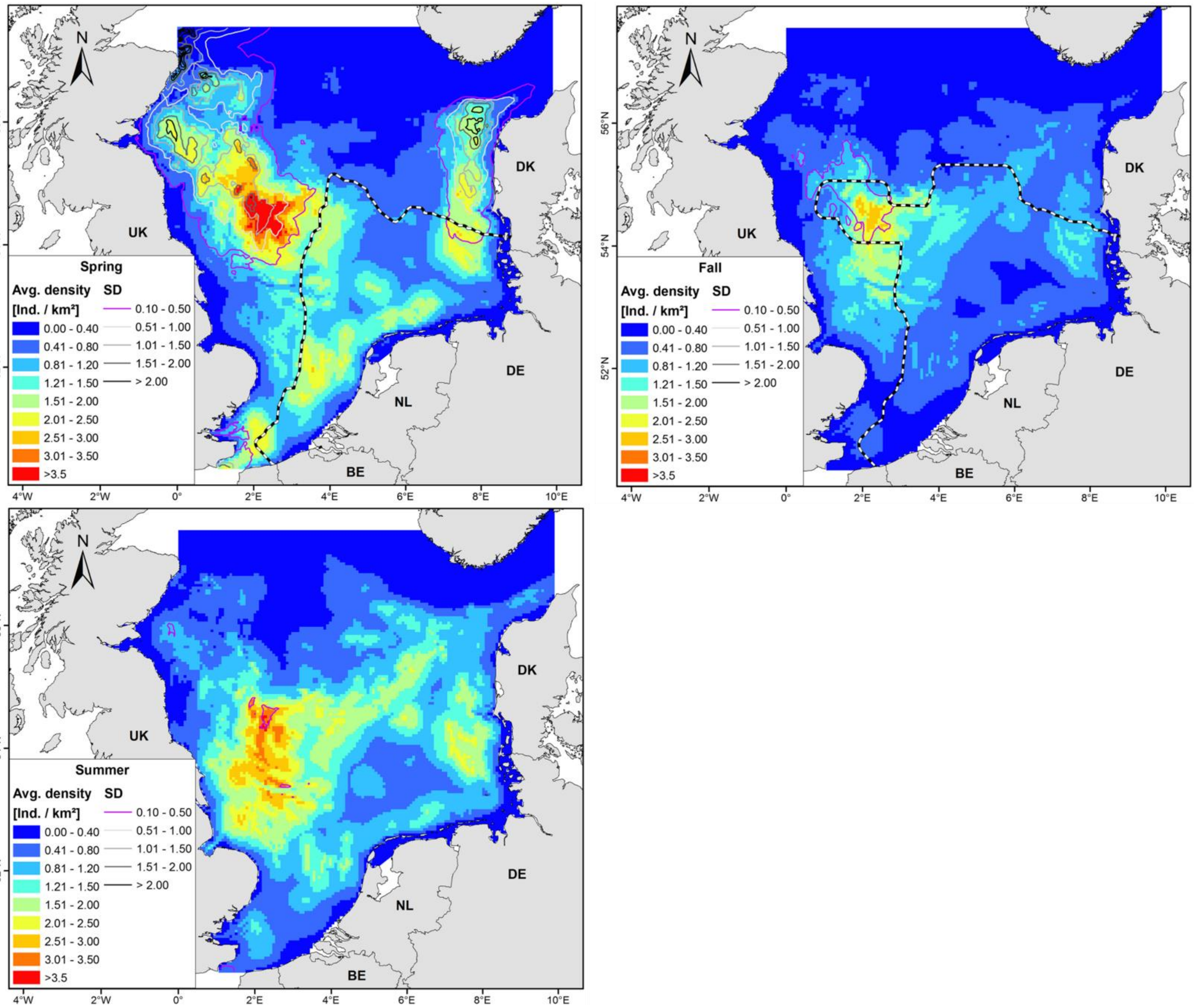

Figure 5-19 **Harbour Porpoise density predictions in the North Sea for spring, summer and fall showing the main concentration areas in these seasons (taken from** (Gilles et al. 2016)**).**

6. SENSITIVITY ANALYSIS

6.1 Method for mapping of baseline conditions

The assessment of the potential effects on marine mammals is based on current knowledge of environmental conditions in and around the gross area for the Thor OWF. Additional field surveys of the marine mammal baseline surveys conducted between 2011 – 2019 (see chapter 4.1) are also considered.

