Marine Mammal surveys – pre-investigations for offshore wind farms in the area North Sea I

Marine mammals

Energinet Eltransmission A/S

Date: 13. November 2024

Contents

List of key terms....7
1. Introduction and objectives....8
1.1 Survey area....8
2. Existing data and knowledge....10
2.1 Cetaceans....10
2.1.1 Harbour porpoises....10
2.1.1.1 Vulnerable periods for harbour porpoises in the North Sea....11
2.1.2 White-beaked dolphins....12
2.1.2.1 Vulnerable periods for white beaked dolphins in the North Sea....12
2.1.3 Minke whales....12
2.1.3.1 Vulnerable periods for minke whales in the North Sea....13
2.2 Seals....14
2.2.1 Harbour seals....14
2.2.2 Grey seals....20
2.2.3 Seal usage of the North Sea I area from tracking data....23
2.2.3.1 Harbour seals....23
2.2.3.2 Grey seals....26
2.3 Underwater soundscape....29
3. Methods and survey(s)....32
3.1 Passive acoustic monitoring of cetaceans....32
3.1.1 Harbour porpoises....32
3.1.1.1 Analysis of FPOD data....36
3.1.2 Influence on PAM results of geophysical surveys....37
3.1.3 Other cetaceans....37
3.1.3.1 Delphinid analysis....38
3.1.3.2 Minke Whale Analysis....39
3.2 Aerial surveys of cetaceans....39
3.2.1 Analysis of aerial survey data....40
3.3 Underwater noise....41
3.3.1 Noise monitoring....41
3.3.2 Turbine noise....42
3.3.3 Harbour porpoise presence near operating turbines....43
3.3.4 Noise exposure maps....47

3.3.5 Overlaying model ... 49

4. Results of survey(s) ... 50
4.1 Passive acoustic monitoring of cetaceans ... 50
4.1.1 Harbour porpoises ... 50
4.1.1.1 FPOD results ... 50
4.1.1.2 Predicted maps of acoustic Species Distribution Models of porpoises ... 57
4.1.1.3 Comparison of CPOD detections over time ... 61
4.1.1.4 Comparison of CPOD and FPOD detections ... 63
4.1.2 Other cetaceans ... 67
4.1.2.1 Minke Whales ... 69
4.1.2.2 Delphinid Analysis ... 70
4.2 Aerial surveys of harbour porpoise ... 72
4.3 Aerial surveys other cetaceans ... 76
4.4 Underwater noise ... 77
4.4.1 Noise monitoring ... 77
4.4.2 Turbine noise ... 81
4.4.3 Harbour porpoise presence near operating turbines ... 89
4.4.4 Noise exposure maps ... 92
4.4.5 Overlaying model ... 95

5. Conclusion from 1st year's survey ... 100
5.1 Harbour porpoise ... 100
5.2 White-beaked dolphin ... 101
5.3 Minke whales ... 101
5.4 Seals ... 101
5.4.1 Seal use of the North Sea I project area ... 101
5.5 Noise ... 102

6. Data and knowledge gaps ... 103
6.1 Influence on PAM results of geophysical surveys in the investigation area ... 103
6.2 Lack of data on seal distribution in the survey area ... 103

7. Referencer ... 104

Rev. no.	Date	Description	Done by	Peer reviewed by	Quality assured by
3	11.11.2024	Marine Mammal surveys – pre-investigations for offshore wind farms in the area North Sea I	Signe Sveegaard (DCE) Jacob Nabe-Nielsen (DCE) Axelle Justine Roxane Cordier (DCE) Floris van Beest (DCE) Anders Galatius (DCE) Jakob Tougaard (DCE) Emily T. Griffiths (DCE) Cristina Marcolin (DCE) Jure Zeleznik (DCE) Michael Ladegaard (BIOL) Line A. Kyhn (NIRAS)	Maria Wilson (NIRAS) Fredrik Oscar Christiansen (DCE)	Jesper Fredshavn (DCE)

Preface

This report was commissioned by Energinet. It describes results obtained from the marine mammal survey program in connection with the planned construction of the offshore wind farms in the North Sea I area.

The report builds upon existing knowledge, as well as new data and analysis collected and conducted during this program and consists of six main chapters and an initial report summary. Chapter 1 is Introduction and objectives of the report. Chapter 2 provides baseline knowledge for each relevant species in the North Sea. Chapter 3 describes the methods, and Chapter 4 describes the results. In Chapter 5, a status per species is provided and Chapter 6 provides the knowledge gaps and Chapter 7 the references.

Declaration of work contributions

This report was published by NIRAS and prepared by Aarhus University and NIRAS as detailed below. BioConsult and OS Energy (third-party contractors) contributed to offshore survey planning and execution.

Quite-Oceans (France) have conducted the underwater noise models for the North Sea.

From Section for Marine Mammal Research, Aarhus University: Signe Sveegaard (editor and responsible for field work and report writing of the subjects of harbour porpoise passive acoustics and aerial surveys), Emily T. Griffiths (report writing and analysis of the content for noise and other whales), Cristina Marcolin (analysis of the data for noise and dolphins), Jure Zeleznik (quality assurance and handling of FPOD data, analysis of the data for noise and dolphins), Jakob Tougaard (field work, analysis and writing of report related to noise and array studies of porpoises near turbines), Floris van Beest (analysis of FPOD passive acoustic harbour porpoise data), Jacob Nabe-Nielsen (writing report related to seals), Anders Galatius (writing report related to seals).

From Section of Zoophysiology, Institut for Biology, Aarhus University: Michael Ladegaard (analysis of decidecade levels at six noise monitoring stations, and analysis of data from array studies of porpoises near turbines).

From NIRAS: Line Anker Kyhn (writing of report, field work for aerial surveys).

The comparison of CPOD and FPOD detections was commissioned to Bioconsult and consequently they produced a separate report on this subject (Voß & Diederichs 2024). In this report, a short summary with main results using text directly from the report is inserted in "section 4.1.1.4 Comparison of CPOD and FPOD detections".

The report and associated investigations were financed by Energinet.

Fredrik Oscar Christiansen, Section for Marine Mammal Research Aarhus University was responsible for scientific review and Jesper Fredshavn, DCE – Danish Center for Environment and Energy, Aarhus University, was responsible for quality assurance.

Maria Wilson, NIRAS, was responsible for quality assurance of the report for NIRAS. There is consensus among all contributors with regard to the main conclusions of the report. Søren Granskov (SGRA) gave final approval from NIRAS for publication. Energinet drafted the introductory section of Chapter 1.

Energinet wrote the three first paragraphs of the "Introduction and Objectives" and have commented on draft versions of the report and comments as well as author replies will be made available at DCEs homepage: https://dce.au.dk/udgivelser/oevrige-dce-udgivelser/eksterne-udgivelser/2024.

List of key terms

A list of terms (in English and Danish) and their explanations in relation to LOT1 - North Sea I.

Table 0-1 Terminology including Danish and English terms as well as explanations

English (abbreviation)	Danish	Explanation
Pre-investigation area	Forundersøgelsesområde	The area defined by Energinet North Sea I
Survey area	Undersøgelsesområde	The area for which field investigations have been carried out and supplementary data and information have been collected. NSI plus 20 km buffer zone around it.
CI	Konfidensinterval	The 95% confidence interval
CV	Variationskoefficient	The coefficient of variation
DEA	Energistyrelsen	Danish Energy Agency
DPM/Day	Minutter med detektioner per dag	Number of minutes per day where harbour porpoises were detected
DPD	Dage med detektion (marsvin eller delfin)	Detection positive days are days, where either harbour porpoises or dolphins are detected
g(0)	Sandsynligheden for at opdage marsvin på nullinjen	The combined probability of detecting a harbour porpoise on the track line (aerial surveys)
GW	Giga Watt	Giga Watt
Mother-calf ratio	Mor-kalve ratio	Number of mother-calf pairs in percent of total number of observed adult harbour porpoises
MSFD	Havstrategi-direktivet	Marine Strategy Framework Directive
NOVANA	NOVANA	The Danish national monitoring program for aquatic environment and nature, run by the Danish Environmental Protection Agency
OWF	Havvindmøllepark	Offshore Windfarm
PAM	Passiv akustisk monitering	Passive Acoustic Monitoring
PAMGuard	PAMGuard	Acoustic analysis program developed by Doug Gillespie
PDV	Sælpest	Phocine Distemper Virus
SCANS	SCANS	Small Cetaceans in European Atlantic waters and the North Sea (European cetacean Survey Programme)
$\hat{u}_m$	Effektive strip bredde (ESW) under moderate betingelser for at se marsvin	The estimated ESW in moderate conditions (aerial surveys)

1. Introduction and objectives

In order to accelerate the expansion of Danish offshore wind production, it was decided with the agreement on the Finance Act for 2022 to offer an additional 2 GW of offshore wind for establishment before the end of 2030. In addition, the parties behind the Climate Agreement on Green Power and Heat 2022 of 25 June 2022 (hereinafter Climate Agreement 2022) decided, that areas that can accommodate an additional 4 GW of offshore wind must be offered for establishment before the end of 2030. Most recently, a political agreement was concluded on 30 May 2023, which establishes the framework for the Climate Agreement 2022 with the development of 9 GW of offshore wind, which potentially can be increased to 14 GW or more if the concession winners – i.e. the tenderers who will set up the offshore wind turbines – use the freedom included in the agreement to establish capacity in addition to the tendered minimum capacity of 1 GW per tendered area.

In order to enable the realization of the political agreements on significantly more energy production from offshore wind before the end of 2030, the Danish Energy Agency has drawn up a plan for the establishment of offshore wind farms in three areas in the North Sea, the Kattegat and the Baltic Sea respectively.

The North Sea I area has a total area of 1.400 km^2 which is divided into three sub-areas planned for offshore wind farms. The North Sea I area is located 20-80 km off the coast of West Jutland and from each of the three sub-areas there will be corridors for export cables connecting the offshore wind farms to the onshore grid.

This report concerns baseline data and information on marine mammals. The study was carried out on behalf of Energinet by DCE in collaboration with NIRAS during April 2023–March 2024.

This technical report concerns the first year of data collection in the Marine mammal work package. The data collection will continue for a second year. The report includes data obtained during the first year from three aerial marine mammal surveys conducted in April, June and August 2023 as well as data from April 2023–March 2024 from 42 PAM stations (9 CPOD/FPOD stations, 6 SoundTrap/FPOD stations and 27 FPOD stations). Furthermore, results from the noise monitoring at North Sea I (NSI), noise recordings of turbine noise at Kriegers Flak offshore windfarm (OWF) and array studies of porpoises and noise at Horns Rev 3 Offshore Wind Farm are presented. The results from the field surveys arre supplemented with existing data and information compiled from literature studies.

The objective of the environmental pre-investigations is to collect new data and compile existing data and information to be handed over to the future concessionaires as environmental baseline information for the concessionaires' environmental permitting processes. The specific aim of this technical report is to provide updated baseline knowledge of marine mammal presence and usage of the North Sea I area as well as an updated underwater soundscape of the area.

1.1 Survey area

The survey area at North Sea I for examining marine mammals and underwater noise encompasses the pre-investigation area as well as a 20 km buffer around this area. The buffer zone of 20 km was chosen since it was assessed to be the largest area that could potentially impact harbour porpoises during the construction due to piling of pin piles/monopiles into the seabed: Several studies have estimated the impact on porpoises during the construction phase of a wind farm, by comparing the presence of harbour 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 empty the core area for harbour porpoises if present) 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).

The survey area is 7630 km^2 and the depths varies from 1 to 45 m. The sea floor mainly consists of sand and mud.

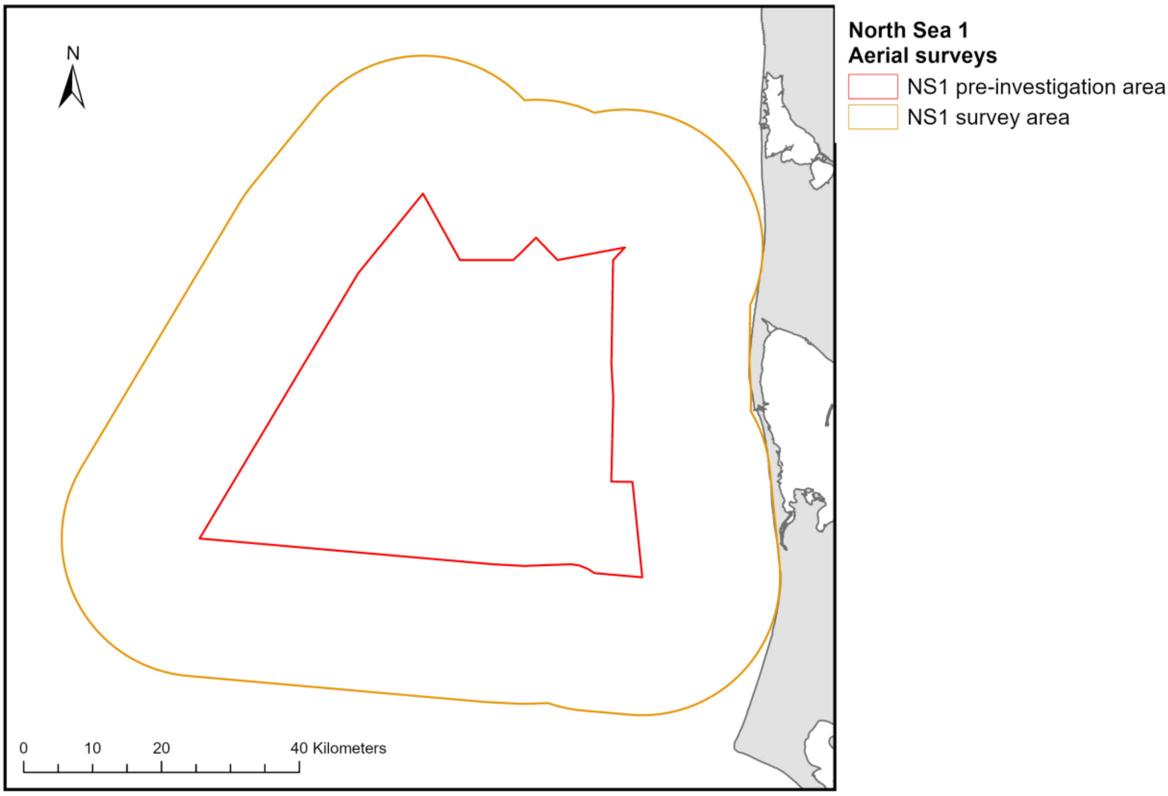

Figure 1-1: The pre-investigation area for North Sea I (red) including 20 km buffer zone, called the survey area (orange).

2. Existing data and knowledge

The North Sea is inhabited by many different species of marine mammals. The most common species in the area relevant for this project are harbour porpoises (*Phocoena phocoena*), harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*). However, several other species of cetaceans also occur at an unknown level in the eastern North Sea, most importantly white-beaked dolphins (*Lagenorhynchus albirostris*) and minke whales (*Balaenoptera acutorostrata*), but also several other species such as bottlenose dolphins (*Tursiops truncatus*) and killer whales (*Orcinus orca*) can be found (Hammond et al. 2013).

This chapter includes all relevant information about the different species before the survey program began and knowledge that became available while the survey was ongoing.

This project did not include collection of new data on the two seal species. Consequently, all information on seals is derived from previous studies in the area and presented in this chapter. The information mainly includes data from seal tagging collected during the Energy island project northwest of the North Sea I project area (2022–2023) and aerial survey data from the nearest haul-out sites along the west coast of Jutland. It is not within the scope of this project to conduct new models or analysis. Thus, the existing data from the Energy Island are presented with focus on their relevance for the North Sea I area.

2.1 Cetaceans

2.1.1 Harbour porpoises

Harbour porpoises are common in the North Sea and the population size is estimated to be stable at around 350,000 individuals (North Sea, Skagerrak and northern Kattegat) throughout the period 1994–2022, as estimated from the four SCANS surveys conducted in 1994, 2005, 2016 and 2022, respectively (Hammond et al. 2002; Hammond et al., 2013; Hammond et al. 2021, Gilles et al. 2023). During SCANS-IV in July 2022, a mean density of 0.55 animals/km^2 was estimated in the North Sea (Gilles et al. 2023). All SCANS data from the North Sea was obtained in the month of July with the same methodology as applied in the North Sea I aerial survey program for cetaceans and the results are therefore directly comparable, although the blocks are larger than the North Sea I survey area. No data on harbour porpoise abundance in the Danish North Sea exists for other times of the year than the summer season.

The distribution of harbour porpoises within the North Sea I survey area is relatively unknown, as the SCANS' transects are too sporadic to illustrate distribution on a smaller scale and the only other source are a few individually tracked harbour porpoises: Aarhus University has tagged 25 harbour porpoises near Skagen since 2000 as well as 6 porpoises in the Wadden Sea (Figure 2.1). The movement of the tracked harbour porpoises showed that the harbour porpoises tagged in Skagen had a preference for the southern slope of the Norwegian Trench, but that they may also explore the areas to the south, including the North Sea I survey area. The six harbour porpoises tagged in the Wadden Sea mainly stayed close to the tagging site and had limited home ranges. However, since only six harbour porpoises were tagged, other individuals from this area may move differently.

Little is known about breeding areas for harbour porpoises in general, as well as in the North Sea. A German study in waters near Sylt (Sonntag et al., 1999) described a calving area based on two aerial surveys one year apart, where they found a calf ratio of 10–17%. The calf ratio is the ratio of mother-calf pairs to single harbour porpoises. This area was also confirmed as a breeding area in later surveys (Gilles et al., 2009; Gilles et al., 2011; Gilles et al., 2016). In the survey program for the North Sea Energy Island conducted in 2021-2023 a similar high mother-calf ratio was found in summer (16%) (Kyhn et al., 2024). Other than this, no breeding areas have been documented near the North Sea I pre-investigation area.

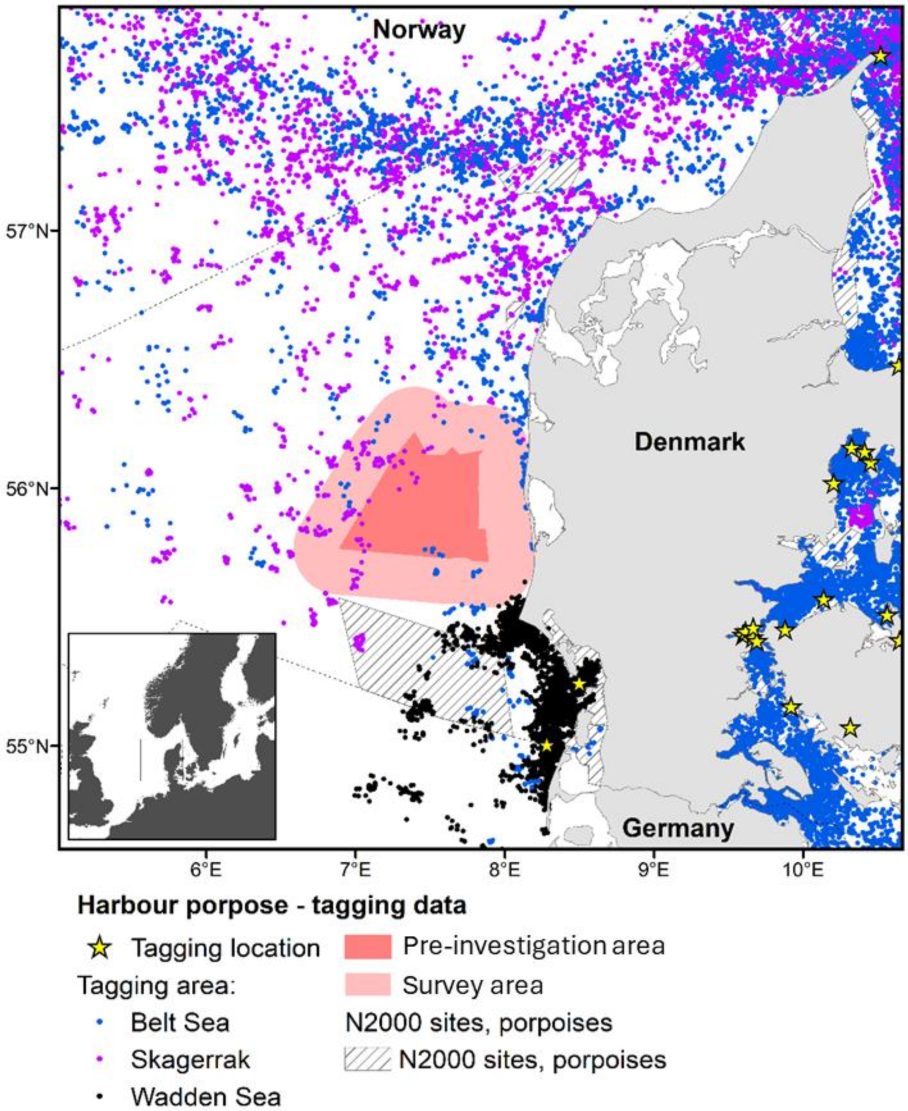

Figure 2-1 Positions from harbour porpoises tagged at Skagen (Purple), in the Belt Sea (blue) and in the Wadden Sea (black) from 1997 to 2022. The Natura 2000 areas are shaded.

2.1.1.1 Vulnerable periods for harbour porpoises in the North Sea

Newborn harbour porpoise calves are entirely dependent on their mother and continue to be for their first ten to eleven months of life, where they suckle and slowly learn to hunt (Camphuysen and Kropp, 2011) before they become independent (Lockyer, 2003; Teilmann et al., 2007). They are therefore sensitive to disturbances that can lead to mother-calf separation in this period. In the North Sea, calves are born from April to September with a peak in June–July (Sonntag et al., 1999). Mating takes place in the first 1–2 months after the mother gives birth, while she is still nursing her calf. Young harbour porpoises less than 1 year old, and therefore newly weaned, are over-represented in bycatch statistics (Berggren, 1994). The vulnerable period for porpoises is therefore year-round.

Recent findings from studies on harbour porpoise energetics suggest that mature female harbour porpoises are most vulnerable to disturbances in late summer and the autumn, when they need to increase their energy storage to increase body fat insulation to survive the cold winter months, while at the same time potentially being pregnant and nursing a calf only a few months of age (Gallagher et al. 2021).

Harbour porpoises are listed in annex IV of the Habitats Directive and in the IUCN Red List evaluated as Least Concern in the North Sea (Braulik et al., 2023). Threats according to the IUCN Red List categories are 1) Fishing: bycatch in nets, reduced food availability and habitat destruction, 2) Pollution from industry and agriculture, 3) Noise pollution, 4) Climate and habitat changes, 5) Recreational activities: physical disturbances and noise.

2.1.2 White-beaked dolphins

White-beaked dolphins are only rarely observed in the survey area (Read et al. 2009, Hammond et al. 2021). However, there have only been a few dedicated surveys and only during the summer months, and consequently there is at present little knowledge on how much and when white-beaked dolphins may occur in the survey area (e.g. Gilles et al. 2023). International surveys (SCANS) have shown that their abundance is known to increase towards the north and west in the North Sea (Hammond et al. 2021, Gilles et al. 2023). There are no migration or movement data for white-beaked dolphins in the North Sea, and their annual presence or migration through the survey area is therefore unknown.

Similar to other dolphins, the vocalizations produced by white-beaked dolphins can be grouped into three types: echolocation clicks, burst pulses, and whistles. Echolocation clicks are short (< 1 ms) sonar signals with predominant energy in the ultrasonic range that enable animals to acoustically search their environment and forage. Tonal whistles are communication signals used for social interactions and group cohesion. The third group of signals, burst pulses – rapid click sequences with tonal qualities – is a mix of signals produced for sonar (prey capture events) and for communication. For white-beaked dolphins, different ranges of echolocation frequency bandwidths have been reported (see Griffiths et al., 2023 for more information).

2.1.2.1 Vulnerable periods for white beaked dolphins in the North Sea

White beaked dolphin calves are born in summer and mating also takes place in summer, although females are highly unlikely to mate every year (Galatius and Kinze, 2013). During calving and mating and in the months thereafter, the dolphins are vulnerable to disturbances that may lead to mother-calf separation. In other more well-studied dolphin species, the calves are dependent on their mother for several years. White-beaked dolphins are listed in annex IV of the Habitats Directive and evaluated as Least Concern in the North Sea by IUCN (Kiszka and Braulik, 2018). Threats according to the IUCN Red List categories are 1) Fishing: bycatch in nets, reduced food availability and habitat destruction, 2) Pollution from industry and agriculture, 3) Noise pollution, 4) Climate and habitat changes, 5) Recreational activities: physical disturbances and noise.

2.1.3 Minke whales

Minke whales have only been observed a few times in the survey area, but similar to white-beaked dolphins there has only been limited dedicated survey effort in this area (Figure 22), (Hammond et al. 2021). It is likely that minke whales are more common in the deeper waters in the North Sea (Hammond et al. 2021, Gilles et al. 2023) and they are commonly observed in the Danish oil and gas sector (Delefosse et al. 2017). Prior to this project, however, due to the lack of dedicated surveys, we have no specific knowledge of when and how often minke whales use the survey area.

Minke whale vocalizations vary greatly across their global geographic range. Around the North Atlantic Ocean, ranging from the Caribbean to the western North Sea, minke whales have been documented producing low-frequency pulse trains (50–400 Hz) (Mellinger et al. 2000, Risch et al. 2013, Risch et al. 2019). Based on these data, an automated pulse train detector was developed and used along the Scottish east coast (Popescu et al. 2013, Risch et al. 2019). Off Scotland, minke whale pulse train detections exhibited seasonal and diel patterns, occurring mostly between June and November in the evening/nautical twilight hours. It is unclear what behavior is associated with the pulse train in minke whales, and therefore whether it is a signal they produce regularly. While it is known that minke whales can produce other vocalizations, no detectors currently exist to automatically search broadband data for these call types.

2.1.3.1 Vulnerable periods for minke whales in the North Sea

It is not known when minke whales are most vulnerable to disturbances in the survey area. However, minke whales are observed in this part of the North Sea and it is assumed that the area has some significance for the species (Reid et al., 2003). There is not enough knowledge about breeding and nursing to point to specific periods as being more vulnerable than others.