6.2 Method to identify potential impacts

The most likely significant impacts of the plan's implementation and reasonable alternatives are assessed based on the baseline mapping, taking into account the plan's objectives and geographical scope. In this context, an environmental impact is understood to mean a potential conflict between the plan and a given environmental parameter. This can be in the form of conflicts with existing or planned area use within the gross area protection interests or environmental goals. This report assesses potential impacts of the plan on the marine mammals.

The plan does not contain a description of specific installation patterns, turbine types, location of high-voltage stations, etc. and is therefore not a framework for the later specific project but must serve to give the public and responsible authorities an overall impression of which impacts the realization of Thor OWF might cause on the environment. The assessment of potential impacts is therefore carried out at a general level (though assuming a base case for piling activities as laid out in the Thor noise report (ITAP 2020 p. 2020). In a potential later EIA phase, it will be possible to assessed environmental impacts of the specific project and a specific layout of the wind turbines in more detail.

As part of the assessment of the overall extent and significance of the impact, it is considered whether the impact can be reduced by optimization measures or mitigation measures.

6.3 Sensitivity of species present and effects on population level

For the analysis of the potential effects on marine mammals the report focusses on the three main species: harbour porpoises, harbour seals and grey seals. It is assumed that all other species occurring rarely as guests in the area are covered by all measures taken to protect these three species. From these three species the harbour porpoise is seen as the most sensible species since only harbour porpoises rely on their auditory system to detect prey via an echolocating system. Thus, a damage of the auditory system can lead to a short- or long-term starvation of harbor porpoises and thus leads to a violation of article 12 of the Flora-Fauna-Habitats-Directive. Compared to the seal species, the auditory system of porpoises is more sensible to effects of harmful noise (e.g., by having a lower threshold level to experience short- or long-term hearing losses), thus all measures to protect harbour porpoises do also include the protection of seal species.

Effects on population levels are difficult to assess and different approaches have been tested including a certain number of individuals that can be removed from a population before an effect occurs (the potential biological removal figure PBR) or an iPCoD model (Interim Population Consequences of Disturbance (Nabe-Nielsen & Harwood 2016)). The most straight forward index however is the 1%-criterion, which is used to assess how many individuals of a population unit are affected. If the affected percentage is higher as one percent this is assumed to be a high level of impact with negative consequences on a population level. An assumed population size of 345.373 individuals would thus experience negative effects if 3354 animals are affected.
For harbour seals it is not known whether animals occurring in the construction area are coming from the colonies in Limfjorden or belong to a colony of the Wadden Sea. Telemetry studies have

shown, that especially younger seals conduct foraging trips of several weeks leading from their place of tagging in the Danish Wadden Sea south of Esbjerg north west, as well along the coast as through open waters (Tougaard et al. 2003). Thus, occurrence of seals from the Danish Wadden Sea in the gross area for the Thor OWF is likely. It is thus assumed that the relevant population size is a combination of the Wadden Sea individuals and the Limfjorden individuals leading to approximately 42.000 animals. This corresponds not only with the 2019 numbers given above but also to earlier estimates from recent reports of the Trilateral Seal Expert Group (TSEG). Thus 420 negatively affects harbour seals would be enough to reach the 1%-criterion.

6.4 Impact of underwater noise

Pile driving is in general seen as the main source of potential harmful underwater noise (Bailey et al. 2010, Tougaard et al. 2012, Skjellerup et al. 2015, Aarts et al. 2018, Rose et al. 2019). A single hammer blow or a series of blows have the potential to elicit injuries in the auditory tissue of mammals and thus impair their hearing ability and (in species relying on their auditory system to hunt for prey) their ability to identify and locate prey. The thresholds of onset of behavioral changes and of a reversible or non-reversible damage (temporal / permanent threshold shift TTS/PTS) have been topics of investigations in harbour porpoises and seals for the last 15 years ((Southall et al. 2007, 2019, Lucke et al. 2008, 2009, Tougaard et al. 2009, 2012, Dähne et al. 2014, Skjellerup et al. 2015, Russell et al. 2016). Nevertheless, a range of weighted and unweighted threshold values has been used in assessments in the last years. For the impacts of pile driving in this report data and threshold values from itap GmbH (ITAP 2020) given in Figure 6-1 are used though these values and their correct calculation and weighting is under discussion (Mikaelsen 2015, Tougaard et al. 2015, Tougaard & Dähne 2017, Tougaard & Michaelsen 2018, 2020).

6.5 Potential impacts and sensitivity of marine mammals

In the following potential impacts of the planned Thor OWF and cable corridors for marine mammals are assessed. The Danish Energy Agency has prepared a scoping report, which determines which environmental issues are to be included in a later SEA and at what level they are to be assessed (Energistyrelsen, 2020). In the delimitation report, the environmental issues that are likely to be affected by the implementation of the offshore wind farms are identified. This initial assessment deals with the potential sources of impacts at an overall level, as the expected impacts will depend on the specific project including choice of turbine types and number, the locations for the individual turbines, foundation methods, etc.

The potential effects on marine mammals caused by the establishment of Thor OWF and the relevant project phases are:

- Disturbance, reversible and/or permanent threshold shifts in marine mammals during piling (and to a lesser extend during decommissioning)

Minor impacts are:

- Disturbance caused by vessel traffic
- Disturbance cause by suspended sediments during cable laying
- Permanent habitat loss by footprint of foundations
- Temporary habitat loss (scour protection, cable protection and construction activities)
- Habitat change

The degree of impact ranks impacts in three levels (“high”, “medium” and “low”) whereas impacts leading to a potential injury of animals is always ranked in the category “high” while effects leading to disturbance or behavioural changes can be ranked between "high" and "low" depending on the number of affected animals, the sensitivity of animals and a potential effect on population level.

As pointed out above, effects with major impact on marine mammals are expected during the construction phase especially during piling of offshore foundations. Though additional noise by emissions from the turbines during the operational phase can be measured, these emissions are at very low frequencies and of low energy and thus have very short ranges. Because the emitted frequencies are mostly in the lower Hz range, they are more relevant to larger, low-frequency marine mammals (Marmo et al. 2013). Studies could show, that harbour porpoises return to windfarm areas after the construction period and occur to the same extend within the windfarms as outside, with effects of piling lasting from a few hours up to several days (Nabe-Nielsen et al. n.d., Brandt et al. 2018, Rose et al. 2019). In addition, earlier studies show that offshore wind farms might provide a valuable habitat due the exclusion of fishing activities and species richness due to the artificial structures as stony reefs and vertical piles (Andersson & Öhman 2010). Compared to the potentially positive effects of the new structures and the overall size of the marine mammal's habitat, the habitat loss due to the footprints of the scour-protection or the monopile itself is neglectable. Disturbance by vessel traffic can have a negative effect on marine mammals, especially on harbour porpoises. It has been shown, that harbour porpoises react to an approaching vessel with either a reduction of vocalisation and a reduction of activity or fleeing (Wisniewska et al. 2018, Roberts et al. 2019). Thus, vessel traffic should be carefully assessed and managed, and measure taken e.g., to reduce vessel speed or channel the traffic on regular lanes. Sediment spill and thus reduced visibility in water is not regarded as a major effect because all marine mammal species have the option to avoid areas with high levels of dissolved sediments or orientate using their acoustic senses. Harbour porpoises and seals are adapted to life in coastal waters and are able to locate prey at low visibility (Dehnhardt et al. 2001, 2003, Verfuß et al. 2009). Harbour porpoises have shown that they not only use their echolocation to identify prey objects and home in on these, but also use their echolocation for spatial orientation and for identifying objects as landmarks (Verfuß et al. 2005).