Minke whales are listed in annex IV of the Habitats Directive and evaluated as Least Concern in the North Sea by IUCN (Sharpe and Berggren, 2023). Threats according to the IUCN Red List categories are 1) Fishing: reduced food availability and habitat destruction, 2) Pollution from industry and agriculture, 3) Noise pollution, 4) Climate and habitat changes.

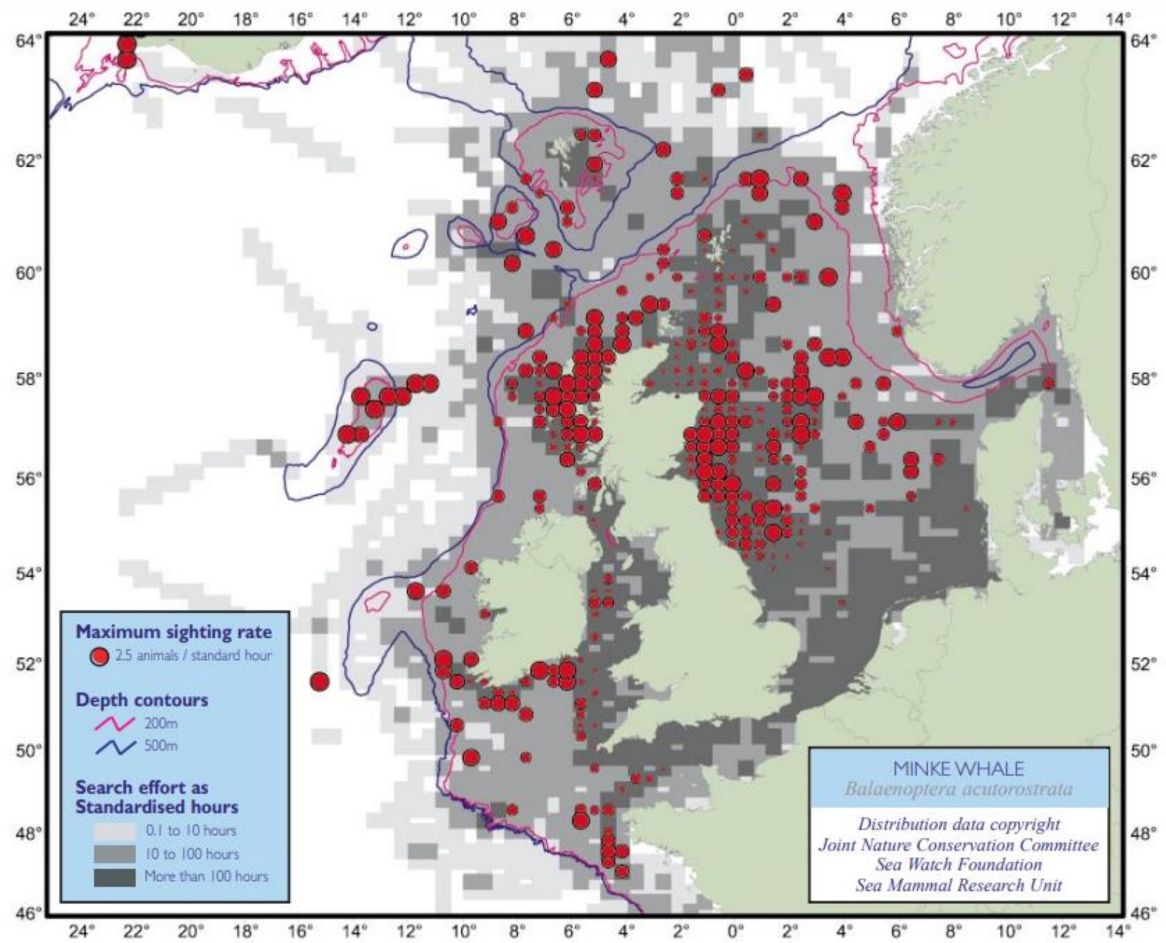

Figure 2-2 Minke whale distribution map from Atlas of Cetacean distribution in north-west European waters. From Reid et al. (2003).

2.2 Seals

Harbour seals and grey seals are the only common seal species in the North Sea. The survey area is located between two very important seal haul-out areas, namely the Wadden Sea and the western part of the Limfjord near Thyborøn. Both locations hold important resting and moulting grounds for both seal species. The Wadden Sea is also an important breeding area for harbour seals, and grey seals have begun to use this area for pupping within the last decade as well, although in very small numbers (<10/yr) (Fast-Jensen et al. 2015).

2.2.1 Harbour seals

The survey area off the Danish west coast may be visited by harbour seals from the Wadden Sea population (Olsen et al. 2014), which is shared between the Netherlands, Germany and Denmark, as well as harbour seals from Nissum Bredning, in the western Limfjord. Seal haul-outs in Nissum Bredning are used by seals from both the Wadden Sea, Kattegat and a separate population of harbour seals in the central Limfjord.

Harbour seals in Denmark have been hunted extensively until their protection in 1976 (Søndergaard et al. 1976). Numbers of harbour seals in Denmark, including the Wadden Sea and Nissum Bredning were severely depleted until the time of their protection, with estimates of 500–600 seals left in the Danish Wadden Sea and 200 in the entire Limfjord (Søndergaard et al. 1976). Since the protection from hunting was introduced, the populations have recovered and only declined during the two Phocine Distemper Virus (PDV) outbreaks in 1988 and 2002 (Härkönen et al. 2006). However, during the last decade, the growth of harbour seal populations in both the larger Wadden Sea area (including Germany and the Netherlands) and Limfjord has been slowing down or numbers have been declining. While numbers of harbour seals along the Dutch and German North Sea coasts have been stable for the last 12 years (Galatius et al. 2023), there have been substantial decreases in the counts in both the Danish Wadden Sea and Nissum Bredning. This may be indicative of a true decline with increased mortality or lower reproduction, or a redistribution of seals to other areas. The reason behind the decline is not known, but the most likely drivers are disturbance at the haul-outs, depletion of prey and increasing numbers of grey seals.

The numbers of seals counted on land provide information about the trends in the population abundance. With knowledge regarding the proportion of seals hauling out at a particular time, total population abundance can be estimated. Such data are not yet available for Nissum Bredning, while there are sparse data on harbour seal haul-out behaviour from the Dutch Wadden Sea (Ries et al. 1998). They would indicate that approximately 68% of the population is hauling out at a given time during June. These data were, however, obtained in the 1990s and environmental changes, age and density dependence are likely to affect haul-out behaviour. Data from harbour seals in other parts of their distribution show haul-out rates ranging from 42% to more than 80% during the moulting season in August (Yochem et al. 1987, Härkönen and Heide-Jørgensen 1990, Olesiuk et al. 1990, Thompson and Harwood 1990, Thompson et al. 1997, Ries et al. 1998, Huber et al. 2001, Simpkins et al. 2003, Gilbert et al. 2005, Cunningham et al. 2009, Harvey and Goley 2011, London et al. 2012, Lonergan et al. 2013), with higher rates generally recorded during low tide in areas with high tidal ranges, as is the case in both the Wadden Sea and Nissum Bredning. Thus, a reasonable estimate, without local data would be that 50–80% of the population is hauled out during the moulting season surveys at low tide in August in both areas.

Monitoring of harbour seals in the Danish Wadden Sea was initiated in 1979, and until 1988, the counts showed exponential growth at around 12% per year (Figure 2-3). In 1988, an epidemic of PDV struck the harbour seal populations in the inner Danish waters and the North Sea area (Härkönen et al., 2006), and decreased counts in the Danish Wadden Sea from approximately 1500 to 900 individuals. After this, the population again grew at a similar exponential rate, until a second PDV epidemic reduced the counts from around 2500 to 1400 individuals in 2002 (Härkönen et al., 2006). After 2002, the population resumed growth at a high rate, until around 2012, at which time numbers stabilized in the larger Wadden Sea area. In the Danish part of the Wadden Sea, numbers peaked at around 2900 individuals in 2012 and then began to decline, and in 2021, the counts were similar to the level immediately after the 2002 epidemic (Figure 2-3). A decline in numbers of harbour seals in the Danish Wadden Sea since 2012 is also reflected in counts from other seasons (Figure 2-4). In 1998, aerial monitoring of annual pup production in the Danish Wadden Sea was initiated during the harbour seal pupping season in June. Since 2010, the pup counts have shown a stable trend with 400–600 pups counted annually, without a significant decline as seen in the counts of older seals (NOVANA data, Figure 2-4). This may be related to either high levels of pup mortality or to changes in adult haul-out behaviour with seals spending less time on land during the moulting season than previously, because of density dependence.

The survey data used for this report includes harbour seals from the Wadden Sea population (Olsen et al., 2014), which is shared between the Netherlands, Germany and Denmark, as well as Nissum Bredning, in the western Limfjord. Haul-outs in Nissum Bredning are used by seals from both the Wadden Sea and a separate population of harbour seals in the central Limfjord.

With the lack of data on haul-out behaviour from the surveyed areas, a reasonable estimate based on data from other areas would be that 50–80% of the population is hauled out during the moulting season surveys at low tide in August in both areas. This would constitute current abundances of around 2200–3600 harbour seals in the Danish Wadden Sea area and 500–800 in Nissum Bredning. Data on the proportion of North Sea grey seals hauling out during the survey periods are not available from any part of the range.

The seasonal variation of harbour seal on land in both areas is similar to what is seen in other areas, with peaks during the summer months where breeding and moulting take place, and much lower numbers on land in the fall, winter and early spring (e.g., (Cunningham et al., 2009; Granquist and Hauksson, 2016; Hamilton et al., 2014; Watts, 1996). This seasonal pattern indicates that longer foraging trips, which would be more likely to involve the area around the North Sea I area, would be more frequent outside the summer period, particularly during winter, when haul-out attendance is lowest.

Grey seals were driven to extinction in these areas in the 1500s (Härkönen et al., 2010) and have been recolonising the continental North Sea coasts since the 1950s (Reijnders et al., 1995). Since the early 2000s, grey seals have regularly occurred in the Danish Wadden Sea, and since 2010 in Nissum Bredning. In 2023, there was a low count of moulting grey seals in the Danish Wadden Sea, but apart from that, numbers of grey seals have been growing both here and in Nissum Bredning, since the species started recolonisation of the Danish North Sea area. Now, up to 350 grey seals can be observed in the Danish Wadden Sea and up to 100 in Nissum Bredning. Only 12 pups have been recorded since monitoring of the grey seal pupping season began in the Wadden Sea in 2014, no pups have been recorded in Nissum Bredning, and North Sea grey seals are still not breeding regularly in Denmark.

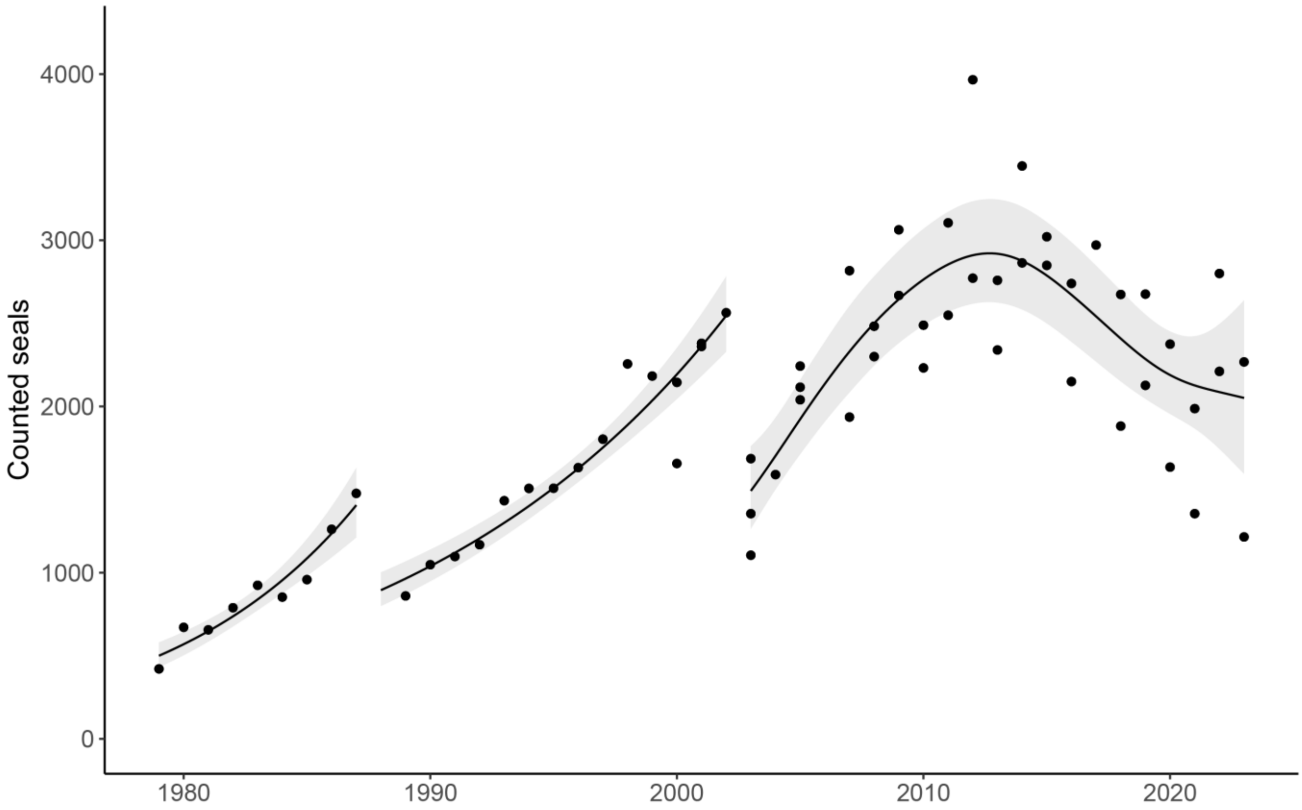

Figure 2-3 Aerial survey counts of hauled-out harbour seals in the Danish Wadden Sea during the moult in August 1979–2023. Black line shows estimated annual count index and grey area shows the 95% confidence interval of the estimate. Modelled time series are interrupted by the Phocine Distemper Virus epidemics of 1988 and 2002. The counts do not include seals at sea during the surveys. Data are from the national monitoring program, NOVANA (Hansen & Høgslund 2024).

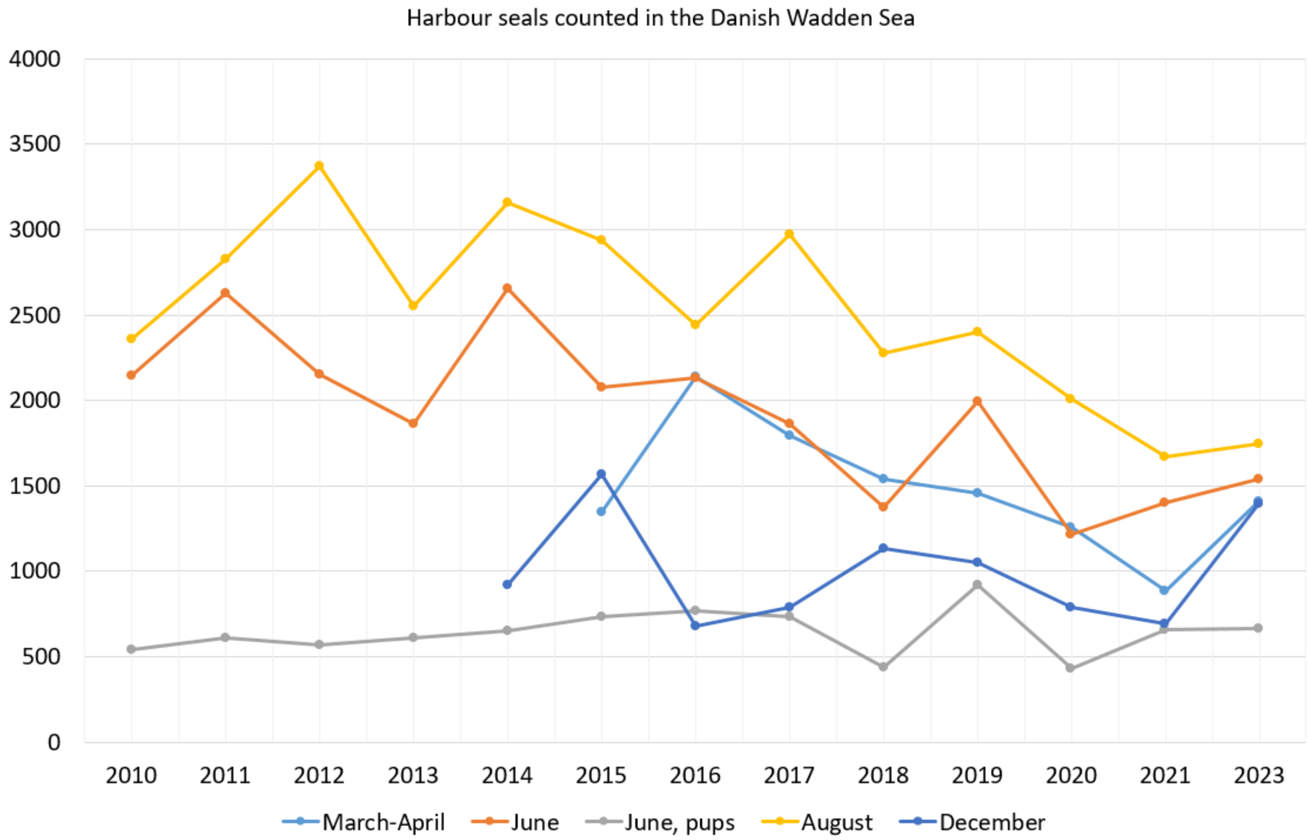

Figure 2-4 Harbour seals counts in the Danish Wadden Sea 2010–2023. Data are presented for four counting seasons, with numbers of both pups alone and for other seals (minus pups) for June and total number of seals for the other seasons. The counts do not include seals at sea during the surveys. Data are from the national monitoring program, NOVANA (Hansen & Høgslund 2024).

Monitoring of harbour seals in the Limfjord was initiated in 1990. A genetic study revealed that harbour seals in this area derive from two populations: in the inner fjord, seals have a distinct genetic signature and are most likely descendants of the seals inhabiting the fjord until a storm opened a connection to the North Sea in 1825 (Olsen, Andersen et al. 2014). In the western part of the fjord, Nissum Bredning, seals from the Wadden Sea occur along with seals from the inner Limfjord and Kattegat. Seals from the inner Limfjord may occasionally venture into the North Sea (Teilman et al. 2020) but tend to stay in the inner Limfjord. Thus, it is the seals hauling out in Nissum Bredning which are most relevant for the study area. In the inner Limfjord, harbour seal numbers grew from 1990 until the PDV epidemic in 2002 where the estimated index of hauled out seals during the moult was 800 in the inner fjord. After the epidemic, the count dropped to approximately 500 and since then, there has not been significant growth (Figure 2.5). In Nissum Bredning, the counts were low before the 2002 epidemic, with around 100 seals on land during the moulting season. Numbers of harbour seals increased substantially in the years following the 2002 PDV epidemic to ca 600 in 2012, but numbers have been declining since then (Figure 2-5). Substantially fewer seals are counted during the harbour seal pupping season than during the moulting season, and there are very few pups (a maximum of 17 pups in Nissum Bredning have been counted since pup counts in the Limfjord were initiated in 2016, NOVANA data, Figure 2-6). This underlines that Nissum Bredning is not currently an important breeding area and the great majority of the harbour seals using the area go to other localities to breed.

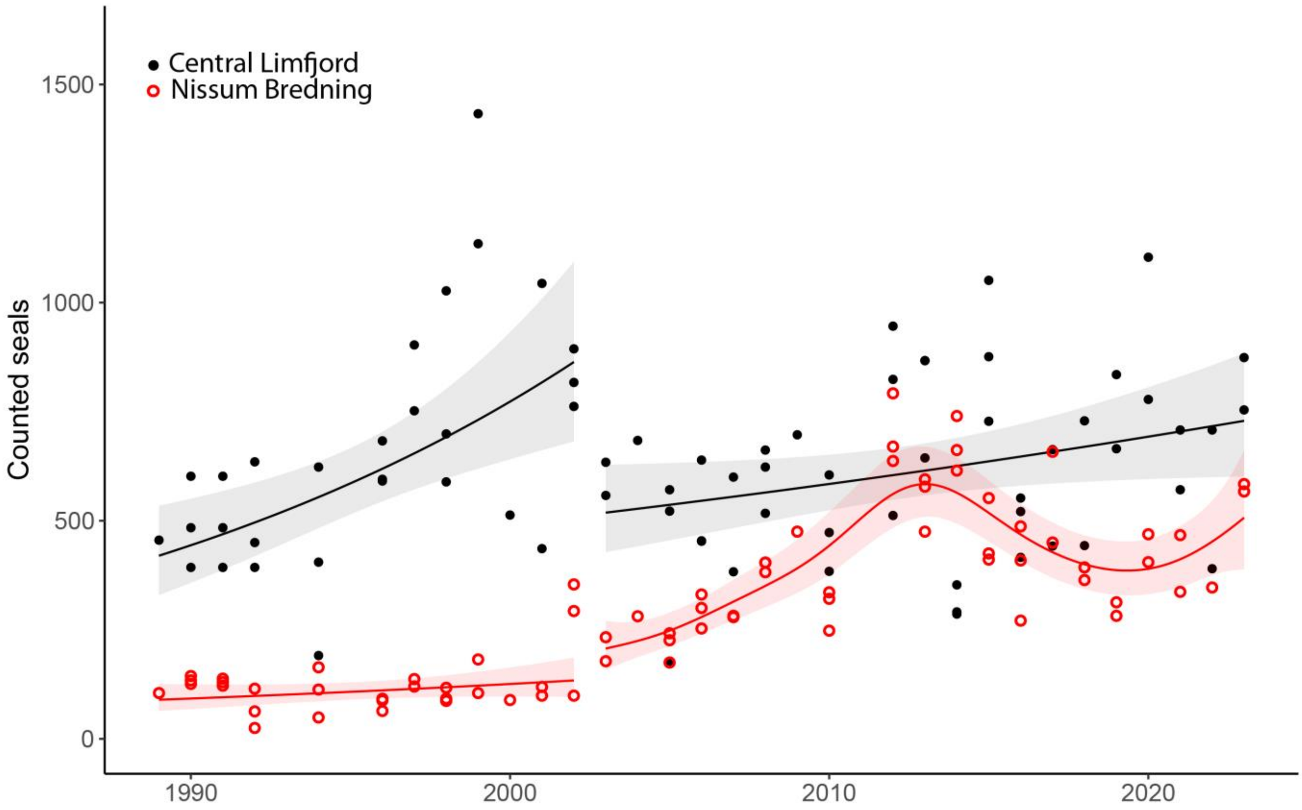

Figure 2-5 Aerial survey counts of harbour seals in the Limfjord during the moult in August, 1989–2023. Black line shows estimated annual count index of the central/Inner part of the Limfjord and grey-shaded area shows the 95% confidence interval of the estimate. Red line shows estimated annual count of Nissum Bredning (western part of the Limfjord) and red-shaded area shows the 95% confidence interval of the estimate. Modelled time series are interrupted by the Phocine Distemper Virus epidemic in 2002. The counts do not include seals at sea during the surveys. Data is from the national monitoring program, NOVANA (Hansen & Høgslund 2024).

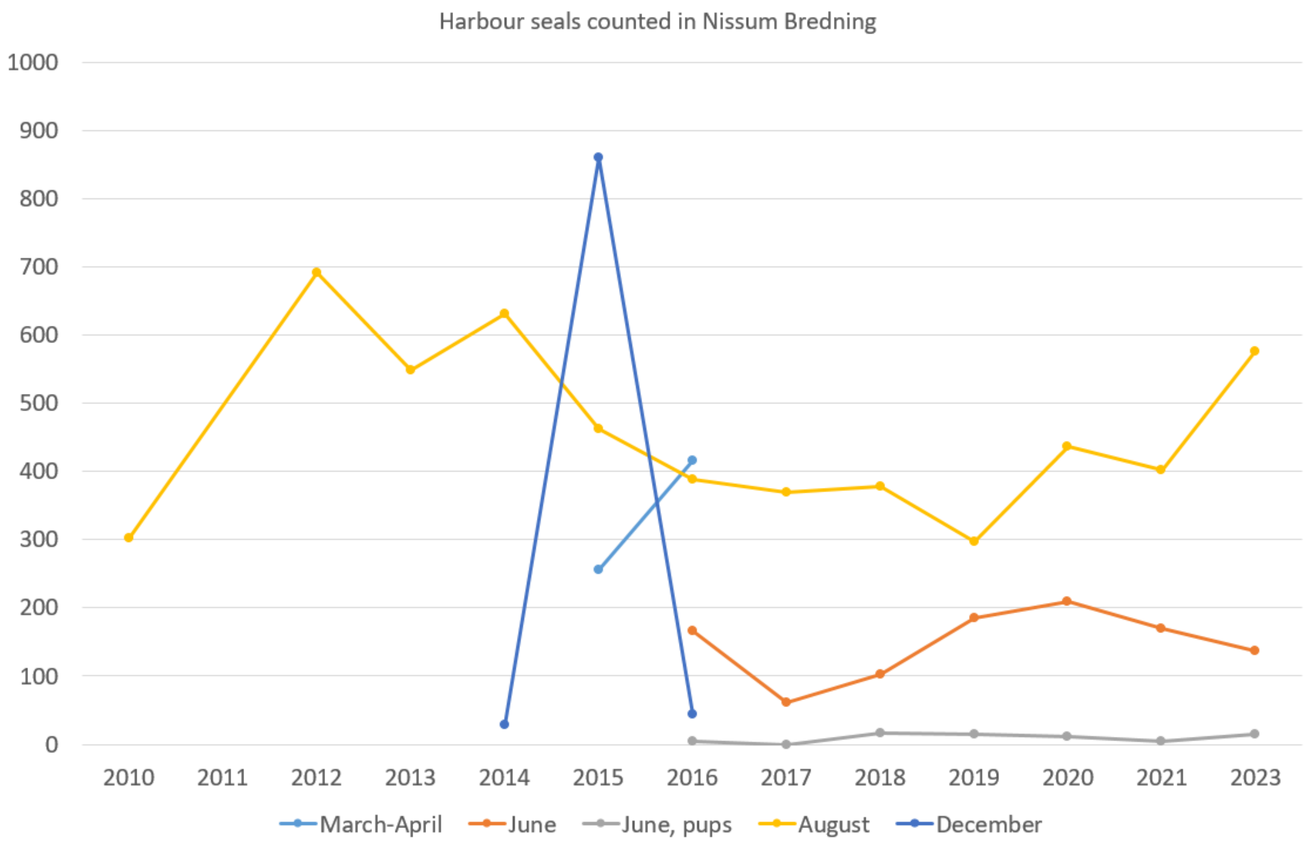

Figure 2-6 Harbour seal counts in Nissum Bredning 2010–2023. Data are presented for four counting seasons, with numbers of both pups and other seals for June and total number for the other seasons. The counts do not include seals at sea during the surveys. Data is from the national monitoring program, NOVANA (Hansen & Høgslund 2024).