The focus in this assessment thus lies on the only major negative effect of the construction period:

To assess the range of potential injuries or disturbance and the number of affected individuals the range of the threshold criteria given in the Underwater Noise Report are translated into affected areas and affected number animals is calculated. Disturbance is included because this is a stressor leading to behavioural changes as leaving an optimal habitat or reducing the hunt for food and the nutritional status of animals (effects are modelled e.g. Nabe Nielsen et al (Nabe-Nielsen et al. 2014, 2018, n.d.). This eventually leads to animals in a reduced physical state, reduced reproduction rates and can thus have effects on the population level. A graphical example taken from a virtual position from the Underwater Noise report (ITAP 2020) of the affected area for seals and harbour porpoise is shown in Figure 6-2 and Figure 6-3. Values for the range of threshold noise criteria are taken as well from the Underwater Noise Report for the Thor OWF gross area as shown in Figure 6-1 (ITAP 2020). For eliciting a PTS or TTS a cumulative sound exposure level SELcum) is used, assuming a noise dose which a marine mammal receives during a complete piling event. For disturbance, a sound exposure level (SEL) of a single hammer blow is used to calculate the impact range. This leads to very similar impact ranges for TTS and disturbance.

Receptor	Impact type	Metric	Fleeing speed [m/s]	Criteria [dB]	Range [km]
HP	PTS	SEL_{cum}	1,5	190	16.017
HP	TTS	SEL_{cum}	1,5	175	49.947
HP	Disturbance	SEL		140	48.183
Seal	PTS	SEL_{cum}	1,5	200	2.953
Seal	TTS	SEL_{cum}	1,5	176	47.344
Seal	Disturbance	SEL		142	43.303

Figure 6-1 Impact ranges (km) for harbour porpoises (HP) and seals for receiving PTS, TTS or eliciting behavioural responses ((ITAP 2020)

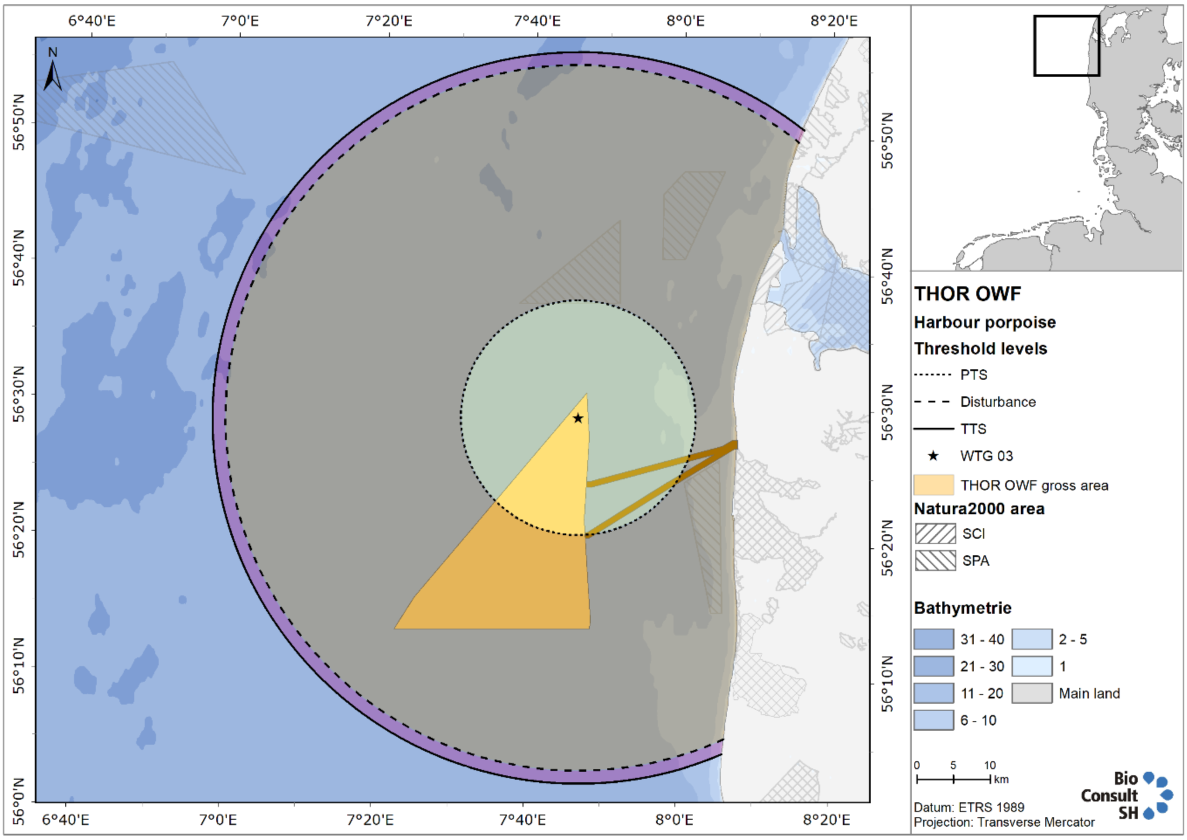

Figure 6-2 Effect ranges and area covered by the noise radii when piling a monopile (13 m diameter) a location WTG 03 in the northern part of the gross area for Thor OWF for PTS, TTS and Disturbance for harbour porpoises