During the investigations for the Energy Island, seals were counted around the year in both the Danish Wadden Sea and western Limfjord (Kyhn et al. 2024a). The seasonal variation of harbour seals on land in both areas is similar to what is seen in other areas, with peaks during the summer months at which time breeding and moulting take place, and much lower numbers on land in the fall, winter and early spring (e.g. Watts 1996, Cunningham et al. 2009, Hamilton et al. 2014, Granquist and Hauksson 2016) (Figure 2-7). A pattern with wider movement range outside the summer period, has previously been documented in harbour seals from Kattegat (Dietz et al., 2013). Thus, it is likely that occurrence of harbour seals is higher in the survey area outside the summer period.

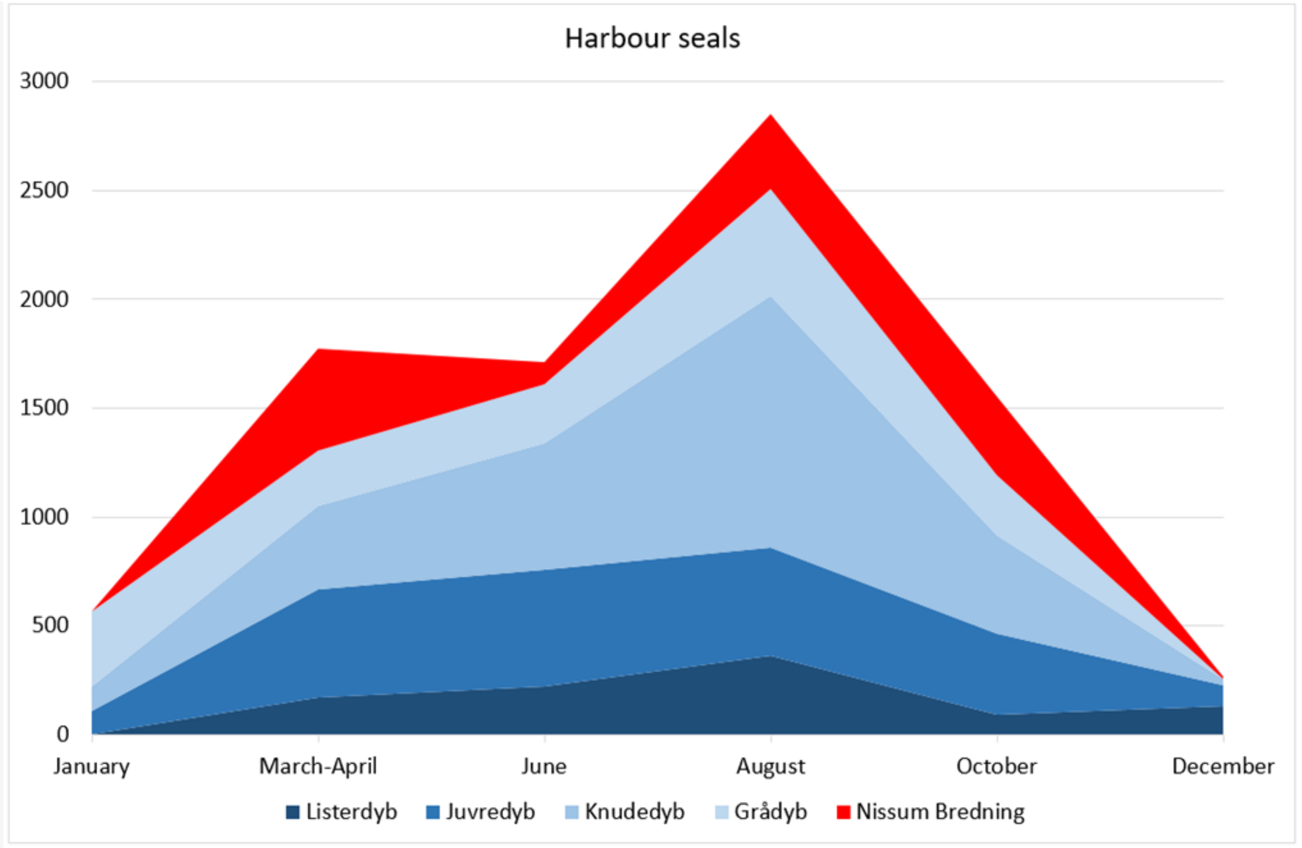

Figure 2-7 Counts of hauled out harbour seals from the Wadden Sea (shades of blue for four subareas) and Nissum Bredning (red) from January to December 2022. Y-axis is number of counted seals. Data from Nissum Bredning in January, March–April, October and December and data from the Wadden Sea in March–April and October derive from the Energy Island investigations (Kyhn et al. 2024). Remaining data are from the national monitoring program, NOVANA (Hansen & Høgslund 2024).

2.2.2 Grey seals

Grey seals in the Danish North Sea are part of a larger population in Eastern North Atlantic, centered around the British Isles (Fietz et al. 2016). Grey seals were locally extinct along the European continental coast in the 1500s, except along the Norwegian coast and the population in the Baltic Sea. Seals were later targets of a bounty hunt campaign from 1889 to 1927, during which grey seals went extinct in Danish waters and harbour seals were severely depleted (Olsen et al. 2018). Grey seals were protected in 1967 and two seal reserves were established in the Danish Wadden Sea area in 1979. There were no grey seals in either area at that time. Grey seals from the British Isles have been recolonizing the continental North Sea coasts since the 1950s (Reijnders, Vandijk et al. 1995). At this time, grey seals began to occur in the Dutch and German parts of the Wadden Sea, and in 1985, the first pup was observed in the Netherlands, while grey seal occurrence continually increased in the Dutch and German Wadden Sea areas.

During 2000–2010, grey seals began occurring regularly in small (always fewer than 50) but increasing numbers in the Danish Wadden Sea (NOVANA data). In December 2014, a monitoring program covering the pupping season in late–November to early-January and the moulting season in March–April was initiated. From 2010 until the initiation of the program, numbers counted during the harbour seal moulting and pupping seasons had been growing and this development continued across all seasons after the initiation of the program, peaking with between 300 and 350 seals counted during the moulting seasons of 2019, 2020 and 2021. Since 2019, there has been a tendency for stagnation in the counted numbers (Figure 2-8), but there is much variance in the data across all seasons, so firm conclusions are not possible. The first grey seal pup was found in Danish Wadden Sea in 2014 and only 12 grey seal pups have been recorded in the Danish Wadden Sea since 2014, peaking with four in 2023–2024 (NOVANA data).

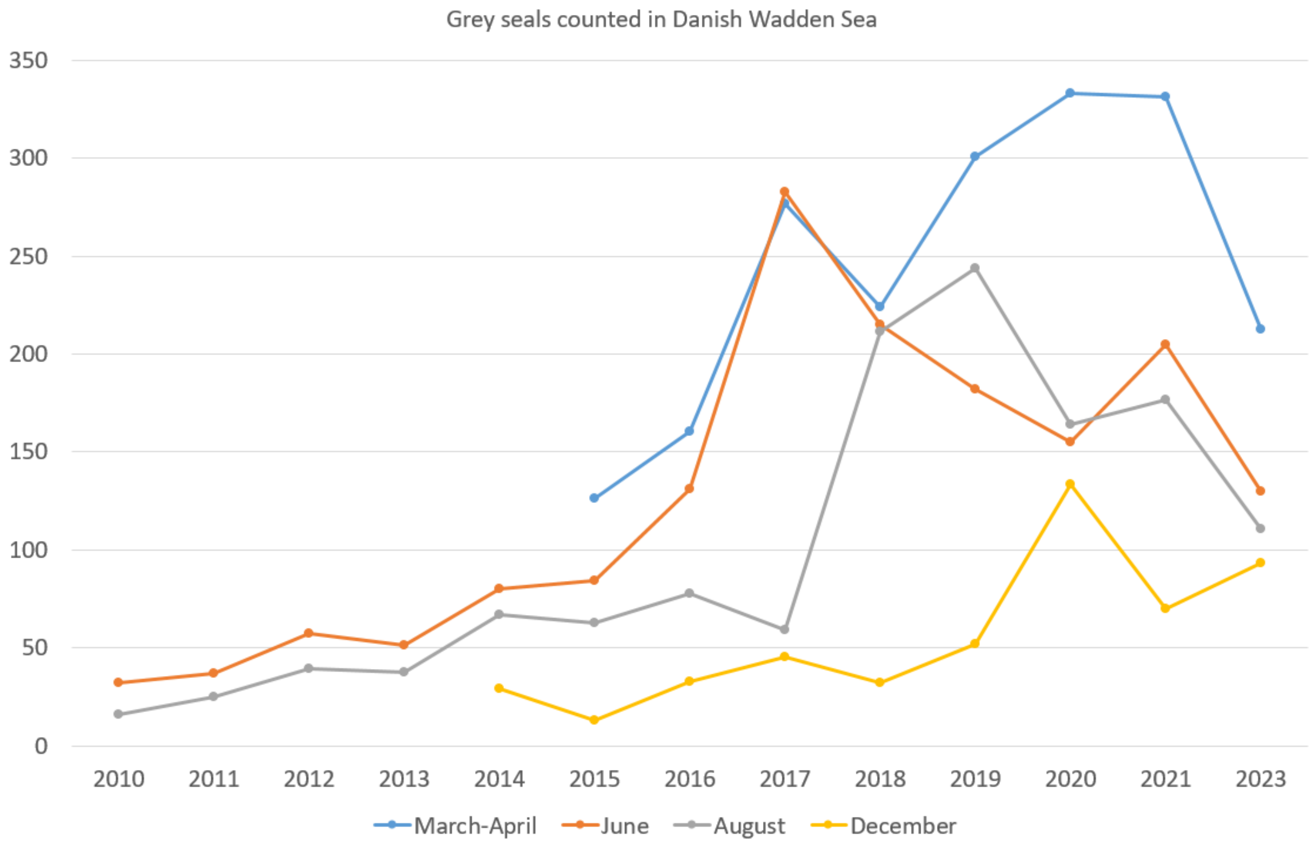

Figure 2-8 Grey seals counted in the Danish Wadden Sea 2010–2023. Data are presented for four counting seasons, namely the grey seal moulting season (March–April), harbour seal pupping season (June), harbour seal moulting season (August) and grey seal pupping season (December). Data are from the national monitoring program, NOVANA (Hansen & Høgslund 2024).

In Nissum Bredning, grey seals were first recorded for the harbour seal monitoring program in August 2009, when two grey seals were found. Since then, numbers have increased, with a maximum of 49 seals in August 2021 (Figure 2-9. In contrast to the Wadden Sea, the highest counts have not been obtained during the moulting season in March–April, but instead in June and August. It must be noted, however, that counts during the grey seal pupping and moulting seasons were only available for 2014–2016 and 2015–2016, respectively, and again in 2022 (Kyhn et al. 2024a) as the area has not been covered by the grey seal monitoring program. No pups have been recorded in the area and the most likely locality for pupping in the area, Rønland Sandø (south of Thyborøn), which has historically been above the high tide water level, has been prone to flooding in recent years, and may thus not support grey seal breeding.

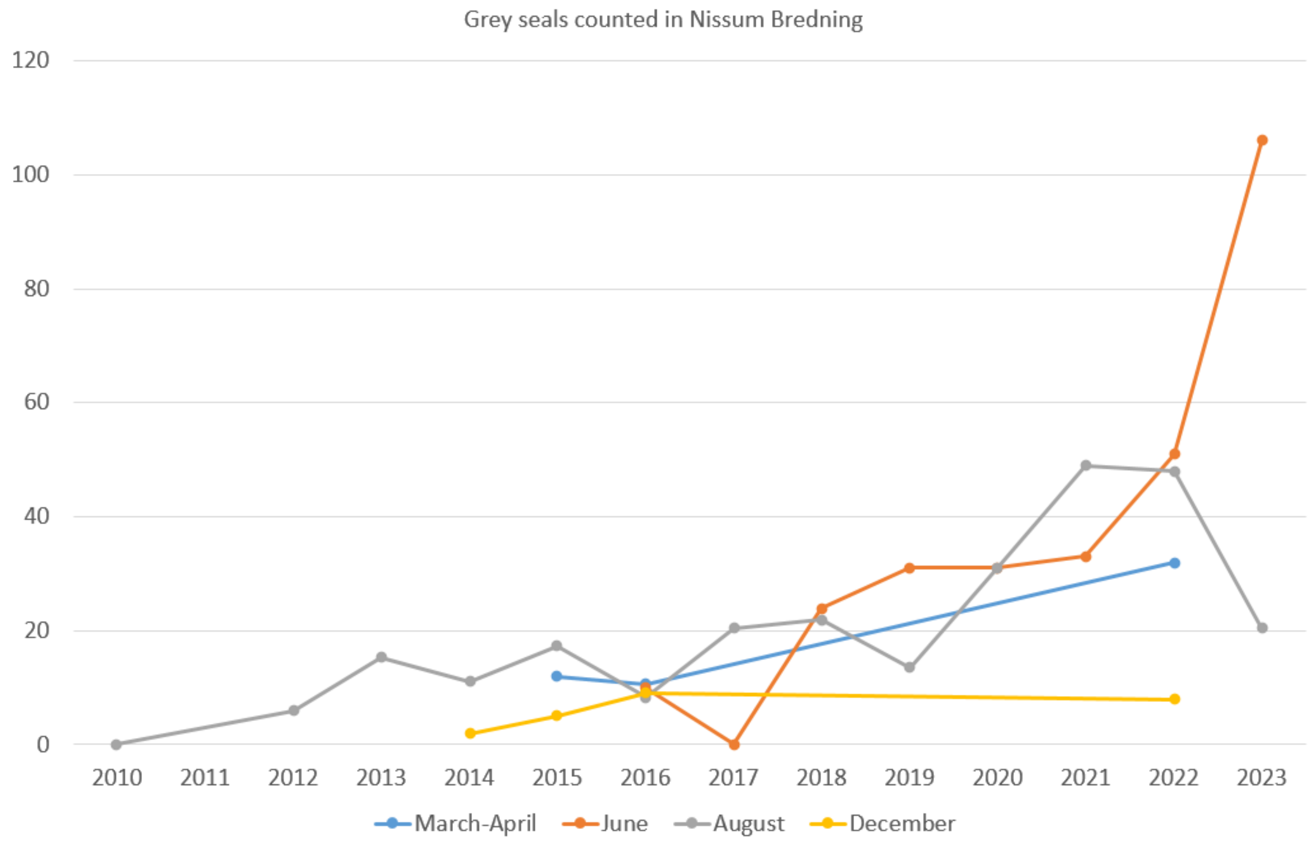

Figure 2-9 Grey seals counted in Nissum Bredning 2010–2023. Data are presented for four counting seasons, namely the grey seal moulting season (March-April), harbour seal pupping season (June), harbour seal moulting season (August) and grey seal pupping season (December). Data are from the national monitoring program, NOVANA (Hansen & Høgslund 2024).

Grey seals are fewer in number than harbour seals and are still recolonizing the Danish North Sea after extinction from this area. As such, they have been classified as being in 'unfavourable conservation status' in Denmark according to the EU Habitats Directive (Fredshavn, Nygaard et al. 2019). Numbers of grey seals at the surveyed haul-outs are increasing across all seasons in the Limfjord (Figure 2-10), while a decrease has been seen in the Wadden Sea in recent years (Figure 2-8). The very low number of pups (max 4 per year for the population) at Danish North Sea haul-outs underline that the recolonization is in a very early phase with few adult females giving birth at the Danish locations. In contrast to the harbour seals, the counts of grey seals are more evenly distributed over the seasons, without peaks during the breeding and moulting periods in winter and spring, but still with a relatively low count in October and a very low count in December (Figure 2-10). This may reflect that grey seals of the North Sea observed in Denmark mainly are immature visitors to the area, coming to forage, and use the haul-outs between foraging trips, while most adult seals return to/stay in their core areas to breed and moult.

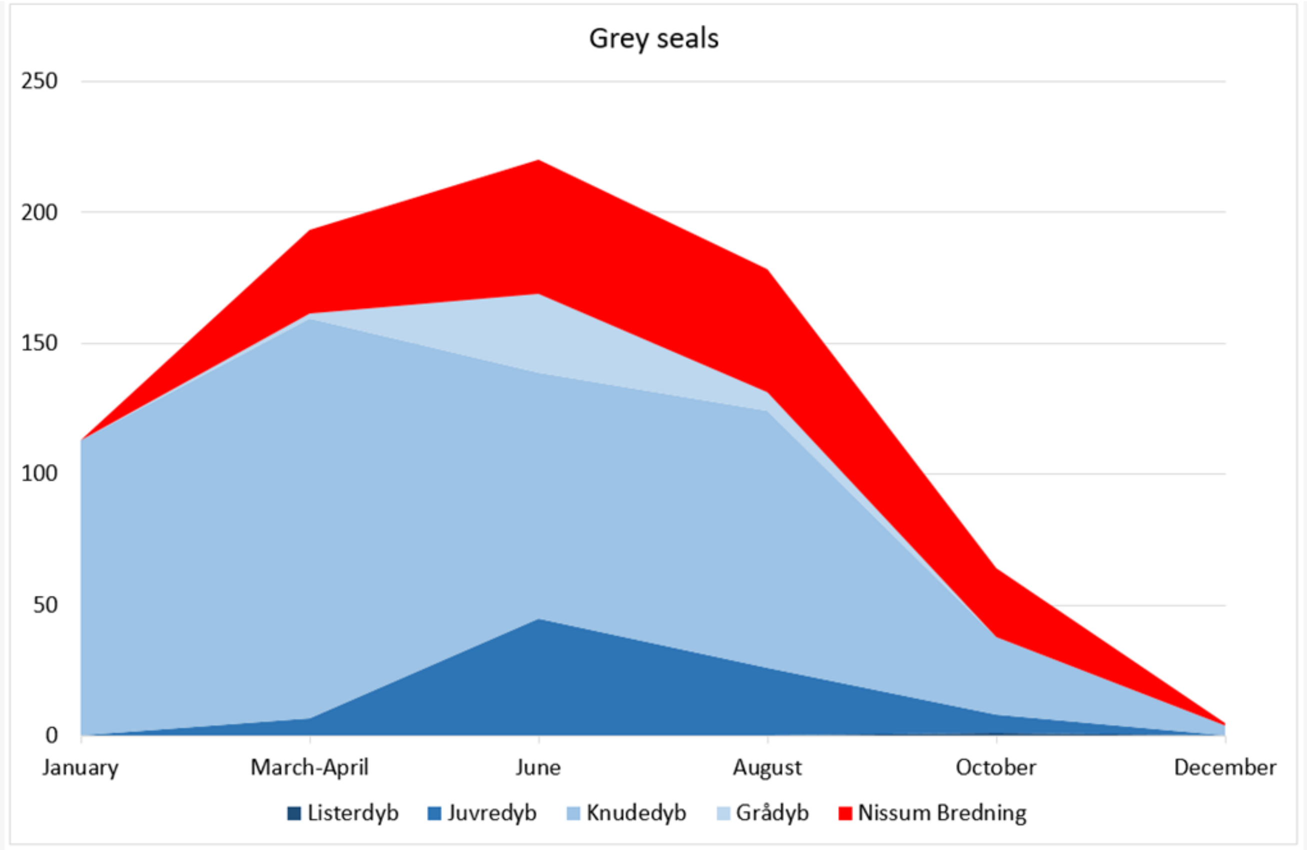

Figure 2-10 Counts of hauled out grey seals from the Wadden Sea (shades of blue for four subareas) and Nissum Bredning (red) from January to August 2022. Y-axis is number of counted seals. Data from Nissum Bredning in January, March–April, October and December and data from the Wadden Sea in March-April and October derive from the Energy Island investigations and are owned by Energinet. Remaining data are from the national monitoring program, NOVANA (Hansen & Høgslund 2024).

2.2.3 Seal usage of the North Sea I area from tracking data

While counting the seals on land can give information on the general trend of seal abundance in the area, only satellite tracking of seals can give direct information on the movement and distribution of seals at sea. Harbour seals are observed as far offshore as in the Danish oil and gas sector and grey seals are known to traverse the North Sea, both from the UK and from the Wadden Sea and the Limfjord. All available information on seal tracking from the relevant part of the North Sea are described below.

2.2.3.1 Harbour seals

In 2017–2020, 31 harbour seals were equipped with satellite transmitters in the inner Limfjord and results showed that none of these seals moved into the North Sea I survey area (Figure 2-11). Harbour seals have also been tagged in the Danish Wadden Sea in 2002–2005. Several of these harbour seals moved into the North Sea I survey area. These data are, however, 19–22 years old and may not reflect the movements of seals in the Wadden Sea today. For the Energy Island North Sea survey program, 27 harbour seals were tagged in Thyborøn/Nissum Bredning between May 2022 and March 2023 by Aarhus University and NIRAS. The methods and results were published in the North Sea Energy Island tagging report (Kyhn et al. 2024b). The results from that study is used in this report to describe the North Sea I area's importance for the seals at the nearest haul-out site. The movement tracks covered a period of 2–4 months for most seals. Most of the positions were recorded in the vicinity of the haul-out sites (Figure 2-12). Empty parts of individual tracks were fitted with a State-Space Model (SSM) to fill the gaps and showed how individual seals used different parts of the North Sea (please see Kyhn et al. (2024b) for methods on the fitted movement tracks).

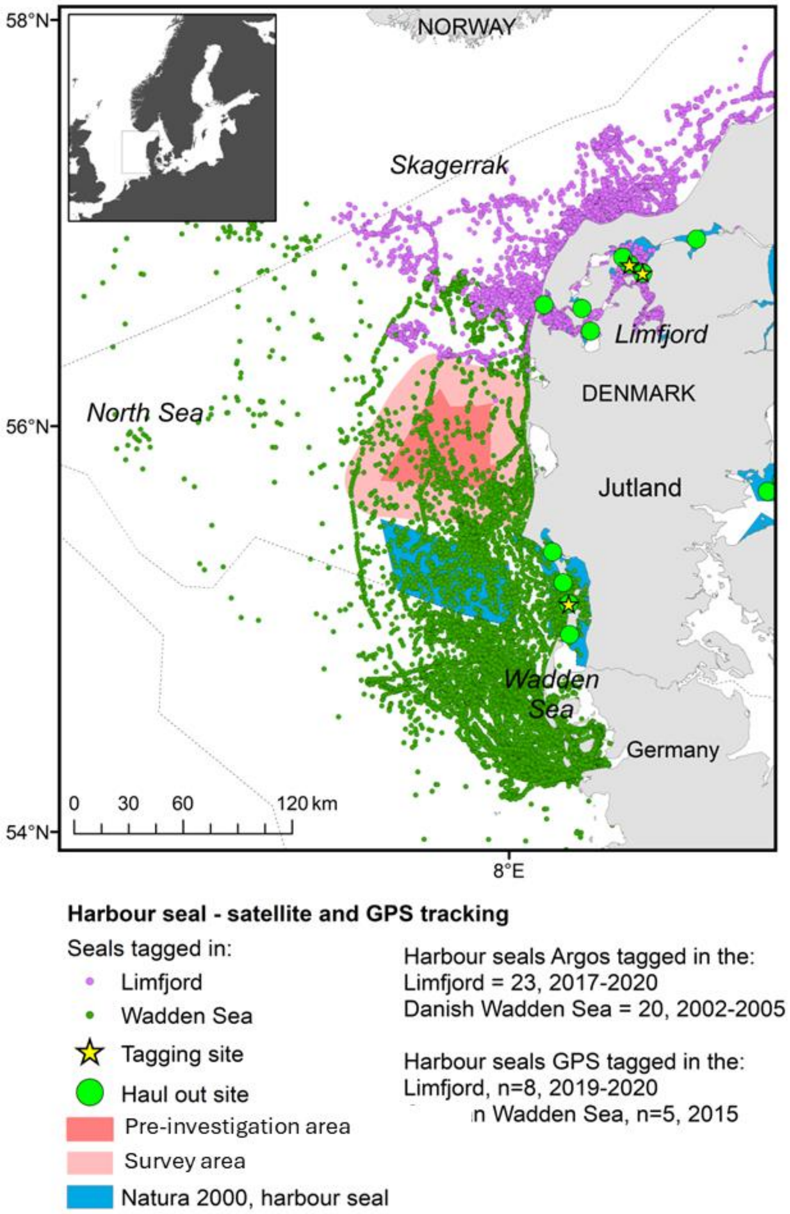

Figure 2-11 Map of positions from tagged harbour seals tagged between 2017 and 2020. The North Sea I investigation area is shown in dark pink and the marine mammal survey area in light pink.