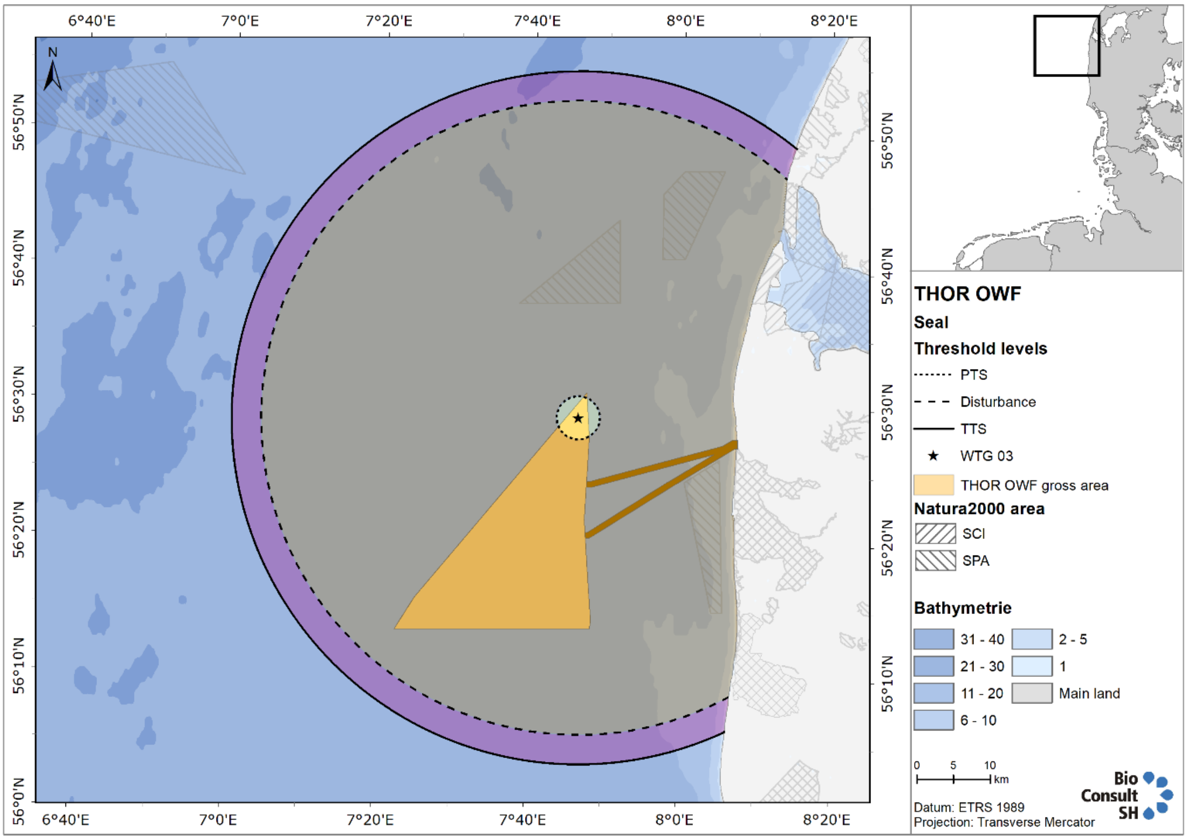

Figure 6-3 Effect ranges and area covered by the noise radii for PTS, TTS and Disturbance for seals when piling a monopile (13 m diameter) at location WTG 03 in the northern part of the gross area for Thor OWF

The effect ranges in which harbour porpoises and seals potentially experience PTS are covering an area of 806 km^2 for harbour porpoises and 27.4 km^2 for seals.

Table 6-1 Effect ranges, areas and threshold levels based on the underwater noise modelling.

Species	Impact	Distance	Area
Harbour Porpoise	PTS	16.2 km	805.96 km^2
Harbour Porpoise	TTS	49.95 km	6164.46 km^2
Harbour Porpoise	Disturbance	48.18 km	5798.57 km^2
Seals	PTS	2.95 km	27.38 km^2
Seals	TTS	47.34 km	5628.18 km^2
Seals	Disturbance	43.3 km	4839.9 km^2

The densities of harbour porpoises calculated for the investigation area are lying between 0.47 individuals per km^2 in Spring 2020 and 0.41 individuals per km ^{2} in Summer 2020. This is slightly higher compared to the densities found in earlier years (2018: 0,38 individuals per km^2 in the Danish area Southern North Sea in late August 2018 (Hansen & Høgslund 2019)). This is also higher than densities calculated for the block M (the area covering the Danish and German EEZ and thus including the Thor gross area) during the scans III flight surveys (0,277 Ind/km^2 (Hammond et al. 2017)). However, the finding of this study for the Thor OWF gross area lie within the range of former counts between 2011 and 2019 (compare chapter 4.1).

Seal densities reach maximum densities of 0,05 Ind/km^2 pooled for both species present in the area in spring 2020 and 0.005 Ind/km^2 pooled for both species in summer 2020. Based on the very low and random counts of grey seals, the estimated population size of 42.000 harbour seals is used as size of the biogeographical population.

Table 6-2 gives an overview of the affected number of individuals and percentage of the total biogeographical population as an indicator for the effect level for PTS, TTS and Disturbance. As a conservative approach the higher density from Summer 2020 is used for the calculation for harbour porpoises and from Spring 2020 for seals. The densities calculated for June 2020 for harbour porpoises are high compared to earlier findings, thus the number of affected individuals is most likely lower than given in Table 6-2. Also, the densities used for the estimates of affected seals in spring is high, so the number of affected animals is most likely lower as given in this conservative approach.

Table 6-2 Effect areas, affected number of individuals and affected percentage of the population per species and impact.

Species	Impact	Area (km$^{2)}$	Ind/km^2	Affected individuals	Population size	Affected population (%)
HP	PTS	805.96	0.47	379	345.373	**0.11**
HP	TTS	6164.46	0.47	2897	345.373	**0.84**
HP	Disturbance	5798.57	0.47	2725	345.373	**0.79**
Seals	PTS	27.38	0.05	1	42.000	**0.003**
Seals	TTS	5628.18	0.05	281	42.000	**0.7**
Seals	Disturbance	4839.9	0.05	242	42.000	**0.6**

Based on the calculation in Table 6-2 a piling event under the prerequisites given in the underwater noise modelling (e.g., a monopile with 13m diameter and a maximum blow energy of 3000kJ and no noise mitigation) would not cause PTS on more than one percent of the population of harbour porpoises and seals. However, the number of harbour porpoises eventually experiencing PTS is calculated to be up to 379 individuals and virtually all porpoises in the investigation area can be affected by TTS or at least disturbance. Under these assumptions up to 1.6% of the population receive a TTS or are disturbed by piling noise. Due to the very low number of seals in the area, seals are at very low risk of experiencing PTS, but are affected by potential TTS or disturbance. The options to reduce the proportion of affected individuals by applying mitigation measures are described in chapter 6.7.

6.6 Natura2000 and Species protection

East and north of the gross area for the Thor OWF are three Natura 2000 sites located which list as species from Article 4 of directive 2009/147/EC and Annex II of the habitats directive 92/43/EEC the harbour porpoise as present (but not seals), namely "Thyborøn Stenvolde" (DK00VA348, Habitat-area H256), "Sandbanker ud for Thyborøn" (DK00VA340, Habitat-area H253) and "Sandbanker ud for Thorsminde" (DK00VA341, Habitat-area H220) Figure 6-4.