Harbour seal – all filtered positions

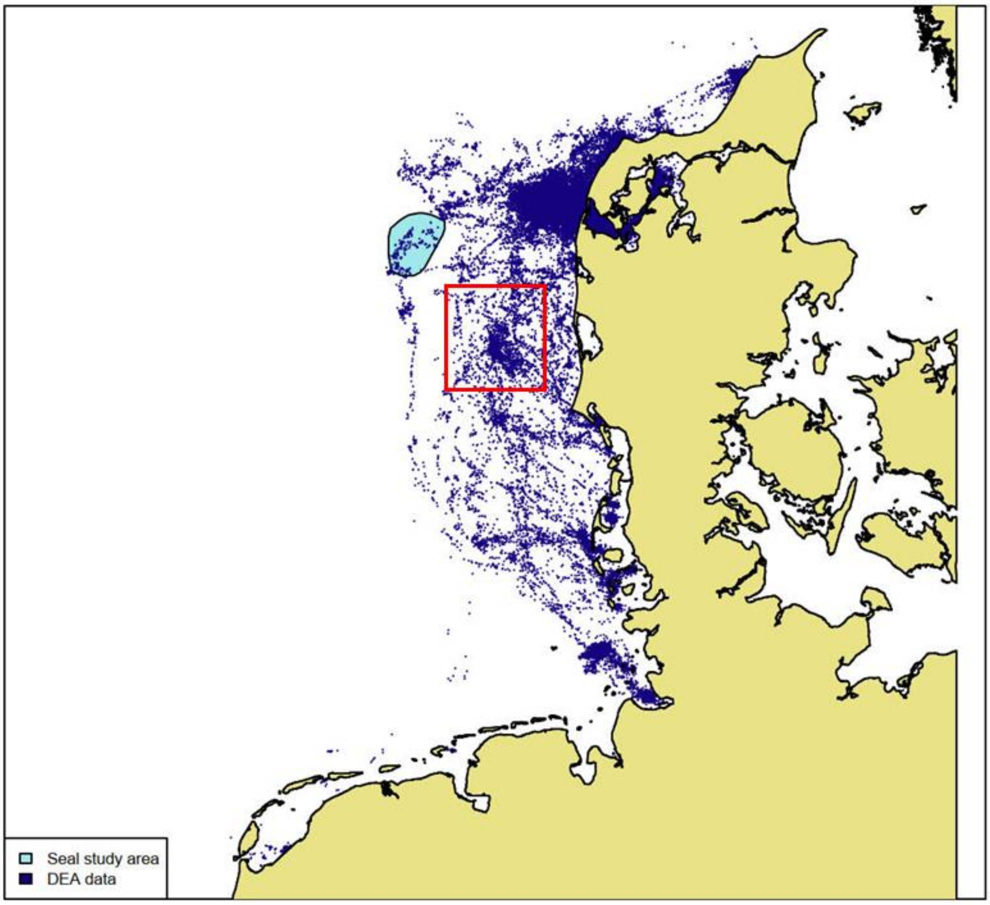

Figure 2-12 All filtered positions from the 27 harbour seals tagged in 2022–2023 for the North Sea Energy Island monitoring program. The light blue "Seal study area" was the area previously considered pre-investigation area for construction of an Energy Island. DEA is Danish Energy Agency. The approximate pre-investigation area for the North Sea I survey area is indicated in a red square. Modified from Kyhn et al. 2024b.

Data from the North Sea Energy Island tagging program as well as number of harbour seals hauled out at the nearest haul-out sites in August 2021 were used to make a habitat suitability model for harbour seals. The methods are thoroughly explained in Kyhn et al. (2024b). A number of variables were included in the model (sea surface temperature, sea surface salinity, current strength, sea surface height, mixed layer depth, distance to tagging site, water depth and substrate type). The habitat suitability model of harbour seal indicated that the likelihood of observing seals in different parts of the North Sea is related to a range of environmental variables and to distance to haul-out sites (Figure 2-13). Models that included all variables (i.e. temperature, salinity, current strength, sea surface height, mixed layer depth, distance to tagging site, water depth and substrate type) were much better than any of the models where one or more predictors were omitted. The best model for harbour seals explained 66% of the variation in seal presence. The habitat suitability maps indicate that the North Sea I survey area – especially the shallow water close to the tagging sites - is frequently used by harbour seals and the likelihood of encountering seals is particularly high close to areas with numerous seals haul-outs, such as the Wadden Sea.

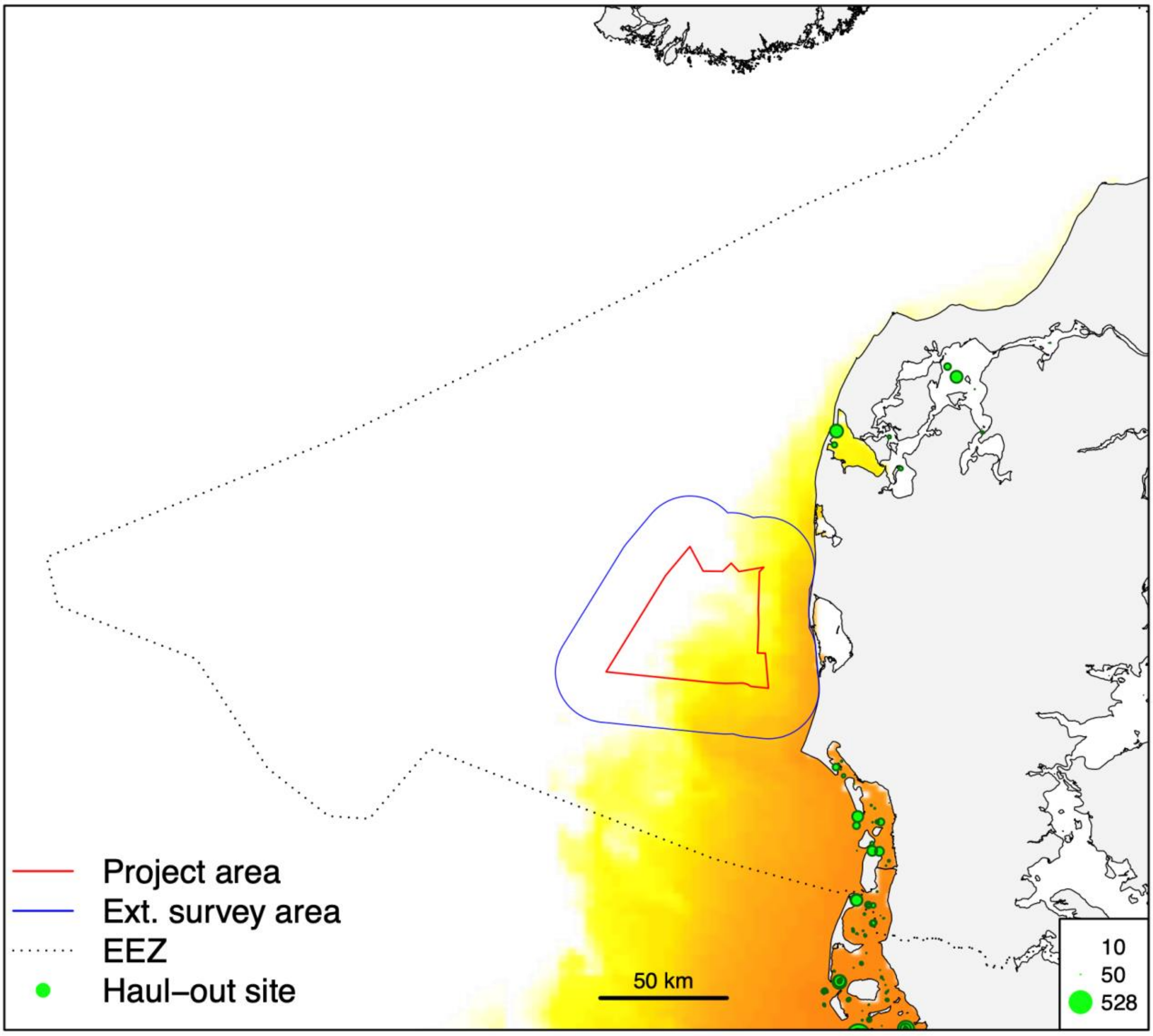

Figure 2-13 Habitat suitability map for harbour seals tagged at Thyborøn/Nissum Bredning for the North Sea Energy Island survey program. Green dots are haul-out areas with seals counted in the moulting season (August 2021); the size of the dots is proportional to the number of seals (1–528 seals per haul-out site). Not all German haul-out sites are shown. The colour scale signifies the relative probability that an area is used by seals with red-orange being high and white/yellow being low.

2.2.3.2 Grey seals

Grey seals have a more varied spatial behaviour than harbour seals. Prior to the North Sea Energy Island tagging program, the existing data on grey seals consisted of two grey seals tagged at Thyborøn and four newborn pups at Helgoland (Figure 2-14). The newborn pups are likely to have different movement patterns and home ranges than the adult individuals. None of these seals moved into the North Sea I survey area.

During the North Sea Energy Island tagging program, a total of 15 grey seals were tagged in Thyborøn between May 2022 and March 2023 by Aarhus University and NIRAS. Furthermore, 33 grey seals pups were tagged by Stiftung Tierärztliche Hochschule Hannover (TIHO) at Helgoland. The methods and results were published in the North Sea Energy Island tagging report (Kyhn et al. 2024b). The results from that study is used in this report to describe the North Sea I area's importance for the seals at the nearest haul-out site.

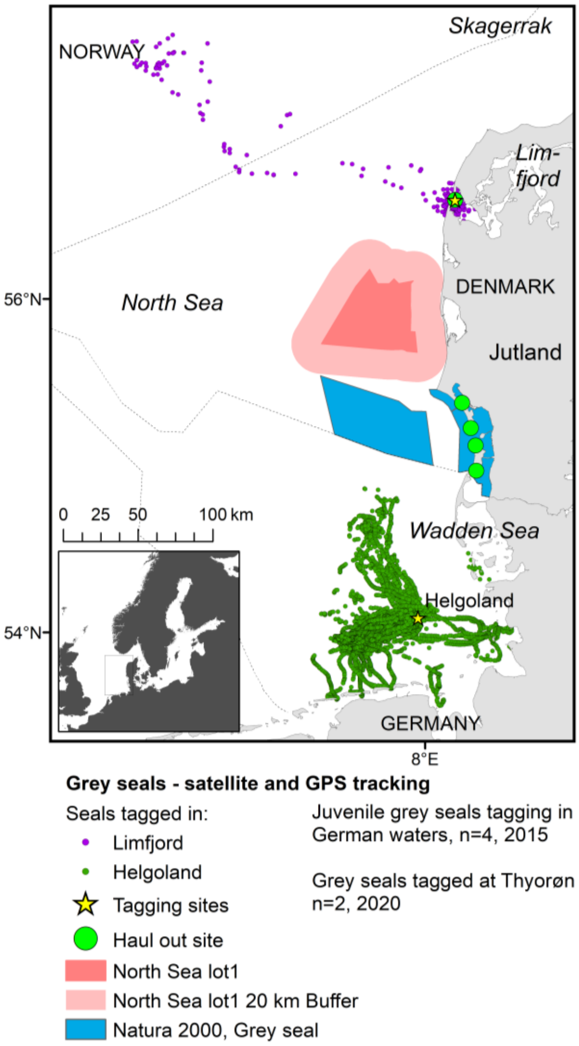

Figure 2-14 Map of positions from tagged grey seals between 2015 and 2020. The North Sea I pre-investigation area is shown in dark pink and the marine mammal survey area in light pink.

The habitat suitability model of grey seals was used unmodified from the North Sea Energy Island tagging report (Kyhn et al. 2024b) and indicated that the likelihood of observing seals in different parts of the North Sea is related to a range of environmental variables and to distance to haul-out sites (Figure 2-18). Models that included all variables (i.e. temperature, salinity, current strength, sea surface height, mixed layer depth, distance to tagging site, water depth and substrate type) were much better than any of the models where one or more predictors were omitted. The best model for grey seals explained 48% the variation in seal presence (please see Kyhn et al. (2024b) for thorough methods and all results).

The habitat suitability map indicates that all of the North Sea I survey area is frequently used by grey seals and the likelihood of encountering seals is highest in the southern part of the pre-investigation area.

The habitat suitability map for grey seals was not extended to the westernmost part of the Danish exclusive economic zone (EEZ), which is an area that is often visited by animals that haul out in the Dutch part of the Wadden Sea (Sophie Brasseur, pers. comm.). This study did not have access to information about the number of seals on the Dutch haul-out sites, and a prediction for grey seals based exclusively on information from Danish and German haul-out sites would underpredict grey seal densities in the western part of the Danish EEZ.

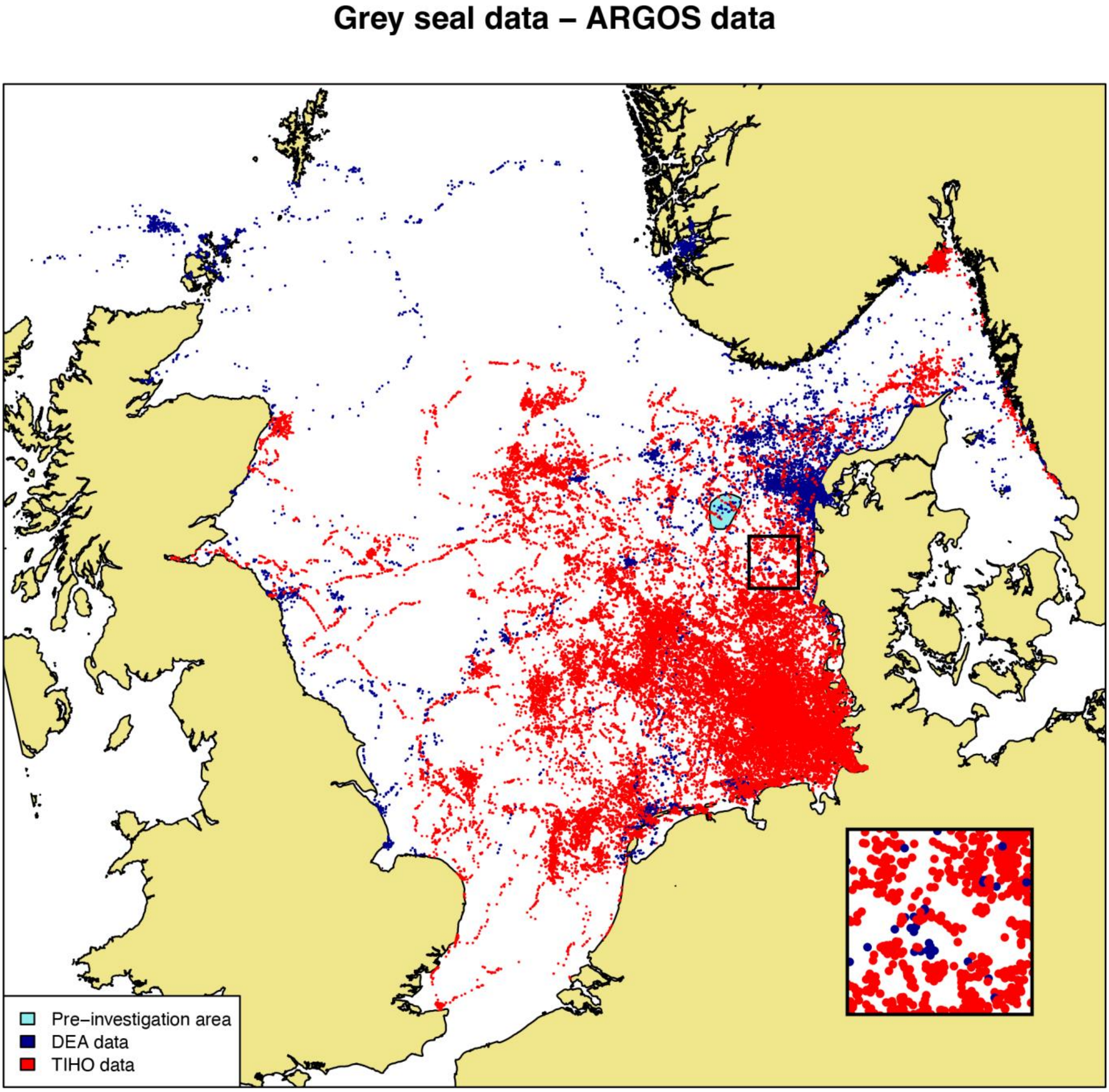

Figure 2-15 All filtered positions from the 15 grey seals tagged in 2022–2023 (dark blue dots) for the North Sea Energy Island monitoring program, as well as for 33 newborn pubs tagged at Helgoland. The light blue "Seal study area" was the pre-investigation area previously considered for construction of an Energy Island and 2–3 wind farms. DEA is the Danish Energy Agency and represents the seals tagged for the North Sea Energy Island program. The map has been copied unmodified from the Energy Island tagging Report (Kyhn et al. 2024b). The approximate area for the North Sea I survey area is indicated in a fat black line (enlarged in the bottom right corner of the figure).

The habitat suitability maps indicate that the North Sea I survey area is frequently used by both grey seals and harbour seals. Both species of seals predominately occur in shallow waters close to the tagging sites, and the likelihood of encountering seals is particularly high close to areas were numerous seals haul out, such as the Wadden Sea.

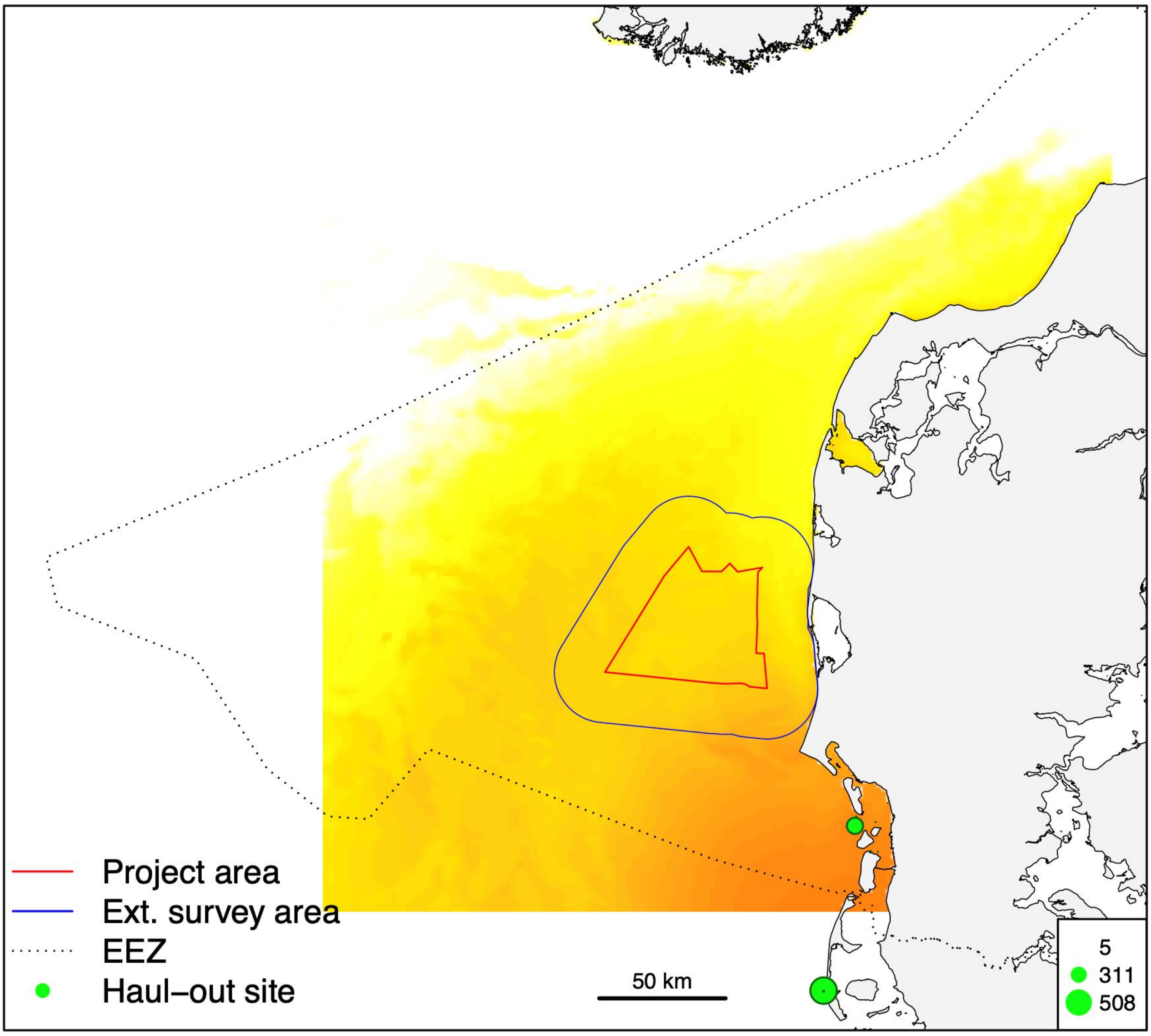

Figure 2-16 Habitat suitability map for grey seals tagged at Helgoland and Thyborøn. The green dots show haul-out sites where seals were counted in the moulting season of 2021, i.e., March–April; the size of the dots is proportional to the number of seals (1–508 seals per haul-out site). Not all German haul-out sites are shown. No seals were counted at Thyborøn in 2021. The colour scale signifies the relative probability that an area is used by seals. The habitat suitability map was copied from the Energy Island tagging report (Kyhn et al. 2024b) but superimposed with the North Sea Lot1 survey area. The map uses the EPSG:3035 ETRS89 projection.

2.3 Underwater soundscape

The present underwater soundscape in the eastern North Sea is dominated by noise contributions from ships in the main shipping lane from the English Channel around Skagen and into the Baltic Sea (Figure 2-17, see also

Kinneging and Tougaard, 2021). The shipping lane runs just outside the NW edge of the North Sea I pre-investigation area (but inside the North Sea I survey area), creating a gradient in the ship noise from west to east, with decreasing noise levels towards the less trafficked area north of Horns Reef OWF.

Underwater radiated noise from operating wind turbines has been measured for a substantial number of turbines (Figure 2-18, Figure 2-19). However, all but one set of measurements have been from turbines with a gear box and not of the direct drive type which is likely to be used in future North Sea wind farms. Furthermore, most of the recordings are from smaller turbines and the measurements of a low quality not suitable for use as input into a sound propagation model. Nevertheless, the noise from the turbines are clearly measurable above ambient noise and the combined noise from all turbines in a wind farm, as well as service ships, will add to the existing ambient noise (Tougaard et al. 2020). Earlier measurements on older and smaller turbines (Tougaard et al., 2020) indicates an increasing trend in noise emission with increasing turbine size, quantified by the nominal power output (Figure 2-18). More recent measurements on larger turbines (Bellmann et al., 2023) do not show the same trend, but indicate that the emitted noise level for turbines above 2 MW nominal power is independent of turbine size (Figure 2-19). The noise survey program will therefore obtain relevant data for the creation of a turbine noise source model and to use this source model as input in a model to estimate the cumulative impact from wind farms in the investigation area and relate this to other pressures (ships).

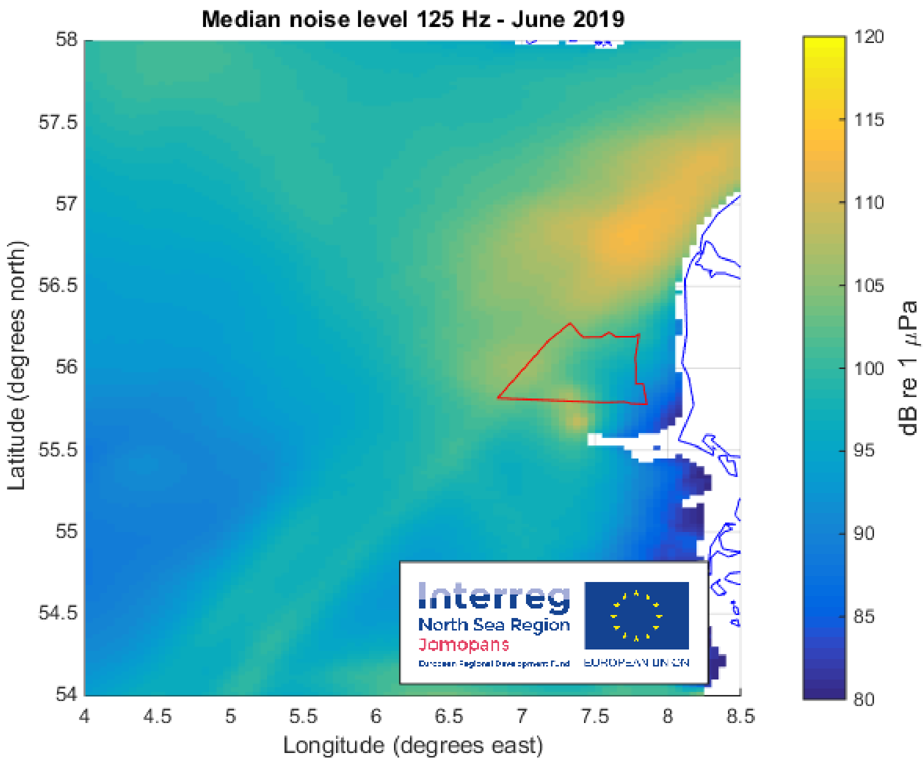

Figure 2-17 Existing underwater noise in the eastern North Sea, as modelled by the JOMOPANS project (de Jong et al. (2022)). Map shows median sound pressure level in the 125 Hz decidecade frequency band for the month of June 2019. The pre-investigation area is indicated with a red line. Courtesy of the JOMOPANS project.

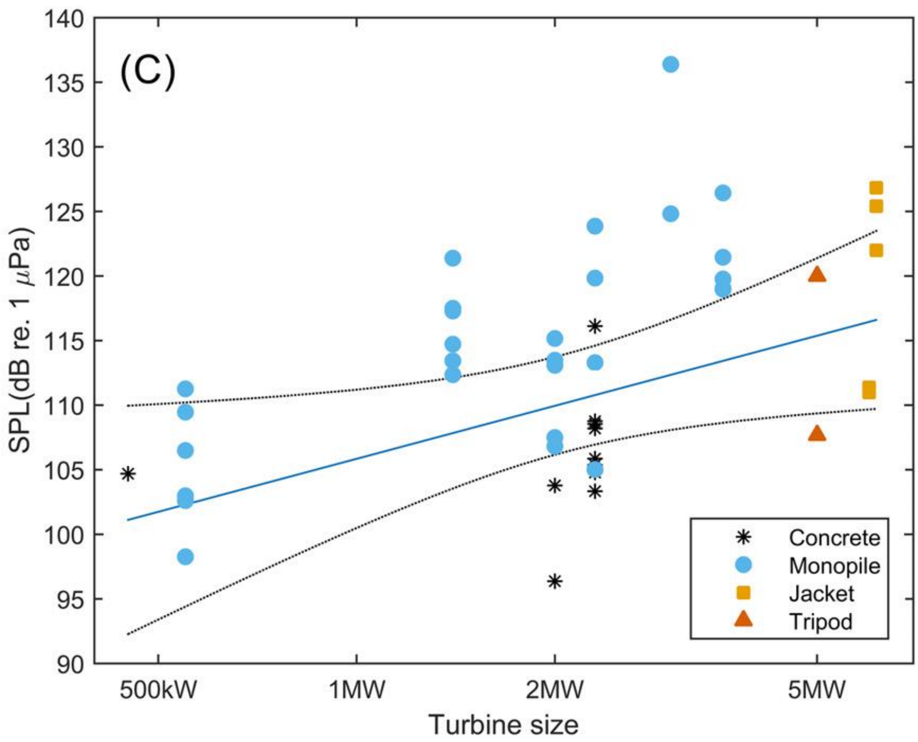

Figure 2-18 Influence of turbine size on measured sound pressure levels normalized to a distance of 100 m and wind speeds of 10 m/s. All turbines were with gear boxes except for one turbine (Block Island) which was direct drive (shown in light orange squares). From Tougaard et al. (2020).