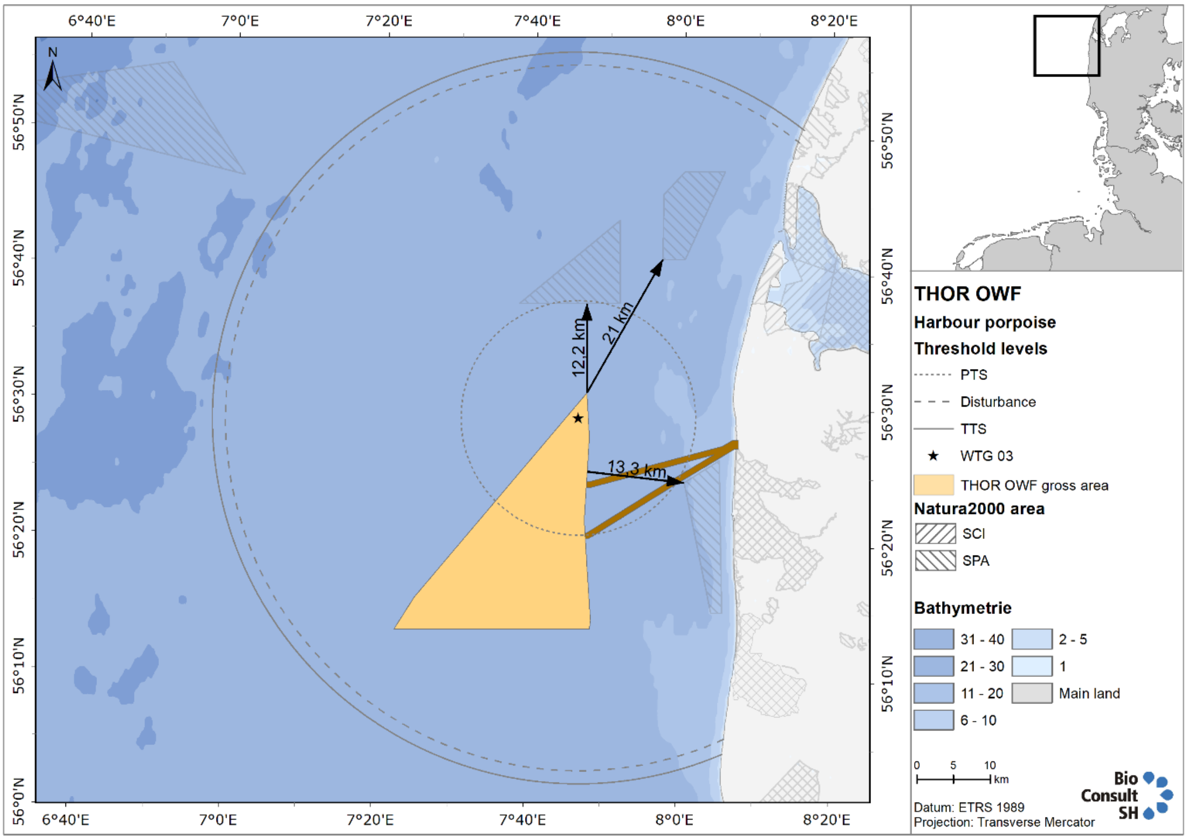

Figure 6-4 The Natura2000 sites affected by noise impact during piling of offshore substations and their shortest distance to the gross area for Thor OWF.

These sites are indexed as Special Areas for Conservation and Sites of Community importance and potentially lie in the impact range of piling activities (compare Figure 6-2 and Figure 6-3). With the parameters chosen for the underwater noise modelling (ITAP 2020), all three areas are covered by the noise contours for TTS and disturbance for harbour porpoise if no mitigation measures are implemented during piling of monopiles in the gross area for Thor OWF.

6.7 Site Optimisation and Mitigation Measures

As shown above, the assessment area is regularly visited by marine mammals, especially harbour porpoises throughout the year without a reasonable gradient showing harbour porpoise preference for a specific site or distance to the coast. The overall importance of the area is deemed to be low to intermediate. The only impact of the category high is occurring due to piling activities, an impact that is limited in time. Because the radii modelled under the given constraints are large, an optimisation of the area would not lead to a reduced number of affected animals. Thus mitigation measures leading to less noise can be a tool to reduce the area in which animals are affected by noise levels to a great extent (BioConsult SH et al. 2019 p. 2).
A reduction of hammer energy or pile diameter compared to the assumptions taken in the underwater noise report is assessed to lead to a reduction in affected animals as well as the use of a bubble curtain or acoustic deterrence devices (e.g., SealScarer or FaunaGuard) to deter individuals from the immediate vicinity of the source should be taken into consideration.
Depending on pile diameter, water currents, water depth and used construction vessels several options for the technical sound attenuation are possible from which bubble curtains, hydrosound dampers and near-pile systems are commercially proven and have been in used for multiple projects. An evaluation of the systems used so far and their effectiveness is given by Bellmann and colleagues (Bellmann et al. 2020)from which the following details ca be concluded

1) Single/double bubble curtains (sBBC, dBBC): Bubble curtains are effective when used in water depths of less than 40m and at low water current. At water depth of around 25m single bubble curtains reach an attenuation of 11-15dB, while double bubble curtains reach at the same water depth twice the attenuation of 14-18dB.
2) HydroSoundDamper (HSD): the HSD has been used in project with water depth up to 40m and reached attenuation values of 11-12dB. The HSD can be combined with a BBC or dBBC and then reaches an attenuation of 15-20dB
3) Near-Pile IHC Noise mitigation screen (NMS): The NMS is combined with a gripper and upending tool, thus providing the installation hardware as well as a mitigation system. The NMS attenuates the source level by 13-17dB, in combinations with bubble curtains up to 23dB.

Depending on the source level and the technical set-up, these systems have the capability to substantially reduce the noise which is emitted into the environment. However, their use can be limited by strong currents and technical details. A thorough evaluation should be performed when foundation type and construction details are assessed and decided upon.

6.8 Knowledge GAP

Existing long-term data of the marine mammal distribution in the North Sea in combination with the 2019/2020 field work for the Thor OWF area provides a solid and sufficient database for the initial impact assessment for marine mammals. The option to compare findings with flight data from 2011 to 2019 and with investigations for near-by areas for offshore wind farms provides sufficient information, thus knowledge gaps for the context of this technical report could not be identified.

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