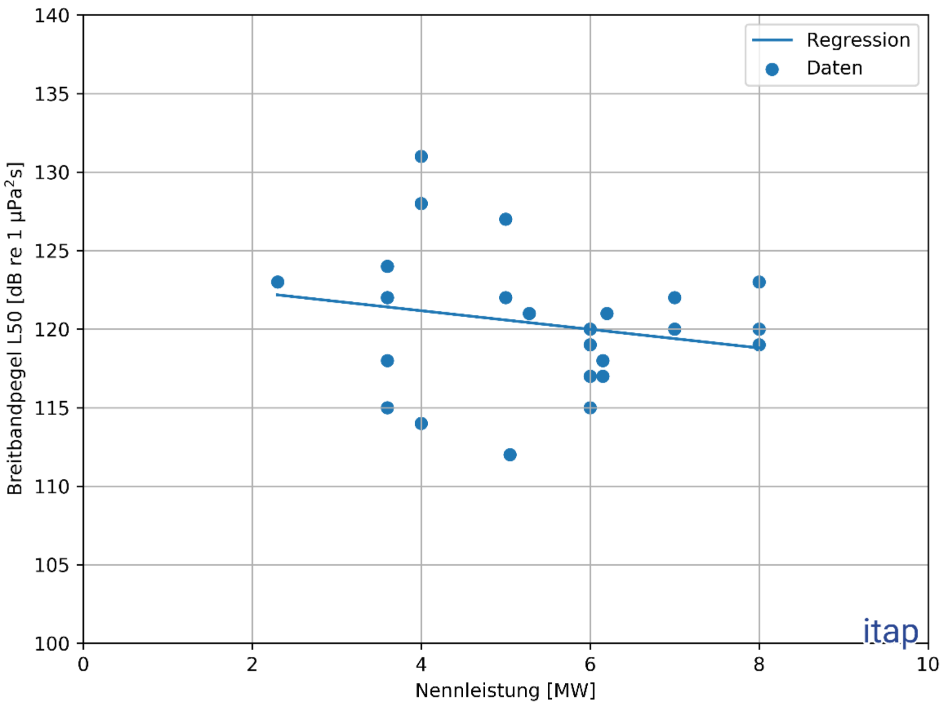

Figure 2-19 Broadband noise levels from larger offshore wind turbines, normalized to a distance of 100 m. From Bellmann et al. (2023).

3. Methods and survey(s)

Several different methods are necessary to monitor and document presence, abundance and density of marine mammals, and specific methods are needed to record, analyze and document underwater noise. The survey program is carried out from April 2023 to April 2025. This report includes data from the first year: April 2023–March 2024.

The data collection and analysis are divided into three parts, which will be described in detail in the following sections:

- Passive acoustic monitoring (PAM) of cetaceans
- Aerial surveys of cetaceans
- Underwater noise:
  1) Underwater noise monitoring
  2) Noise levels from turbines
  3) Harbour porpoise movements near operating turbines
  4) Noise exposure maps

3.1 Passive acoustic monitoring of cetaceans

Deployment of passive acoustic monitoring (PAM) systems within the survey area is conducted for two years to study the detailed temporal presence of harbour porpoises and other cetaceans. Two different instruments are used to be able to capture and analyze signals from both harbour porpoises, delphinids and minke whales.

3.1.1 Harbour porpoises

As the harbour porpoise is the most common cetacean species in Danish waters, F-PODs were used as the main PAM system. The F-POD has been specifically developed for detecting harbour porpoise echolocation signals.

The F-PODs have very good temporal resolution but relatively low spatial coverage, since the harbour porpoise detection range of F-PODs is less than some 500-1000 m (DeRuiter et al. 2010). This is caused by the low source level, high frequency and narrow beam pattern of harbour porpoises and applies to all PAM systems designed to detect harbour porpoises in salt water. Because the presence of harbour porpoises may vary with habitat and hence distribution of various prey species, F-PODs were placed with an evenly distributed grid across the survey area (Figure 3.1). This design captures the variation in bathymetry (14–40 m) in the area, which may be an important driver for harbour porpoise distribution, thereby allowing for spatial distribution models to be conducted for each season. The grid spacing was decided based on results from the Danish national monitoring program NOVANA. Here, power analysis has shown that five stations is appropriate to monitor the Natura 2000 sites in the Inner Danish waters with the density of harbour porpoises given there. The largest of these ("Storebælt og Vresen") is 630 km^2. The NS1 survey area is approx. 10 times this size. Thus, the grid should fit in 50 stations. However, the area is relatively uniform in both bathymetry and sediment types, and therefore less variation in porpoise presence is expected compared to Inner Danish waters. Consequently, it was decided to lower the number to 35 stations. The grid was adjusted to fit this number inside the survey area.

To compare with previous studies and examine the long-term trend and stability of harbour porpoises in the area, seven additional stations were deployed (two in the Thor OWF area and five in and near Horns Rev III) (Figure 3-1). To facilitate the comparison with previously gathered data, stations in the OWFs (as well as the two stations in the grid located within the areas of Thor OWF and Horns Rev III) were deployed with both C-PODs and F-PODs, as the older studies were conducted with CPODs (which are no longer commercially available). This means that in total 42 stations were deployed. The positions were all approved by the Danish Maritime Authorities on 16th of January 2023 and both Vattenfall (Horns Rev 3 Offshore Wind Farm) and RWE (Thor OWF) have approved deployment within "their" OWF sites. Metadata for all PAM positions are shown in Table 3-1. Statistical analyses of the data collected at Horns Rev 3 Offshore Wind Farm and Thor Offshore Wind Farm were done using generalised mixed effect models. The main purpose of the analyses was to assess differences in harbour porpoise echolocation activity around the wind farms at different years and for Horns Rev 3 Offshore Wind Farm also for differences between the three stations deployed inside the wind farm and the three stations deployed outside the wind farm. PPM per day was fitted as the response variable in all models using a Poisson error distribution and Station ID nested within month as random variables (to account for unbalanced data design). The model constructed for Thor OWF had year of data collection (i.e. 2019-2020 versus 2023-2024) fitted as an explanatory 2-factor level. A similar model was constructed for Horns Rev 3 Offshore Wind Farm but comparing data collected in 2012-2013 versus 2023-2024 but fitted as an interaction with the placement of the stations (i.e. inside or outside the OWF). Differences in harbour porpoise echolocation activity between years and placement were then estimated using a Tukey post-hoc test for mixed models. For all models, statistical differences in PPM per day between years and placements were considered to be present with a P-value <0.05.

Table 3-1 Metadata for all PAM stations as well as depth and mooring type. FPODs and CPODs record harbour porpoises. A SoundTrap is a wideband acoustic recorder aimed for cetacean detections other than harbour porpoises and noise.

StationID	Longitude	Latitude	Equipment - Cetacean	Depth (m)	Mooring
NS1	6.5290	55.7760	FPOD	-41	Normal surface bouy
NS2	6.6906	55.8746	FPOD + SoundTrap	-39	Normal surface bouy
NS3	6.7018	55.6842	FPOD	-37	Normal surface bouy
NS4	6.8652	55.7824	FPOD	-35	Normal surface bouy
NS5	6.8547	55.9729	FPOD	-39	Normal surface bouy
NS6	6.8441	56.1634	FPOD + SoundTrap	-39	Normal surface bouy
NS7	7.0390	55.6900	FPOD	-32	Normal surface bouy
NS8	7.0286	55.8810	FPOD	-32	Normal surface bouy
NS9	7.0197	56.0710	FPOD	-35	Normal surface bouy
NS10	7.0099	56.2615	FPOD	-36	Normal surface bouy
NS11	7.2033	55.7879	FPOD	-29	Normal surface bouy
NS12	7.1960	55.9784	FPOD	-33	Normal surface bouy
NS13	7.1871	56.1690	FPOD + SoundTrap	-34	Normal surface bouy
NS14	7.1765	56.3594	FPOD + SoundTrap	-34	Normal surface bouy
NS15	7.3763	55.6949	FPOD	-23	Normal surface bouy
NS16	7.3684	55.8855	FPOD + SoundTrap	-24	Normal surface bouy
NS17	7.3601	56.0771	FPOD	-30	Normal surface bouy
NS18	7.3522	56.2665	FPOD	-34	Normal surface bouy
NS19	7.5397	55.7923	FPOD	-16	Normal surface bouy
NS20	7.5325	55.9829	FPOD	-26	Normal surface bouy
NS21	7.5251	56.1734	FPOD	-33	Normal surface bouy
NS22	7.5197	56.3639	FPOD	-32	Normal surface bouy
NS24	7.7079	55.8895	FPOD	-23	Large surface bouy
NS25	7.7015	56.0814	FPOD + SoundTrap	-30	Normal surface bouy
NS27	7.8851	55.6053	FPOD	-14	Large surface bouy
NS28	7.8797	55.7959	FPOD	-20	Large surface bouy
NS29	7.8742	55.9864	FPOD	-23	Normal surface bouy
NS30	7.8686	56.1770	FPOD	-27	Normal surface bouy
NS31	7.8630	56.3676	FPOD	-26	Normal surface bouy
NS32	8.0512	55.7020	FPOD	-17	Large surface bouy
NS33	8.0465	55.8926	FPOD	-20	Normal surface bouy
NS34	8.0418	56.0832	FPOD	-14	Normal surface bouy
NS35	8.0371	56.2737	FPOD	-21	Normal surface bouy
HR3_1	7.6081	55.7148	CPOD/FPOD	-17	acoustic release
HR3_2	7.6725	55.6485	CPOD/FPOD	-12	acoustic release
HR3_3/NS	7.7141	55.7012	CPOD/FPOD	-19	acoustic release
HR3_4	7.7908	55.7348	CPOD/FPOD	-18	Large surface bouy
HR3_5	7.8519	55.7173	CPOD/FPOD	-16	Large surface bouy
HR3_6	7.9010	55.7487	CPOD/FPOD	-18	Large surface bouy
T2	7.5437	56.2799	CPOD/FPOD	-32	Normal surface bouy
T3/NS26	7.6946	56.2706	CPOD/FPOD	-31	Normal surface bouy
T4	7.6816	56.3391	CPOD/FPOD	-29	Normal surface bouy

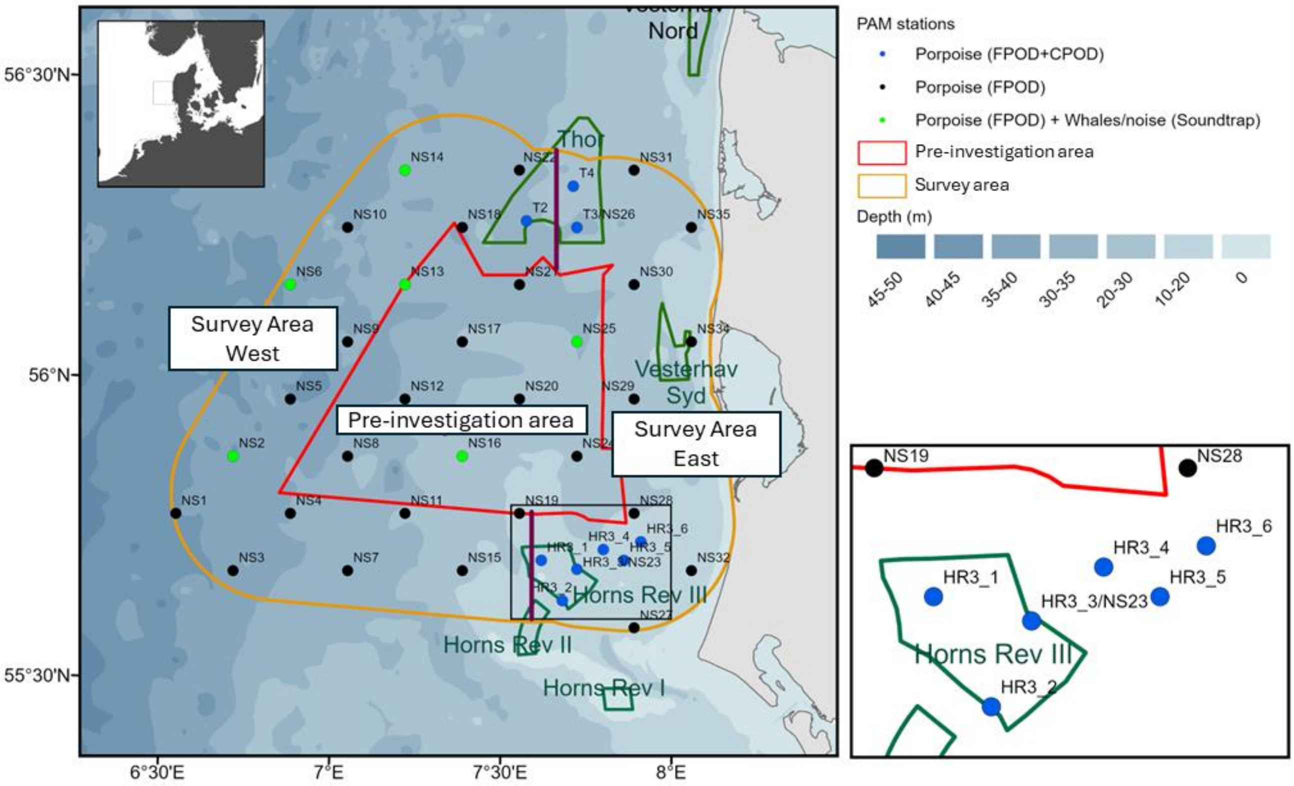

Figure 3-1 Overview of the PAM program with 42 stations in the survey area. Six of these have SoundTraps for broadband species monitoring/noise measurements (green positions), 9 have both F-PODs and C-PODs (blue positions) and the rest only F-PODS (black positions). The PAM stations were placed following a regular grid. For result illustration purposes, the stations were divided into groups: the pre-investigation area, the survey area west and survey area east (division lines marked in burgundy).

A 6 m yellow surface buoy (type N225/6) was used “to guard” the F-POD at each monitoring station by informing trawling vessels of their presence. The setup was developed by Bioconsult SH and have been used successfully in several projects e.g. at Thor OWF and Horns Rev III OWF - both located within the current survey area. The surface buoy was connected to the equipment by a rope along the sea bottom (see sketch of setup in Figure 3-2). All surface buoys were equipped with a satellite transmitter allowing us to monitor their continuous presence. In case the buoy was removed by trawlers or hit by a vessel, we could follow its location, which allowed us to regain it. The stations were serviced approximately every third month and data was downloaded and validated immediately after each survey.

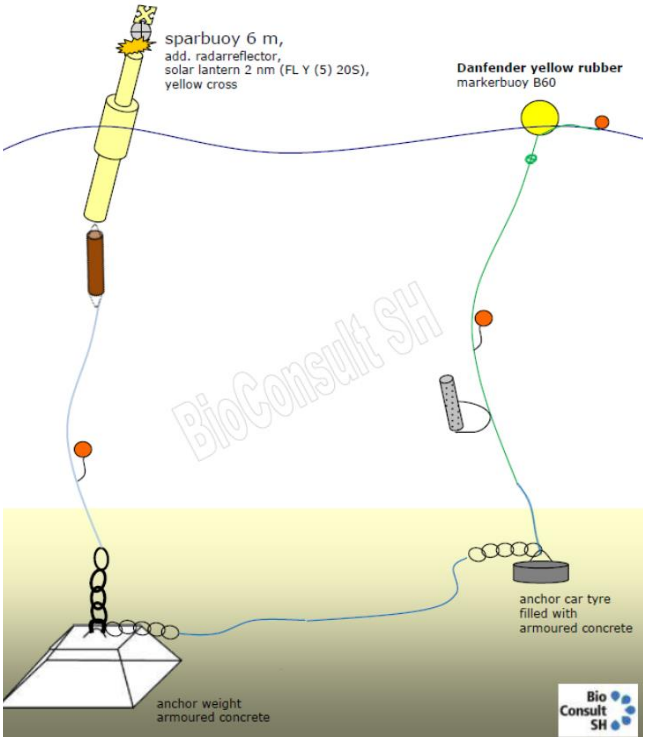

Figure 3-2 PAM setup. The large surface buoy is connected to a large concrete anchor. The concrete anchor is connected with a rope to a smaller cement tyre anchor which is connected to a small rubber float at the surface. The recording device (F-POD, C-POD and/or Sound trap) is positioned on the rope approx. 2 m from the sea floor.

3.1.1.1 Analysis of FPOD data

Data from FPODs are analyzed using the program FPOD.exe (Chelonia Ltd.). Here, the recorded CHE files are converted to FP1 files, where click events are found according to an inbuild algorithm. FP1 files are then converted to FP3 files where clicks are ascribed to trains of various origin. These are Narrow Band High Frequency (NBHF) - which in the North Sea is exclusively harbour porpoises - delphinids and (shipborne) sonar. Each click train is associated with a likelihood ratio, related to the probability that it originated from the source it was classified as (NBHF, Delphinids or sonar. Here only click trains of high or moderate likelihood of arriving from NBHF species were exported and used for analyses. Data from the day of deployment and the day of retrieval were discarded to exclude effects of the service vessel on presence of porpoises from the analysis. To assess variation in harbour porpoise presence, FPOD data exported as Porpoise Positive Minutes (PPM) per day was summarized and graphically illustrated across months, stations, and each of the three areas (project area and the two buffer zones: east and west). In FPOD.exe data are exported using the following train filters: Quality High and Moderate for the "NBHF" (Narrow Band High Frequency) and "Other cetaceans" filter. A porpoise positive minute is a minute with at least one porpoise click from a click train in the category high or moderate likelihood of arriving from a NBHF source recorded. Graphs show either the absolute values of PPM per day or the mean and standard error around the mean (SEM).

To model any spatial and temporal variation in porpoise presence as a function of environmental conditions, acoustic Species Distribution Maps (aSDMs) were generated based on generalized additive models (GAMs). A separate GAM was developed for each month using PPM per day as the response variable. Eleven environmental features were considered as predictor variables including bathymetry, seabed slope, seabed rugosity (i.e. ruggedness), distance to nearest sandeel spawning ground, sea bottom temperature, sea surface temperature, sea surface salinity, sea surface height, current velocity, and mixed layer thickness. Raster data on the environmental features were obtained through the open-access, online sources Copernicus and Emodnet and linked to the stations via their geographical coordinates and the date of recording. Multicollinearity among the 11 candidate predictor variables was substantial with variance inflation factor >20 and Spearman's rho >0.7 for various variable combinations. Based on a backwards, stepwise procedure, we removed seabed rugosity and sea bottom temperature as this produced variance inflation factors <5 and Spearman's rho <0.6. All uncorrelated environmental predictor variables (N=8) were fitted in the monthly GAMs as a smoothed term with shrinkage, which allows for uninformative terms to be penalized to zero, effectively making them linear. To ensure smooth functions reflected plausible biological relationships, the number of knots (k) was restricted to 4, as higher knots lead to increasingly complex functions that are difficult to explain biologically. Station ID was included as a random intercept so that the relationships in the models were estimated across PAM stations rather than data points, ensuring that data-rich stations did not have a disproportionate influence on the overall trends. Spatial autocorrelation in the data was estimated by incorporating the interaction between the XY coordinates of each station as a smoothed term. For each monthly model, the regression coefficients were used to predict and map variation in harbour porpoise presence across the area. To do so, a prediction layer of PPM was generated for each day of the month which were then used to calculate the mean.

3.1.2 Influence on PAM results of geophysical surveys

Geophysical surveys were conducted in the survey area while the PAM data was being collected. The potential effect of survey activities on the data is currently being investigated in a separate study and the results will be included in the report resulting from the 2nd year of surveying.

3.1.3 Other cetaceans

The presence of other relevant cetaceans with a focus on white beaked dolphins and minke whales within the survey area was unknown prior to this study. These species are usually found in deeper waters, and therefore their presence was assumed to be confined to the deeper, western waters of the survey area. The F-POD is not able to detect low frequency sounds below 20 kHz, such as those produced by minke whales, and echolocation clicks from dolphins are unlikely to be categorized correctly with F-PODs (Cosentino et al., 2024). Instead, other cetacean vocalizations (echolocation clicks and communication sounds) were captured by broadband sound recorders (ST600HF SoundTraps, Ocean Instruments), which were deployed along with F-PODs at selected stations, mainly in deeper waters, though with coverage in each quarter of the survey area. Thus, at six of the PAM stations, SoundTraps (see Figure 3-1) for recording other cetaceans and underwater noise were deployed. This enables documentation and seasonal presence of other cetacean species and provide noise recordings needed to determine potential exposure of harbour porpoises to underwater noise. The SoundTraps are broadband sound recorders and have an integrated hydrophone, with a frequency response of 20 Hz–150 kHz and a sensitivity range between 174.4–176.7 dB re. 1 µPa/V. In order to capture the full bandwidth of marine mammal vocalizations, including delphinid echolocation clicks, the marine mammal stations were programed to record with a sampling rate of 384 kHz on a 45-minute on per hour duty cycle to allow recording for three months at a time. It is not possible to record continuously for three months at a time due to battery and memory limitations, which was the service interval in the survey program. Forty-five minutes per hour was selected as these sound recordings will also be used in the noise analysis, which requires a minimum of 30-minute sound files (BIAS). However, for deployment D (February 2024) and onwards, due to the erratic servicing of stations caused by weather, a duty cycle of 30 minutes on per hour was selected to maximize battery/memory life. This change allows full temporal coverage for up to five months.

Recordings from each deployed instrument was individually assessed for usable data, also known as quality assurance/quality control (QA/QC), therefore a preliminary analysis outside of the detection and classification of marine mammals and noise processing was conducted, to remove periods of recordings that are not representative of the conditions in the surroundings. Additionally, the recordings from each deployment were quality checked to ensure the broadband recorder captured the marine soundscape without so-called parasitic signals of internal origin (self-noise of the electronics) or external origin (noise from the mooring).

3.1.3.1 Delphinid analysis

Following the QA/QC, data was analyzed with the open access software platform PAMGuard (Gillespie, et. al. 2008) to detect and classify possible whistles and click encounters from odontocetes, by means of built-in and custom detectors and classifiers (Griffiths et al., 2023). One detector was tasked with finding dolphin whistles, and another tasked with finding echolocation clicks and burst pulses from non-porpoise odontocetes. After a manual review of the detector results, whistles and clicks were categorized to species groups, as far as possible. An event was defined as the time between the start and end of recorded odontocete vocalizations. By definition, events were separated by at least 10 minutes before a new event began. Non-porpoise odontocetes are notoriously difficult to classify to species based on acoustics alone but are very easy to separate from harbour porpoises. Most often, encounters could be classified into either of two groups: white-beaked dolphins, identified by spectral banding in both echolocation and burst pulses, and other delphinids, which contain the possibility to include killer whales (*Orcinus orca*), long-fined pilot whales (*Globicephala melas*), bottlenose dolphins (*Tursiops truncatus*), white-beaked dolphin, and potentially Atlantic white-sided dolphin (*L. acutus*). Not all white-beaked dolphin events contain spectral banding, and therefore it is possible that some events categorized as ''other delphinid' also contain white-beaked dolphin encounters. To investigate if there was a diurnal pattern in dolphin events, the time between sunrise and sunset needed to be normalized, since daylight varies dramatically throughout the year in the survey area. Sunrise and sunset times were extracted in R based on the solar azimuth, solar elevation, and the declination angle of the sun (Meeus et al., 1991). Daylight was normalized between 0 (sunrise) and 1 (sunset), while nighttime was normalized between -1 (sunset) and 0 (sunrise) per day around the center of the study area (56°N & 7°30’E).

The data collection methods in this study are similar to data collected during the North Sea Energy Island survey program (Kyhn et al. 2024a), but differ in recording length. Similar to the previous analysis, the review of broadband data for odontocete vocalizations is highly time-consuming and therefore duty-cycling analysis is employed. This approach has been shown to not have a significant impact on the ability to detect odontocete vocal activity (Kyhn et al. 2024a). However, in the North Sea Energy Island survey program, which duty-cycled 10–12 minutes per 15, the individual sound files were able to be treated as snapshots, a time window in which animal presence was documented in a point-transect survey style that ignores animal movement and correlation (Buckland, 2006). If one of the four quarters/sound files per hour contained a dolphin detection, that was then considered a detection positive hour (DPH) for delphinids. To make the methods used currently more directly comparable to those within the North Sea Energy Island monitoring program, 15-minute intervals between the start and end time of each deployment were generated. How the measured recordings overlapped with those snapshot intervals were then observed. Using this method, it is possible to calculate how many hours from the deployment were included in the duty-cycled delphinid analysis (Figure 3-3). The calculation of DPH per deployment will then be based on hours available for analysis, rather than the full deployment timeframe. This method is robust and comparable to changes in recording length, measuring how much coverage there was available per hour.

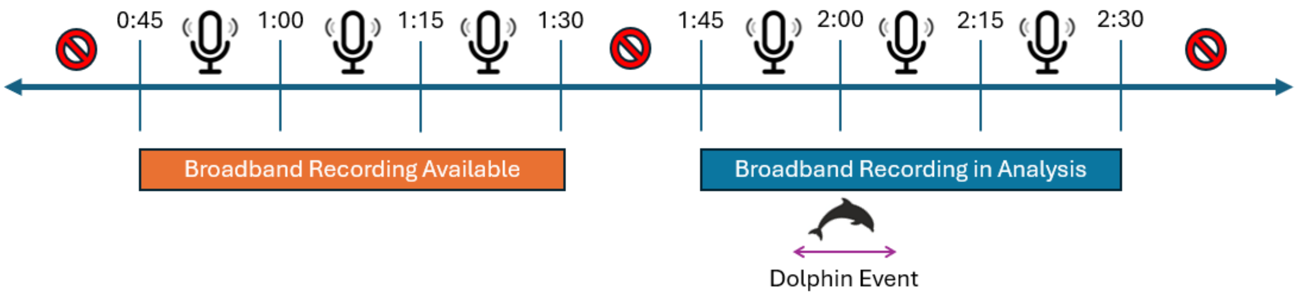

Figure 3-3 Overview of snapshot data processing. Each hour is divided into four 15-minute quarters, based on the start times of the sound file. If a dolphin event duration spans two quarters included in analysis, it is counted in both quarters, as this is how the data would have been counted in the North Sea Energy Island survey program (Kyhn et al. 2024a).

3.1.3.2 Minke Whale Analysis

Based on survey observations, the North Sea is a known habitat for minke whales, and there exists published methods to detect and classify minke whale pulse trains from autonomous recordings (Risch et al., 2013; Risch et al., 2014; Risch et al., 2019). These methods have been used to help monitor minke whale migration and seasonal use of western North Atlantic waters and have been successfully applied to the Moray Firth along the east coast of Scotland, which is adjacent to our study area in the North Sea. Our original acoustic survey design for minke whales was to employ the methods developed by Risch et al. in our waters, which targets the minke whale pulse train (Risch et al., 2019).

The published version of the Risch minke whale detector is not feasible for this report due to issues with the XBAT (Figueroa & Robbins, 2008) platform no longer being supported or maintained. In the past year, however, the tool has been redesigned and integrated into the ketos python framework (MERIDIAN 2020). While this revised tool is still in beta development, access was granted to test the tool on this data. Therefore, it should be noted that when the revised tool undergoes peer-review, it may be changed and thus the results may vary. Using the same periodic subsampling from the odontocete analysis, the new minke whale detector was run on 25% of all stations, ensuring that at least one 45-minute file would be analyzed per four hours for full temporal coverage of the survey. The output of the detector is a csv file which contains times minke whale vocalizations may have been detected. Additionally, the detector generates clips for each detection, as well as a jpg file of each clip. This allows for the results to be manually audited and verified.

3.2 Aerial surveys of cetaceans

Aerial cetacean surveys were conducted to obtain information on abundance across seasons within the survey area. However, since the hours of daylight are few and the weather likely to be poor in the winter, the aerial cetacean surveys were planned to be conducted from April to October 2023. The aerial surveys also provided information on the presence and distribution of calves in order to determine whether the survey area is a potential calving ground or not.

Aerial surveys using observers is at present the only method for abundance estimation comparable to previously conducted surveys in and near the area e.g. the annual NOVANA aerial porpoises surveys in the southern North Sea and Skagerrak (Hansen & Høgslund 2021) and the international SCANS surveys, lastly conducted in July 2022 (Gilles et al. 2023).

Aerial surveys of cetaceans followed pre-designed transect lines that ensured equal coverage probability within one full day's survey (average transect length was 83 km and the total length 1084 km). The aerial surveys were conducted by three experienced observers on board the aircraft (Partenavia 68 with bubble windows): two observers positioned at the bubble windows and one data collector. During line transect distance sampling, the perpendicular distance of a porpoise sighting to the track line was measured with a clinometer. The distances are used in the 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 at a constant speed of 100 knots. Transect lines are defined in a parallel design of east-west lines in the investigation area i.e. perpendicular to the depth contours as recommended for this method. This means that the data is representative of the entire survey area (Figure 3-4). OWFs can not be covered, as it is not allowed to fly that low over windfarms. OWFs are therefore excluded in all aerial surveys.

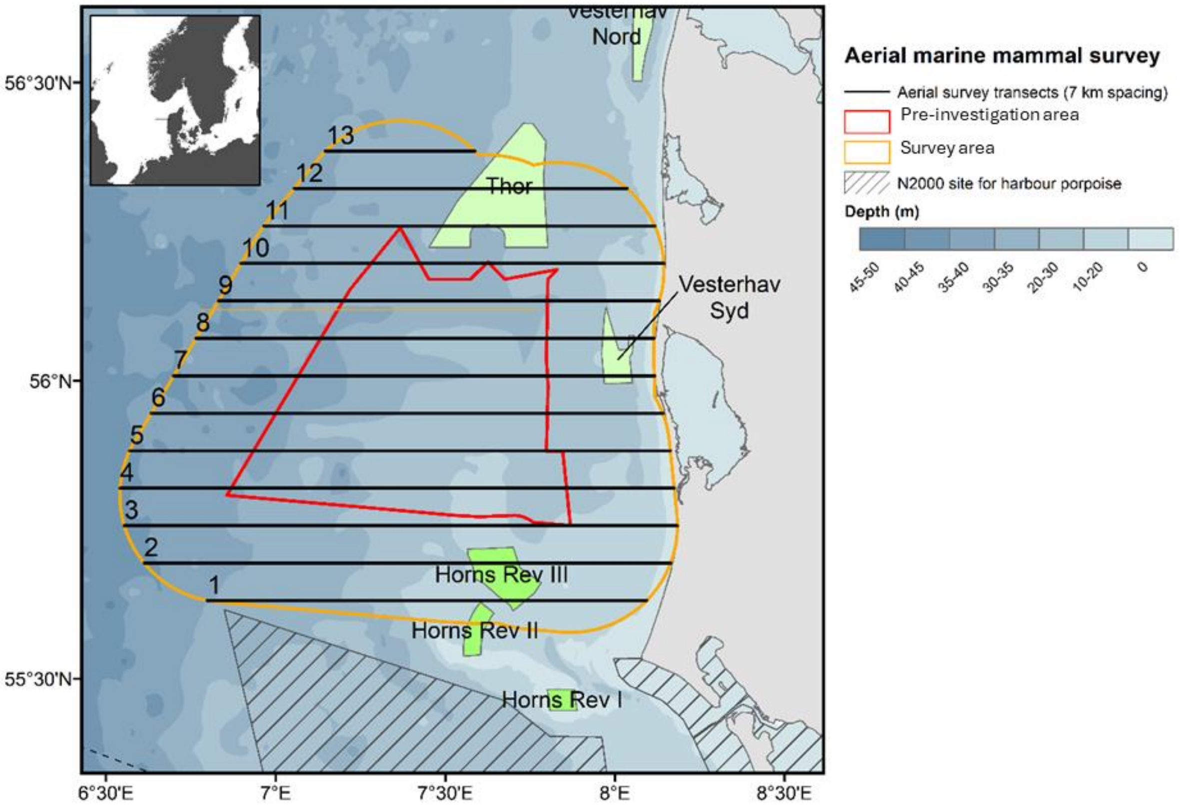

Figure 3-4 Overview of the aerial survey program for marine mammals in the investigation area. The transect lines are placed with a distance of 7 km.

During the aerial surveys, all detected marine mammals were recorded and the location and number of observations per species were documented. Marine mammals were also observed during the aerial bird surveys (for details see the North Sea I Technical report for birds). These data are included in the presentation of dolphins and minke whale presence. However, because these data are collected with a different methodology and at a different height, these observations cannot be included in the density calculations.

3.2.1 Analysis of aerial survey data

After the survey, the collected data was analyzed to estimate abundance and density of all species (for which enough data was collected), distribution of harbour porpoises and presence of harbour porpoise calves.

Analysis of abundance was conducted in the software R using a special script developed during SCANS-IV. The analyses included variables such as weather and sea state to estimate the abundance and densities covering the observation period.

The number of harbour 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 of data from the survey area, the observer team, methodology and the survey plane were consistent with the one used during SCANS-IV in 2022 in European (incl. Danish) waters and thus the g(0) value and other relevant information such as the effective strip width used during SCANS-IV (Gilles et al. 2023) was applied. The major advantage of this method is that it takes into account both availability and perception bias with the same data collected.

Harbour porpoise abundance in the survey 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).

3.3 Underwater noise

The potential exposure to underwater noise and vibrations is investigated to create a model that combines information on distribution of marine mammals, reaction of these animals to relevant noise sources, and underwater noise exposure maps. Thus, this work consists of three parts:

1. Creating noise exposure maps encompassing the exposure levels from all combined noise sources prior to the construction of the proposed wind farm. These maps are conceptually similar to the JOMOPANS maps (Figure 2.4) but updated with actual ship traffic from 2023 and including noise emission from operating wind turbines (see further description below).
2. Gain knowledge on how harbour porpoises react to the included noise sources, in particular operating wind turbines. This includes recordings of operating turbines at different wind speeds and field recordings of harbour porpoise presence near operating turbines.
3. Overlaying model combining part 1-2 (as done by Faulkner et al. 2018, see further description below).

3.3.1 Noise monitoring

The existing underwater noise in the survey area was monitored as an integral part of the PAM monitoring for dolphins and minke whales (see section 2.3.2 on cetacean PAM). Broadband acoustic recorders, the SoundTrap ST600 (Ocean Instruments, Inc.) were deployed at six of the 42 PAM stations (as described above for PAM). The recorders were programmed to record broadband sound in the range 10 Hz to 192 kHz. For baseline noise, the recordings were analyzed in decidecade bands[1] from 10 Hz to 80 kHz with a time resolution of 1 second, in accordance with JOMOPANS data processing standards (Ward et al, 2021). The processed data are used to calibrate the Quonops sound propagation model developed and used by QuietOceans (see below). The decidecade band level will be made available for future impact assessments of individual wind farms, as they are in the format commonly used to share this type of data, exemplified by the ICES continuous noise register, maintained for the regional seas' conventions HELCOM and OSPAR. Aggregated results are reported in the form of monthly statistics (distributions of decidecade levels described by exceedance levels L_5, L_{10}, L_{25}, L_{50} (median), L_{75}, L_{90}, and L_{95}). Exceedance levels are upper percentiles and the L_5 exceedance level for example thus represents the sound pressure level exceeded 5% of the time. In addition to sound pressure levels also the ship noise excess level will be computed. The excess level is calculated as the difference between the L_5 calculated with a short time base (10 min) and the L_{95} calculated with a long time base (5 hours). L_5 calculated in short windows is a robust metric of the maximum sound pressure level from passing ships, whereas L_{95} computed over long periods expresses the sound pressure level when it is the most quiet, approaching the natural ambient noise. The excess level thereby quantifies how much the natural ambient noise has been elevated by the presence of ships and other anthropogenic sound sources.

3.3.2 Turbine noise

Underwater noise emission from operating wind turbines were obtained by deploying a noise recorder (Soundtrap ST600) approximately 100 m from a turbine on two occasions: once in Kriegers Flak Offshore Wind Farm and once in Horns Reef 3 Offshore Wind Farm (Figure 3-5). These two wind farms were selected because they are among the largest wind turbines currently in operation offshore in Danish waters and they each represent different technologies: direct drive and gearbox drive[2], respectively. Deployment and recovery of the recorder was done by AU's vessel Niisa, sailing from Hvide Sande. Deployment time was 1 month to allow recordings of as wide a range of wind speeds as possible. Measurements from a turbine of the direct drive type, anticipated to be a common type in the projects at Thor Offshore Wind Farm and the North Sea I, was obtained by deployment of a noise recorder at a turbine in Kriegers Flak Offshore Wind Farm. Deployment and recovery were by AU's vessel Niisa, sailing from Trelleborg. Deployment time was 3 months. Information about wind speed (10 minute averages) were obtained from the operator of the wind farms, in both cases Vattenfall.

In addition to measurements with the ST600 single channel recorder, which provides information about the sound pressure level, measurements with a four-hydrophone array (see detailed description below in 3.3.3) were obtained about 100 m from an operating turbine in Horns Reef 3. Because the four recording channels, each recording from a single hydrophone mounted in the corners of a tetrahedral array (see Figure 3-6), were tightly synchronized, the particle velocity will be calculated by the pressure gradient method (Wahlberg et al. 2008).

[1] Decidecade bands have a bandwidth of 1/10 of a decade, corresponding to 23% of the centre frequency of the band. The bandwidth of the successive decidecade bands therefore increase with increasing centre frequency, but the ratio of bandwidth (in Hz) to the centre frequency remains constant independently of the frequency. See ISO 18405 standard for underwater acoustics terminology.

[2] In a direct drive turbine, the generator is driven directly by the main axle and thus rotates with the same speed as the wings. In turbines with a gearbox, the generator rotates with a different speed than the wings, sometimes variable. As the main source of underwater noise from the latter type is known to be caused by the gearbox (the noise from meshing of gears), it is expected that direct drive turbines will have a different noise profile than the turbines with a gear box.

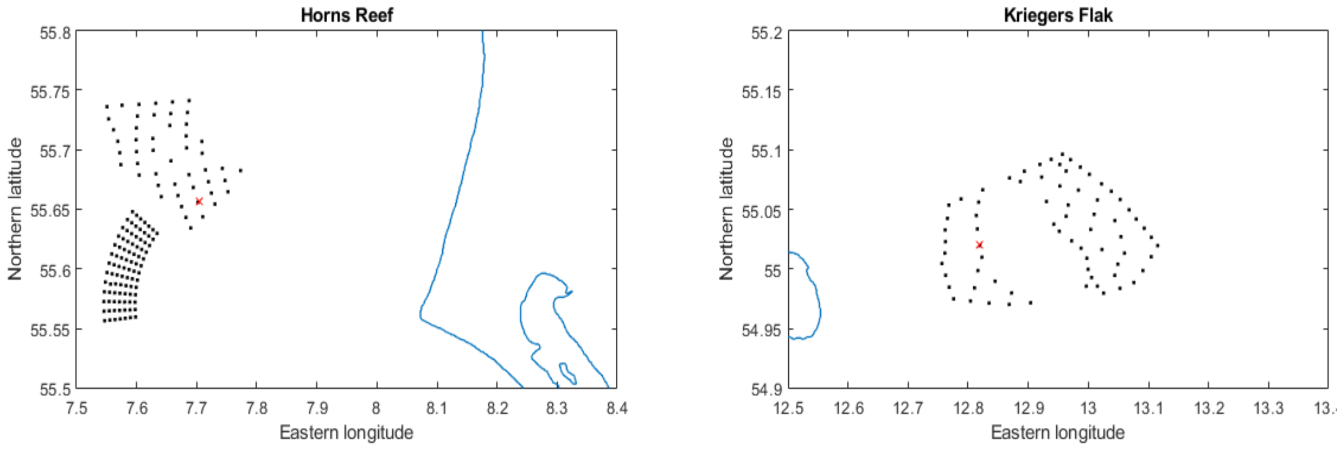

Figure 3-5 Position of noise recorders (Sound-trap ST600) approximately 100 m from a turbine in Horns Reef 3 Offshore Wind Farm (Left) and Kriegers Flak Offshore Wind Farm (right).

3.3.3 Harbour porpoise presence near operating turbines

Offshore wind turbines radiate noise to the underwater environment. This noise originates in the nacelle, from the generator, bearings and gear box (if present) and is propagated down through the tower and into the water (Pangerc et al., 2016; Tougaard et al. 2020). As absolute noise levels are not high, the noise is likely only audible to harbour porpoises within hundreds of meters of the foundation. This means that the presence of harbour porpoises close to the foundations must be accurately mapped in order to assess the potential exposure of the animals to the noise. This is achieved by means of acoustic tracking, making use of the echolocation signals that are emitted by the animals almost continuously (Figure 3-6). By measuring the difference in arrival time of the same signal at different locations by means of multi-hydrophone systems, the accurate position of the vocalizing animal can be determined by triangulation.

Thus, to study presence of harbour porpoises with high spatial resolution near turbine foundations, two 4-channel hydrophone arrays near existing wind turbines at Horns Rev III were deployed (Table 3-2).

Table 3-2 Dates and position of array deployments at Horns Rev 3 Offshore Wind Farm.

Position ID	Deployment dates	N. latitude (Decimal degrees)	E. longitude (Decimal degrees)	Distance to turbine (m)	Recording time
Array1	1) 7/9-10/9/2023 and 2) 19/3-8/4/2024	55.6549	7.7020	102	1) ~24 hours and 2) ~4 days
Array2		55.6553	7.7034	108	

While the general methodology has been applied before, for example to track harbour porpoises around tidal turbines in Scotland (MacAuley et al. 2017, Malinka et al., 2018; Gillespie et al. 2021), the methodology requires adaptation to offshore wind turbines and the environmental conditions in the North Sea. The methodology was adapted to the following steps:

A. Construction of first version of the array, test of electronics, calibration (summer 2023)

B. Test conducted in Aarhus harbour (August 2023)

C. Test of methods for deployment and recovery of array from boat, conducted in Bay of Aarhus (August 2023)

D. First deployment at Horns Reef 3 (September 2023)

E. Development of analysis methods, modification of array, switch to new datalogger type (winter 2023/24)

F. Second deployment at Horns Reef 3 (March 2024, Figure 3-6)

G. Further work on analysis procedure (spring and summer 2024)

Additional deployments anticipated in autumn 2024 that will be reported in the report of the second year of survey.

Deployments and recovery were done with AUs boat Niisa.

The first deployment with the RTsys recorder system (RESEA, RTsys, France; equipped with HTI99 hydrophones) had a very short endurance time, about 24 hours, limited by battery life and memory capacity. Deployment and recovery were also found to be difficult due to the large size of the array. A smaller version of the array (see Figure 3-7) was developed and a different recorder was used, the SoundTrap ST3400, also with HTI99 hydrophones. This recorder had a longer endurance, about 4 days in the deployment in March 2024, but still below expectations. Deployments in autumn 2024 will be conducted with the newest version of the recorder, SoundTrap6300, which is expected to have an endurance of at least one month on continuous recording.

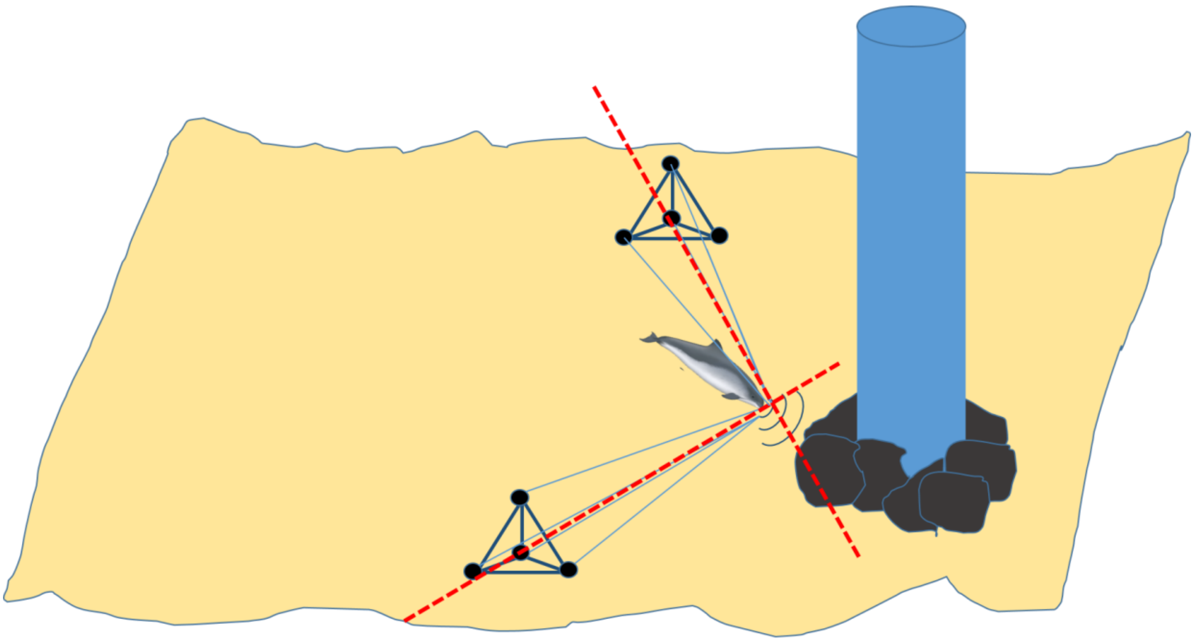

Figure 3-6. Illustration of setup to study fine scale movements of harbour porpoises near a turbine foundation (blue tube): two 4-channel hydrophone arrays (marked in black) near an existing wind turbine at Horns Rev III. Each 4-channel array is equipped with four hydrophones (black dots) and mounted on a tripod (black lines). Due to differences in time of arrival of received echo-location clicks (because of differences in distances - blue lines) the position of the harbour porpoise can be determined (dotted red line) by measuring time-of-arrival differences at the four synchronized recording channels.

Analysis of data is exemplified by the preliminary analysis of the recordings from the deployment in March 2024. The four acoustic sensors on each array were sampled and digitized by a SoundTrap 4300 logger from where the data was offloaded as synchronized 4-channel wav-files. The wav-files were analyzed using PAMGuard, an open-source software developed for detection and analysis of marine mammal vocalizations (Gillespie et al. 2008, www.pamguard.org). Harbour porpoise echolocation clicks were detected using the PAMGuard Click Detector module, where the data was initially filtered using a 20 kHz 4-pole Butterworth high pass filter. The detector triggered when the signal-to-noise ratio (SNR) exceeded a 10 dB detection threshold on all four channels for each array. For a transient to be classified as a harbour porpoise click, the energy in the frequency band from 100 kHz to the Nyquist frequency (which was either 144 kHz or 192 kHz for the two arrays) had to exceed both the 40 to 70 kHz band and the 70 to 100 kHz band by 6 dB, and both the peak and centroid frequencies had to exceed 100 kHz. Further, the signal duration of harbour porpoise clicks had to be within 10 to 200 µs, when measured as the duration between the -6 dB points on either side of the peak of the amplitude envelope, and the signals were required to perform between 5 to 50 zero-crossings over this duration. Bearing estimates were then obtained from the PAMGuard Click Detector module, which estimates bearing to sound sources for small-aperture arrays based on time-of-arrival-differences (TOAD) measured as the difference between click detection times on each channel. An example of what the raw recordings look like is provided in the screenshot in Figure 3-8.

The outputs of the PAMGuard click analyses were exported using scripts from the PAMGuard Matlab repository (https://github.com/PAMGuard/PAMGuardMatlab) to MATLAB (version 2024a, MathWorks, Natick, Massachusetts, USA) for postprocessing and visualization of the results. Harbour porpoise detections were plotted as porpoise positive minutes per hour for each array.

Next, the porpoise bearings had to be translated into position estimates. The porpoise bearings extracted from PAMGuard were bearings relative to the xyz-configuration of each array, but given that the two arrays were deployed with unknown azimuth rotation when lowered to the seafloor, the bearing estimates had to be corrected relative to the azimuth offset from true North. To achieve this, a bearing was estimated from each array to a common sound source, namely the nearby wind turbine (this noise is shown in Figure 4-23 below). A 1-hour window of recordings was extracted from each array and down-sampled 100 times, as the dominant noise emission from the wind turbine is below 1 kHz. Because this noise emission is a continuous signal, unlike the porpoise clicks, a time-of-arrival difference could not be estimated directly from the recorded waveforms, but could instead be estimated in the frequency domain by computing the phase difference between all channel pairs for each array. A difference in phase for a given frequency between two channels is directly proportional to a difference in time-of-arrival. Inspection of spectrograms made from the raw data showed that turbine noise had a consistent peak in the 40 to 100 Hz range, which was therefore used for the spectral analysis, where the intensity over this frequency band was split into xyz-components from which the azimuth and elevation to the sound source was then estimated. Porpoise bearings were then corrected for this array-to-sound source azimuth. To turn the porpoise bearings into bearings relative to true North, the bearing estimates were then further corrected for the compass bearing from the known latitude and longitude coordinates of each array position towards the known position of the wind turbine. Finally, the crossing points of the corrected porpoise bearings from each array position could then be estimated. Because the two arrays were not likely to be ensonified by a porpoise echolocation beam at exactly the same time, the porpoise bearings were divided into 5-s median bearing estimates, and bearing crossing points were then computed whenever bearing estimates were available for both arrays over the same 5-s time windows. This 5-s duration was chosen under the considerations that longer windows increase the likelihood that both arrays will be ensonified and shorter time windows decrease the distance that the porpoise will be able to swim (a typical swim speed is on the order of ~2 m/s). The bearing crossing points were extracted as latitude and longitude coordinates.

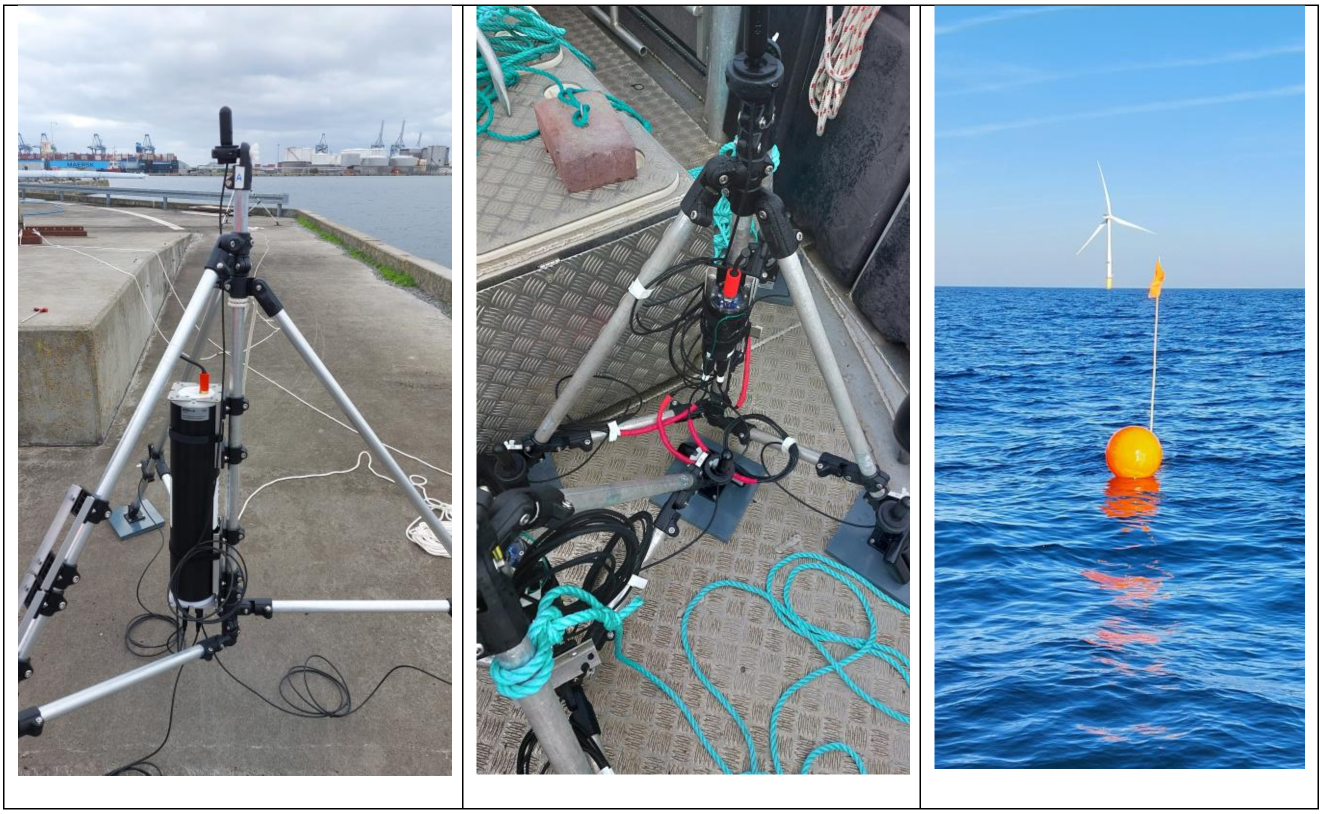

Figure 3-7. The tripod array. Left: original 140 cm array, with RTsys recorder mounted (black cylinder in middle). Middle: Reduced 70 cm array with Soundtrap ST4300 mounted in middle. Right: surface marker of the array with distant turbine in the background (not the turbine recorded from).

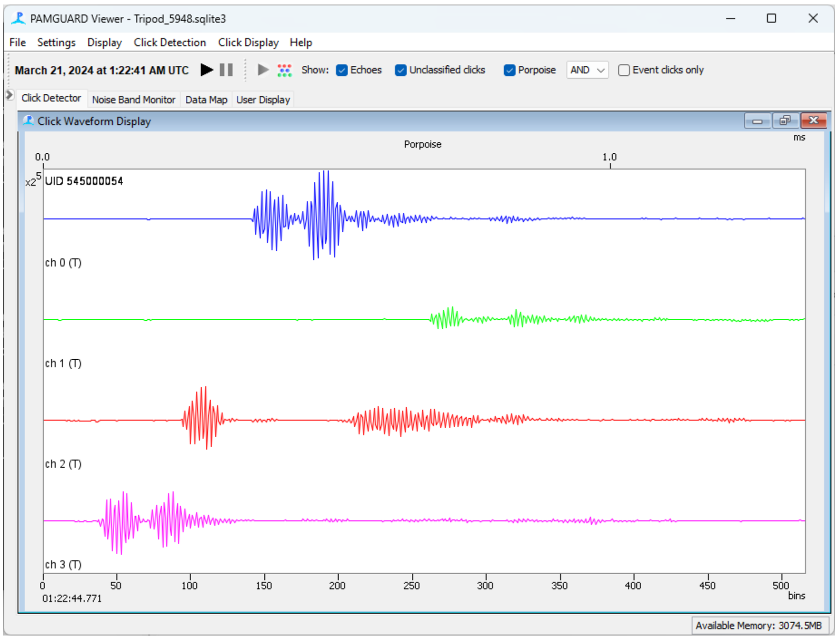

Figure 3-8 Screenshot from the PamGuard software, showing a single harbour porpoise echolocation click recorded on each of the four hydrophones. Time is on the x-axis, sound pressure on the y-axis. Due to the spatial separation between the hydrophones the click arrives with different delays at the four hydrophones. The trailing signals after the initial pulse are reflections from the surface, the seabed or the array itself and are filtered out in the later analysis. The duration of the recording segment shown is about 1.3 ms.

The analysis tested different hypotheses regarding the presence of harbour porpoises close to the turbine foundation. The simplest test makes use of the axis going through the two array positions, arrays and the nearest distance from each porpoise position to this line. If there is no effect of the turbine on harbour porpoises (attraction or repulsion), then there should be no difference in the number of harbour porpoises tracked on either side of the line between the two recording arrays. Contrary, if significantly more, harbour porpoises are detected on one side of the line through the setups it can be concluded that the porpoises are either avoiding or attracted to the turbine, depending on the sign of the difference. If a sufficient number of animals can be tracked, then the relative density of observed animals can be mapped in the area from the turbine and out to a few hundred meters from the turbine, providing an estimate of the gradient in porpoise density (if any) and quantification of the attraction/deterrence (if any) of the turbine. It should be noted that harbour porpoise presence is currently only tested on one turbine and in order to extrapolate to other offshore wind farms, the experiment should be repeated at different locations. As a simpler means to assess the variation among turbine sites, 8 PAM-stations (ST600 Soundtraps) will be deployed in pairs during the second year of this project at four different turbines, with one station 50 m from the turbine and one 200 m from the turbine. This design will provide an estimate of the variance among turbine sites and allow for an assessment of the required number of replicates in order to generalize the results.

3.3.4 Noise exposure maps

Previous studies show that the main sources of underwater noise prior to the construction of an offshore wind farm are ship traffic (see section 2.3). Neighboring wind turbines such as Horns Rev III may also influence the soundscape on a smaller spatial scale. The noise exposure map represents the underwater noise exposure map from a 2023 scenario and thus include the Horns Rev OWFs but not the newly constructed Vesterhav Syd OWF and the planned Thor OWF. Four monthly maps, each representative for one season, of the total noise from natural sources (wind and waves), ships (including wind farm service vessels) and wind turbines were modelled by the Quonops modelling framework by the company Quiet-Oceans (Brest, France). The wind farms included in the modelling are those that are in operation in the Danish North Sea by the end of 2023 (Table 3-3). Only the noise from operational activities are included in the model, i.e. noise from construction and pre-construction surveys at the planned or newly constructed wind farms at Thor and Vesterhav Syd were not included, as these activities were short-term.

Table 3-3 Wind farms included in the modelling scenario within the survey area.

Wind Farm	Turbines	Turbine type	Generator and gearbox
Horns Rev 1	80	Vestas V80-2.0 MW	3 stage planetary gear
Horns Rev 2	91	Siemens SWT-2.3-93	3-stage spur/planetary gear
Horns Rev 3	49	Vestas V164-8.0	Planetary gear

Based on the measurements of underwater noise from operating turbines (described above) and the measurements in the literature (Bellmann et al., 2023) two source models for the turbines were developed, one for turbines with gear box and one for direct drive generators. The cumulative noise contribution from the wind farm area and surroundings was modelled and compared to the contribution from natural sources (wind and waves) and shipping. The model was calibrated and validated against the measurements from the six noise logger PAM stations as well as measurements from the North Sea Energy Island survey program (Kyhn et al., 2024). The cumulative exposure levels of the noise within the survey area were modelled by the same model, by including turbines from all existing wind farms in the survey area (Table 3-3) thereby allowing a quantification of total exposure to noise and vibrations and a separation of the contribution into natural sources, ships, and wind turbines + service vessels.

The noise exposure maps represent four monthly statistics of the noise (April 2023, July 2023, October 2023, January 2024) representing the four seasons. They were generated from all available information about individual sources of noise in the area. For every hour (referred to as a 'snap-shot') of the modelling period (April 2023-April 2024) the position and speed of all ships in the area were obtained from AIS and VMS data (obtained from the Danish Shipping Authority and the Danish Fisheries Agency, respectively). Based on the type of each ship, its length and speed, the noise emission (source level) was estimated from a standard model (RANDI3-JE, MacGillivray and de Jong, 2021). Positions of individual wind turbines were obtained from the Danish Energy Agency. For each snap-shot also the radiated noise from each individual turbine was modelled based on the source models developed, which links noise emission of individual turbines to wind speed, also including the influence of turbine size (nominal power rating) and type (gear box or direct drive). Wind speed at the location and time of the snap-shot were obtained from meteorological hind-cast models. The noise radiated from all individual sources were fed to a sound propagation model, which models the sound propagation (by parabolic equations methodology) into the surrounding waters. The individual contributions from all sources were summed and added to the natural ambient noise in each modelling grid cell of the model. The natural (wind driven) noise was modelled from the wind speed (from the hind-cast models) and locally determined curves relating wind speed and underwater noise (so-called Knudsen- or Wenz-curves, Knudsen, 1949; Wenz, 1962). All snapshots for each month modelled were combined into spatially explicit distributions, i.e. representations of the statistical distribution of noise levels in each particular grid cell of the modelling area. For each grid cell, this monthly distribution is described by a selected number of percentiles. The output of the Quonops model is therefore maps representing selected monthly percentiles of the noise distribution, i.e. maps representing the noise level exceeded a specified proportion of the time. In addition to these total noise levels, the so-called excess level is also represented. The excess level is defined as the elevation of the noise level caused by the non-natural sources, obtained by subtracting the natural ambient noise from the total noise level.

3.3.5 Overlaying model

The underwater noise exposure maps for the survey area (described above in 3.3.4) were overlayed with the comparable four monthly distribution maps of harbour porpoises based on PAM data. For the harbour porpoise, this enabled the area where animals may respond to underwater noise and vibrations to be assessed (in line with what was done by Faulkner et al. 2018 and in the HELCOM HOLAS 3 assessment, HELCOM 2023). Maps of the noise distribution related to the harbour porpoises' reaction threshold was overlayed with the harbour porpoise distribution map. Based on measurements of reactions of individual wild porpoises to ship noise (Wisniewska et al., 2018), supported by reviews of other available data (Tougaard 2021) a reaction threshold for ship noise has been established as 96 dB re 1 µPa in the 16 kHz decidecade frequency band. Due to the stereotypic frequency spectra of ship noise (e.g. MacGillivray and de Jong, 2021), it is possible to extrapolate this threshold into the low frequency bands used for noise modelling, even though porpoises have very poor hearing at these low frequencies. For ship noise, this has resulted in a proxy threshold of 115 dB re 1µPa in the 125 Hz decidecade band (Tougaard et al, 2023). Thresholds for turbine noise for harbour porpoises may be higher than this (i.e. more noise is required before animals react), as it has been shown that harbour porpoises are less responsive to noise below 2 kHz than to noise above (Dyndo et al., 2015) and measurements show that there is no significant energy in the turbine noise above ambient at frequencies above 1 kHz (Tougaard et al. 2020, Bellmann et al., 2023).

4. Results of survey(s)

4.1 Passive acoustic monitoring of cetaceans

The passive acoustic monitoring program was aimed at harbour porpoises (FPODs), delphinids and minke whales (SoundTraps). The results of the first years' monitoring are presented in the sections below.

4.1.1 Harbour porpoises

4.1.1.1 FPOD results

In April 2023, 42 PAM stations were deployed in the survey area (Figure 3.1). The original plan was to service every station approximately every three months. This did not turn out to be realistic since it took so long time to service the PAM stations that the weather often turned bad before we were able to finish the service. Consequently, the service (performed primarily by Bioconsult) have been ongoing with service trips almost every month and with each service trip prioritizing the stations that had been deployed the longest. This proved to be a successful method. The FPOD and CPOD can record for at least 5 months upon deployment and so far, no data have been lost due to battery depletion. For year 1, 86% of the possible days of data collection have been successfully retrieved and for 20 stations 98-100% of data are recovered (Table 4-1, Figure 4-1, Figure 4-2 and Figure 4-3). Data has been lost due to other reasons. For instance, station NS1 moved 10 km southwest in May 2023 which was likely due to it being accidentally dragged by a ship. Also, the first chosen brand of acoustic releasers (Sonardyne) performed unexpectedly poorly and released prematurely, which also caused data loss. Furthermore, during the winter storm of December 2023, the acoustic releaser stations were moved by the large waves to a location 2–3 km from the deployment position. One of these stations was later found (NS23_HR3-3) while others were lost. Some of this equipment may still float ashore during the coming year and can then be included in the data set for the report covering the second year of data collection. Due to the problems with the releaser stations, the three acoustic releaser stations were deployed with GPS-transmitters for year two to provide a warning if they surface prematurely.

In Figure 4-1, Figure 4-2 and Figure 4-3, porpoise positive minutes (PPM, i.e. number of minutes per day with minimum one harbour porpoise click detected) per station are shown for each of the three areas, the "Pre-investigation area", "Survey area West" and "Survey area East", respectively. Visual inspection of the figures shows that there are large variations in harbour porpoise detections both between days, month and stations. The three figures are combined in Figure 4-4 for each of the three areas. Here, an average of approximately 100 PPM per day per month, with peaks of individual stations up to 800 PPM pr day and up to 300 PPM per day per month, were found, but again with some variation between month and areas. There were no clear seasonal variations detected. It is interesting to notice that unlike the other two areas, most stations in Survey area East had very few detections in January 2024. The "survey area east" is close to the coast and could indicate that harbour porpoises move further offshore during the coldest months. This corresponds to the results from tagged harbour porpoises in the Skagerrak region. Here, the porpoises moved further west into the North Sea during the winter the deeper waters (Sveegaard et al. 2011)

Table 4-1 Overview of collected harbour porpoise data (porpoise positive minutes per day) during the North Sea I PAM program from April 2023 to March 2024. Causes for stations with less than 50 % of possible data retrieved are explained in the comment column. %success refers to the percentage of days with successfully functional equipment.

Station	2023									2024			Data			Comments
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Days with detections	Potential days of detections	%success	
HR3_1	2										4	31	37	341	11	Released early on two deployments and two was lost
HR3_2			20	2	29	29	29	26	30	31	29	31	256	345	74	
HR3_3					31	30	31	30	20		4	31	177	345	51	1st deployment lost
HR3_4		13	30	31	30	29	30	29	29	30	28	31	310	345	90	
HR3_5	14	31	29	31	30	30	31	29	31	31	29	31	347	347	100	
HR3_6	14	31	30	31	29	30	31	29	30	31	28	31	345	345	100	
NS1	12	15			26	30	31	29	31	30	29	31	264	345	77	
NS2	12	31	30	31	30	30	31	30	31	3	3	29	291	345	84	
NS3	12	31	30	31	30	30	31	29	23	24	29	30	330	345	96	
NS4	12	31	30	30	4					23	29	30	189	345	55	2nd deployment lost
NS5	11	31	30	31	30	30	31	30	30	28	29	31	342	342	100	
NS6	9	30	30	30	30	29	31	29	1		3	31	253	341	74	
NS7	12	31	30	31	30	30	31	30	8	24	29	30	316	345	92	
NS8	11	31	30	31	30	30	31	29	29	30	29	31	342	342	100	
NS9	11	31	30	31	30	30	31	30	31	27	28	31	341	342	100	
NS10	9	31	30	31	30	30	31	30	30	31	28	31	342	341	100	
NS11	13	31	30	30	31	30	31	29	31	28	29	31	344	345	100	
NS12					25	30	31	28	30	30	29	30	233	345	68	
NS13	11	31	30	31	1						2	31	137	344	40	2nd deployment lost
NS14	9	31	30	31	30	30	31	28			3	31	254	341	74	
NS15	13	31	29	30	31	30	30	27	30	28	28	30	337	345	98	
NS16	11	31	30	31	29	30	26		27	29	27	31	302	344	88	
NS17	10	31	29	31	29	30	30	28	30	30	29	31	338	340	99	
NS18	9	31	30	31	30	30	31	29	30	31	29	30	341	341	100	
NS19	12	31	30	30	31	29	29	29	28	27	28	30	334	345	97	
NS20	11	31	30	31	29	30	31	30	28	8			259	342	76	
NS21	10	31	30	31	30	30	31	29	30	31	29	31	343	343	100	
NS22	9	31	30	30	30	30	30	28	31	31	29	31	340	341	100	
NS24	13	31	30	30	29	30	31	24	30	31	29	31	339	345	98	
NS25	10	31	30	31	30	30	31	29			2	31	255	343	74	
NS27	16	31	30	31	31	30	5	10	29	31	29	30	303	345	88	
NS28	15	31	30	31	29	29	31	19			2	31	248	345	72	
NS29	10	31	30	31	5			2	31	31	29	31	231	343	67	
NS30	10	31	30	31	30	30	30	27	30	29	29	31	338	342	99	
NS31	9	31	30	31	30	30	31	27	29	31	28	31	338	341	99	
NS32	16	31	29	31	29	30	31	29	31	31	29	31	348	348	100	
NS33	10	31	30	31	30	30	31	29	31	30	29	31	343	343	100	
NS34	10	31	30	30	30	29	25	2	29	28	29	30	303	343	88	
NS35	9	31	30	31	30	30	31	26	30	29	29	31	337	341	99	
T2	9	31	30	31	30	30	31	28	31	30	29	31	341	341	100	
T3	9	31	30	31	30	30	31	27		23	29	31	302	341	89	
T4	9	31	30	31	30	29	31	29	31	31	29	30	341	341	100	

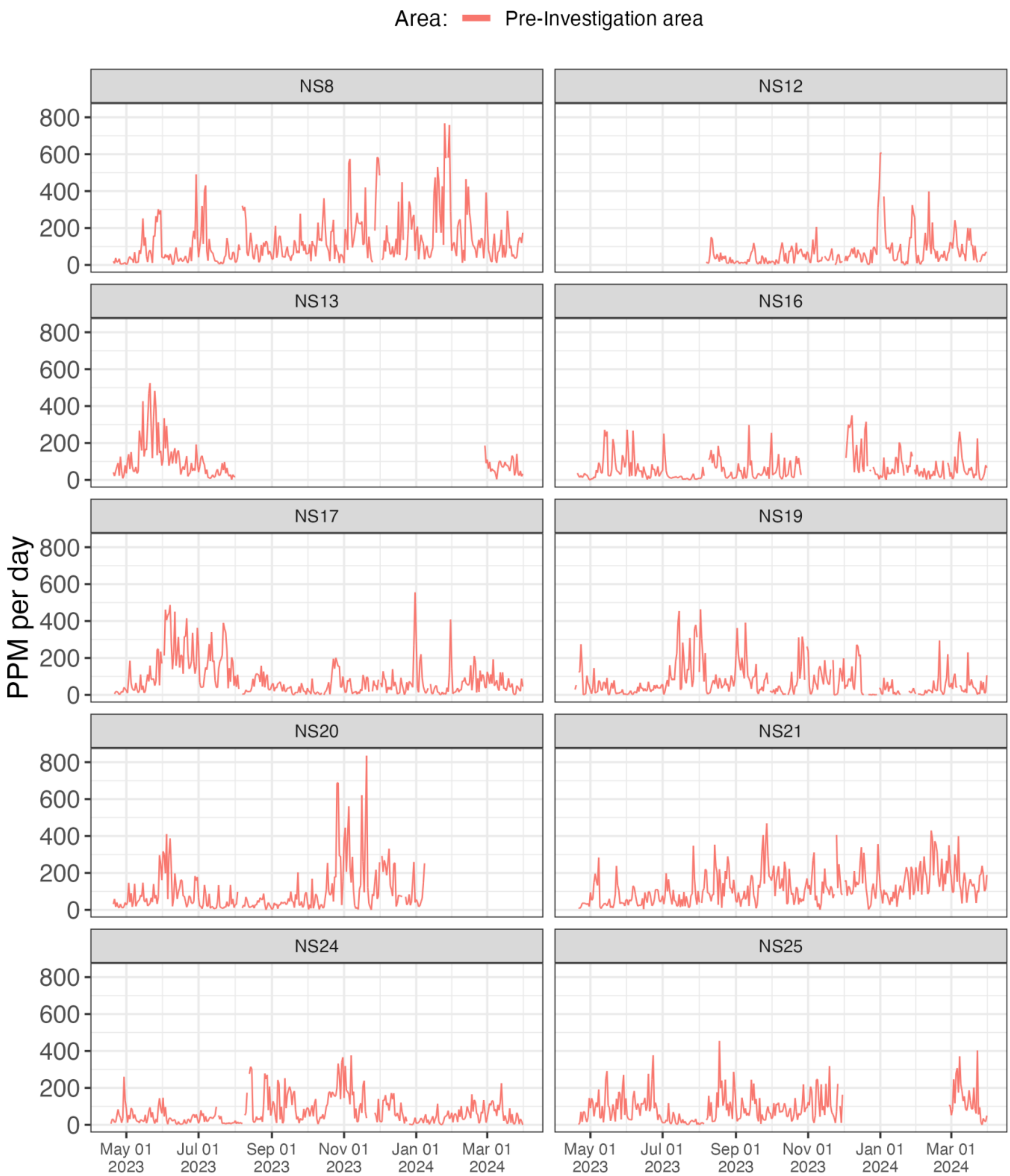

Figure 4-1 Porpoise Positive Minutes (PPM) per day for each station within the Pre-investigation area (See Figure 3-1) April 2023 – March 2024.

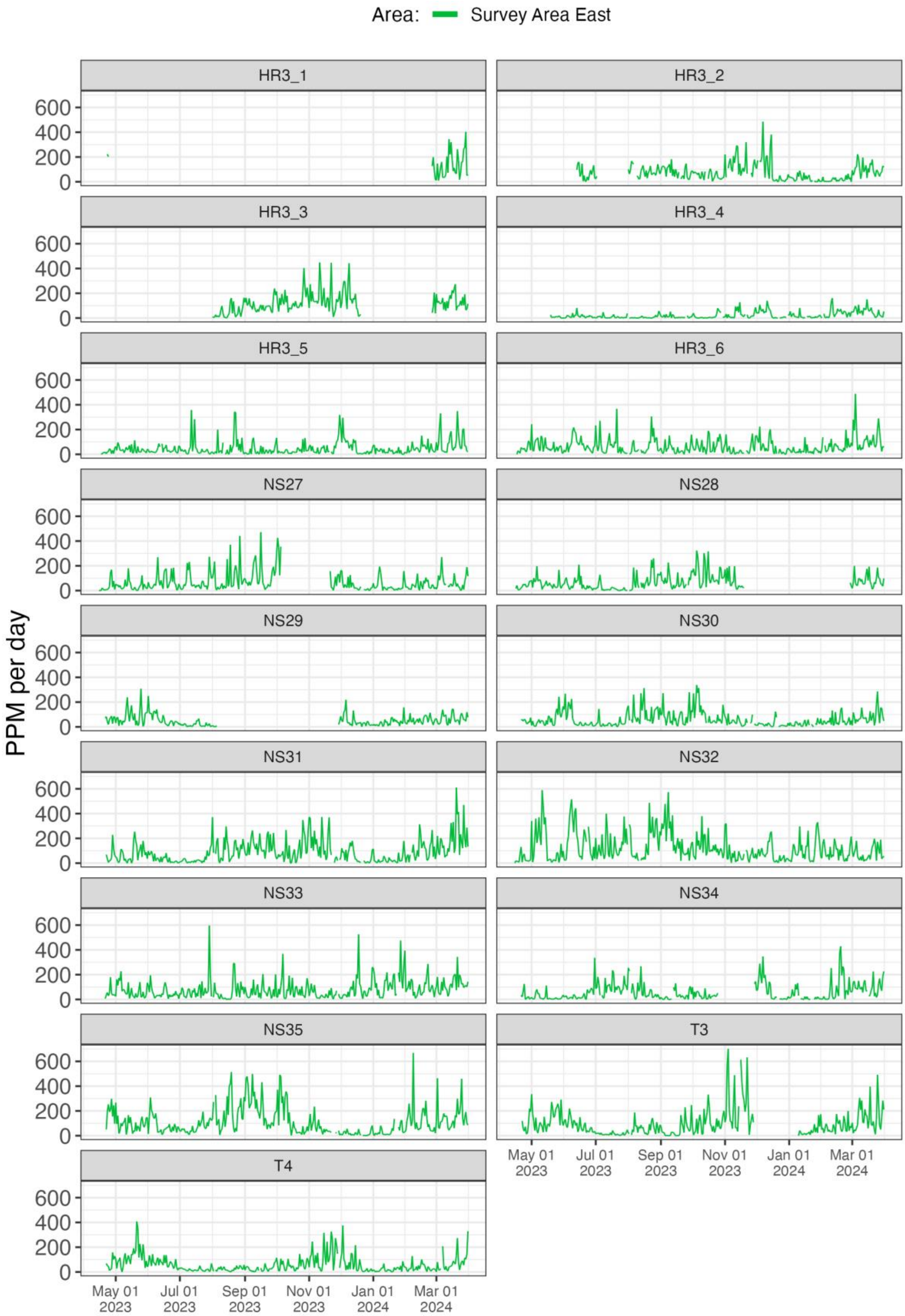

Figure 4-2 Porpoise Positive Minutes (PPM) per day for each station within the “survey area East” (See Figure 3-1) April 2023 – March 2024.

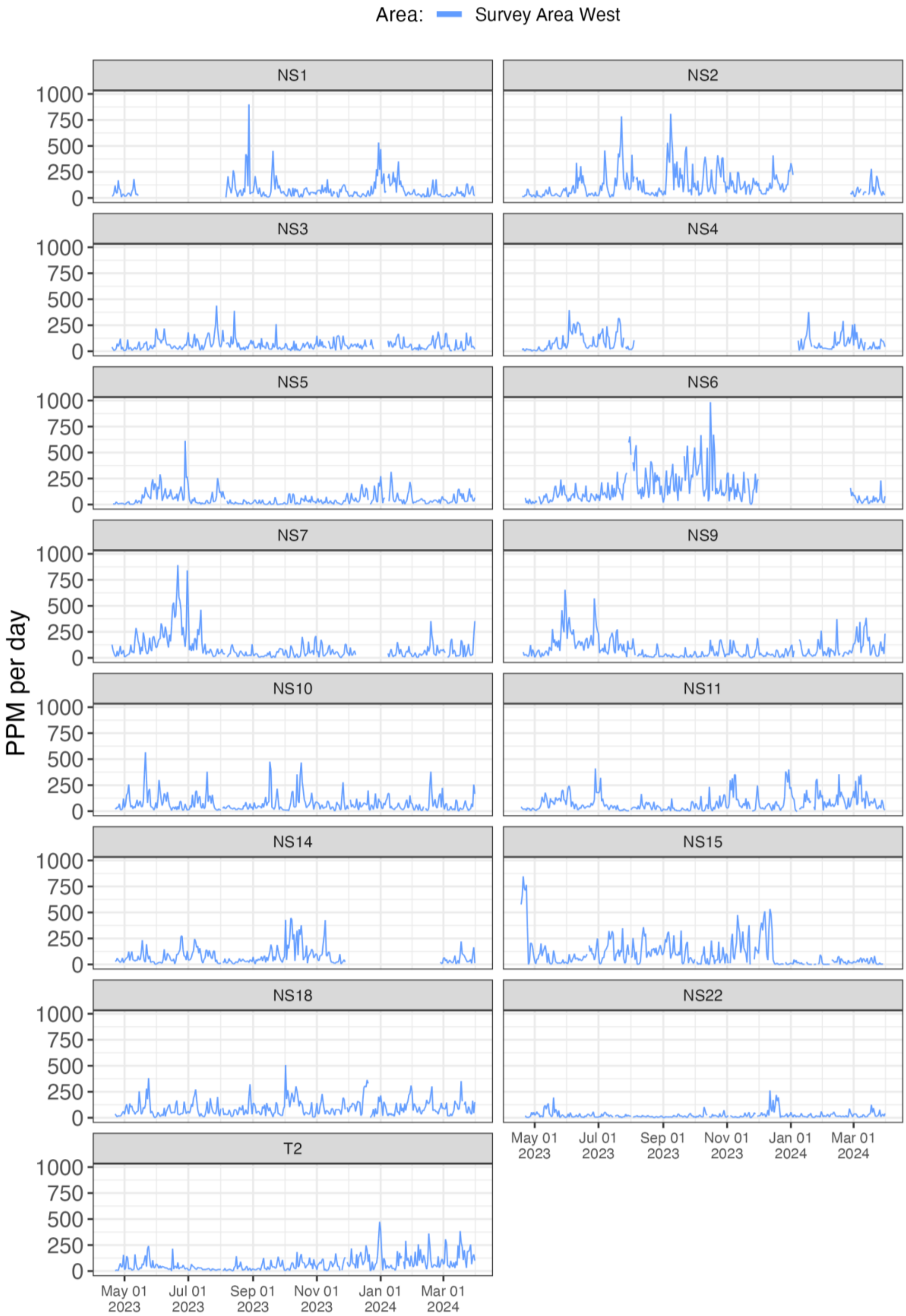

Figure 4-3 Porpoise Positive Minutes (PPM) per day for each station within the "survey area West" (See Figure 3-1) April 2023 – March 2024.

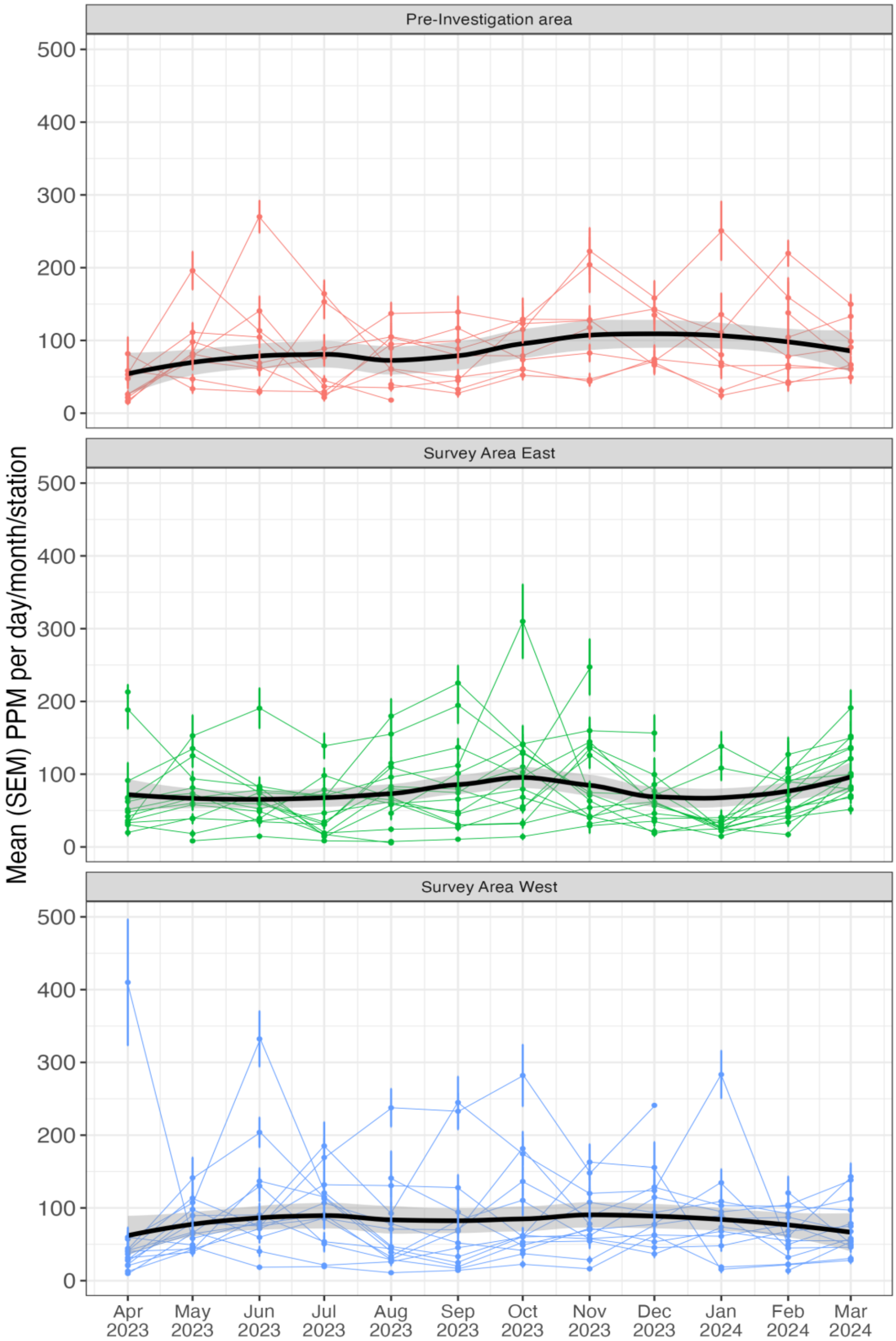

Figure 4-4 Porpoise positive minutes (PPM) per day calculated as average (and standard error [SEM]) per month for each of the 42 FPOD stations within the three different areas. The black line indicates the average for each area with the light grey shading indicating the 95% confidence interval.

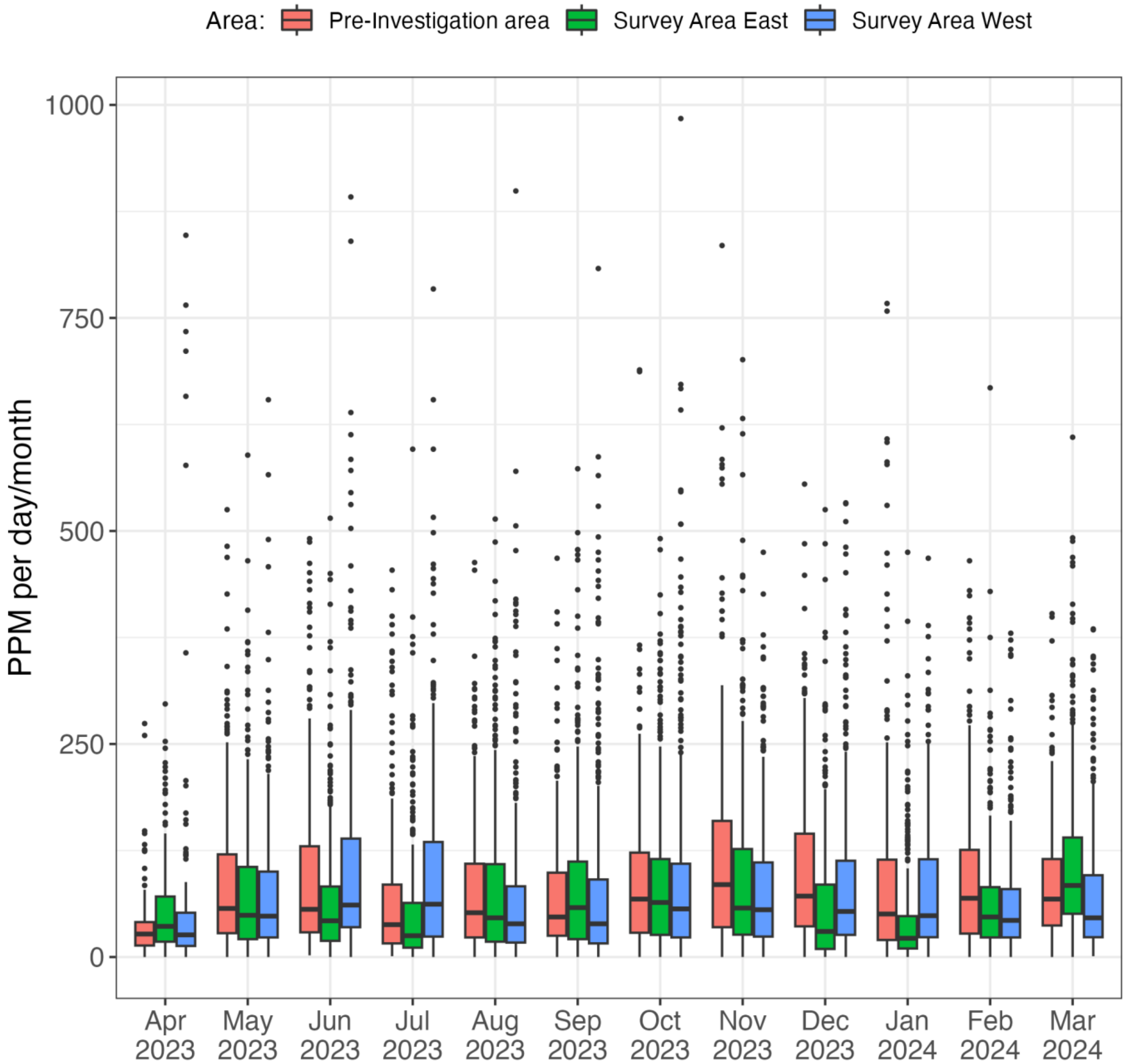

Figure 4-5. Boxplots of porpoise positive minutes (PPM) per day/month for each of the three areas; Pre-investigation area, Survey Area East and Survey Area West. Each boxplots shows the distribution of the data based on a five-number summary including the minimum (lower whisker), first quartile (lower part of box), median (horizontal black line inside box), third quartile (upper part of box), maximum (upper whisker) as well as outliers (solid black circles).

In figure 4-5 boxplots of porpoise positive minutes per day and month are shown for each of the three areas: Pre-Investigation area, Survey area East and Survey area West. Here again, it is noticeable that there is substantial variation in the data across months and areas, but also large variation between individual days as can be seen from the many outliers (black dots) with PPM>500 detected in most months and areas on some days.

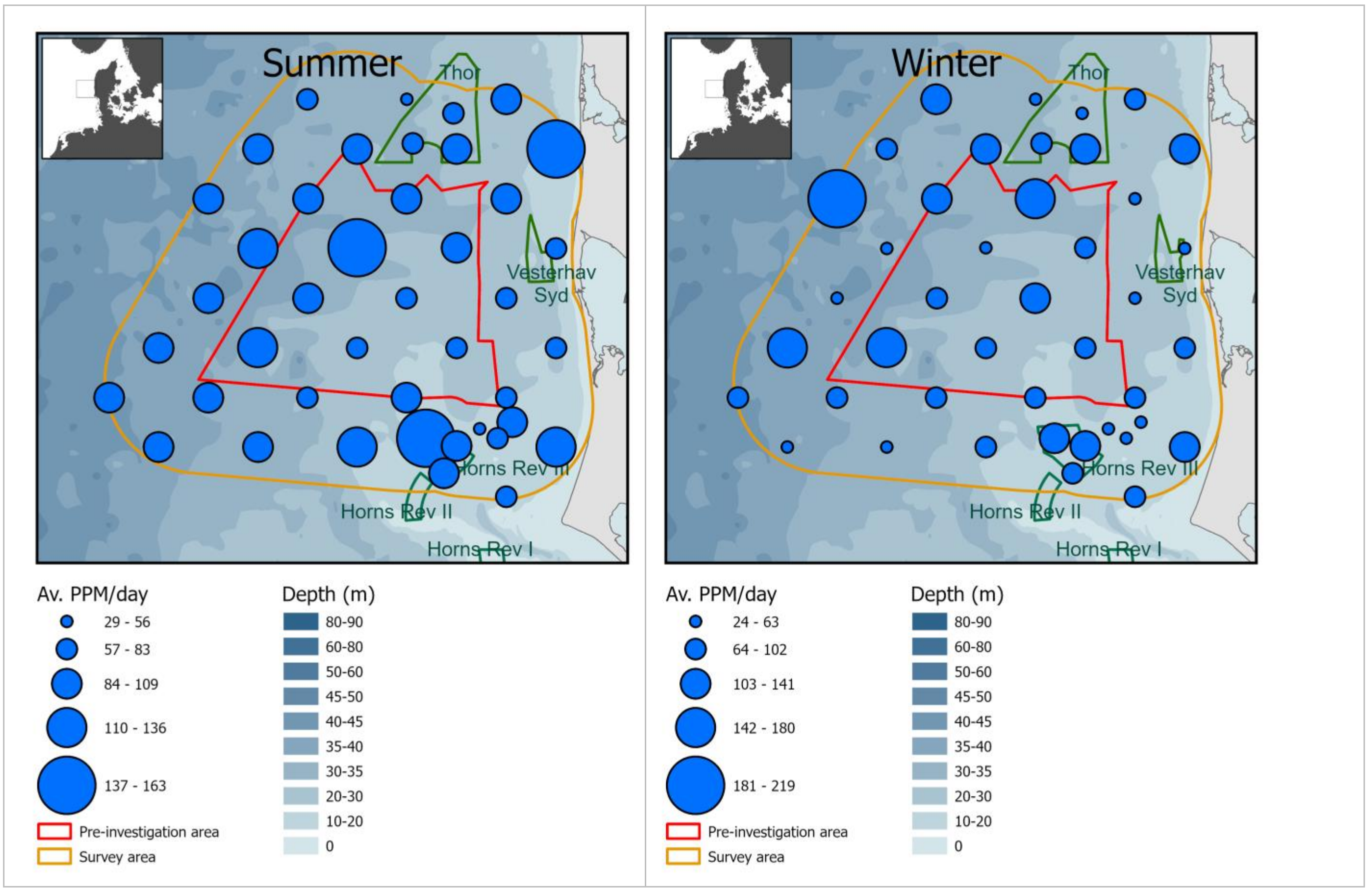

Figure 4-6. Overview of PAM data divided by half year (average DPM/day): winter (Sep–Feb) and summer (Mar–Aug). The size of the circle indicates the average number of PPM for each station.

Figure 4-6 illustrates the geographical distribution of harbour porpoise detections (average PPM per day per month) for the winter (Sep–Feb) and summer (Mar–Aug) periods. There are generally more detections in the summer. Interestingly, the level of harbour porpoise detections are higher inside the Horns Rev 3 Offshore Wind Farm compared to the neighbouring stations outside the farm area. This indicates that the prey availability is higher inside the park than outside as harbour porpoise distribution generally is driven by prey availability (Wisniewska et al. 2016).

4.1.1.2 Predicted maps of acoustic Species Distribution Models of porpoises

Monthly models of PPM per day revealed considerable spatial and temporal variation in harbour porpoise presence in the survey area (Figure 4-7). The models explained on average 50.68% (min= 42.4% in May and max=66.6% in April) of the deviation in the data (Table 4-2). Bathymetry and seabed slope did not correlate strongly with harbour porpoise acoustic activity, while PPM per day generally declined with increasing distance from sandeel spawning grounds (Figure 4-7).

The dynamic forcing variables: mixed layer thickness, sea surface salinity, temperature, height and current velocity explained most of the variation in the data and all correlated with PPM per day in a non-linear fashion that differed between months (Figure 4-7) likely due to seasonal changes in environmental conditions and thus prey availability in the area.

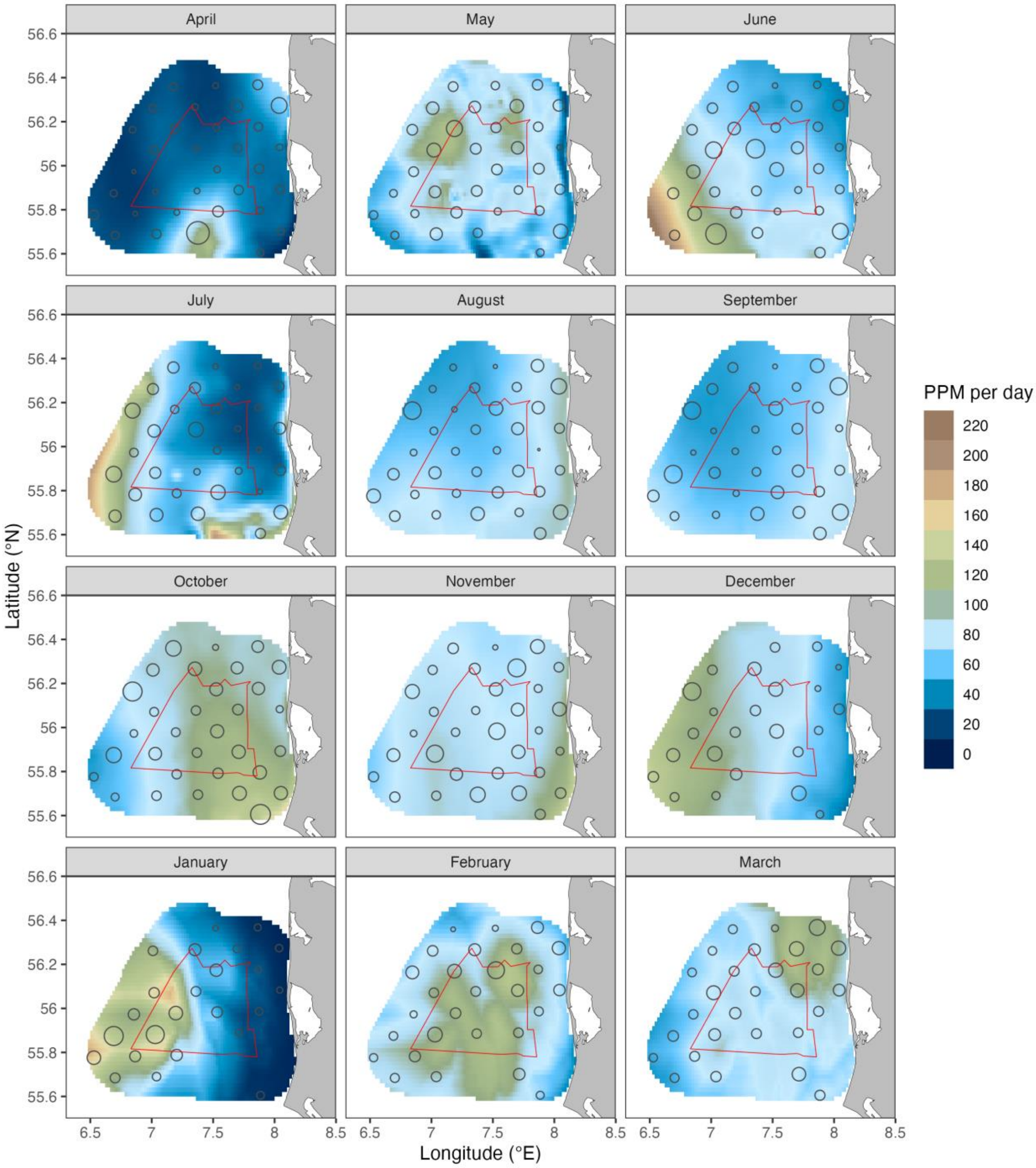

Figure 4-7 Monthly maps of the predicted mean PPM per day across the survey area from April 2023 to March 2024. Black circles indicate the mean PPM per day detected by each station during a specific month. The red line indicates the pre-investigation survey area.

Table 4-2 Overview of the deviance explained (%) and adjusted R^2 for each monthly acoustic Species Distribution Model. The means across all months are provided at the bottom of the table.

Model month	Deviance explained (%)	R^2adjusted
April	66.6	0.617
May	42.4	0.427
June	54.8	0.543
July	49.3	0.421
August	45.2	0.402
September	57.7	0.559
October	45.7	0.438
November	46.4	0.410
December	53.6	0.511
January	58.9	0.591
February	44.4	0.391
March	43.1	0.396
Mean	50.68	0.476

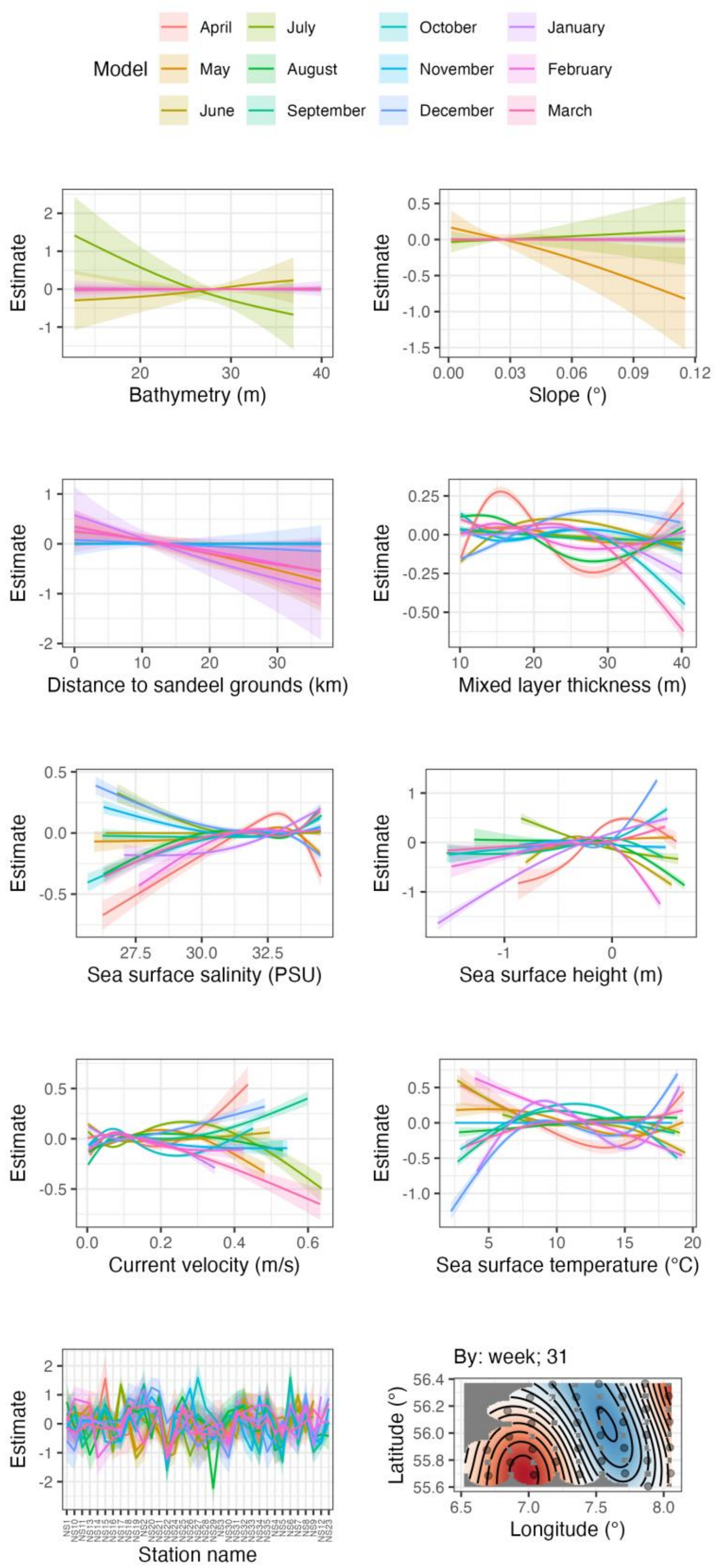

Figure 4-8 Response curves showing the estimated association between the eight environmental conditions and monthly variation in PPM per day across the survey area. Note that the bottom two panels show the effect of station name, which was included as a random effect and the XY coordinates of the stations were included to account for spatial autocorrelation on a weekly basis.

4.1.1.3 Comparison of CPOD detections over time

In order to compare levels of harbour porpoise detections over time, six stations at or near Horns Rev 3 Offshore Wind Farm and three stations within the planned Thor OWF were redeployed at the same positions that were monitored during the pre-investigations for these offshore wind farms using CPODs (Dec-2012 to Nov-2013 at Horns Rev 3 and Dec-2019 to Nov-2020 at Thor OWF). The CPOD data for the first year (April-2023 to March 2024) collected during this project are displayed in Figure 4-7 for the three Thor OWF deployments and in Figure 4-8 for the six Horns Rev 3 deployments.

The Thor Offshore Wind Farm is planned to be constructed in 2025 and consequently no large change in the habitat has occurred since the baseline survey in 2019-2020. However, here the mean PPM per day was significantly higher ($p<0.001$) in 2023–2024 (mean= 13.3, lower 95% CL= 11.0 upper 95% CL=16.1) compared to 2019–2020 (mean= 36.5, lower 95% CL=30.2 upper 95% CL=44.7). It is also clear from Figure 4-9 that the detected levels of harbour porpoise clicks are significantly higher in 2023-24 in all months except January, April and July with especially high peaks in the spring and winter.

The construction of Horns Rev 3 Offshore Windfarm was finished in 2019. The baseline survey included six stations; three which are now located inside the wind farm and three located outside the wind farm to the east. The mean PPM per day at Horns Rev 3 Offshore Wind Farm for the three stations located inside the wind farm was significantly ($p<0.001$) higher in 2012-2013 (mean= 70.1, lower 95% CL= 49.4, upper 95% CL=99.4) compared to 2023-2024 (mean= 40.4, lower 95% CL= 28.5, upper 95% CL= 56.8) (Figure 4-10). This is clearly caused by a peak in detections in July and August in 2012-13, which was not detected in 2023-24. Similarly, the mean PPM per day outside the wind farm was significantly ($p<0.001$) higher in 2012-2013 (mean= 41.6, lower 95% CL= 29.3, upper 95% CL=58.5) compared to 2023-2024 (mean= 21.3, lower 95% CL= 15.0, upper 95% CL= 33.1). Moreover, the difference in mean PPM per day inside vs outside the wind farm during 2012-2013 was not statistically significant ($p=0.157$), while the difference in mean PPM per day inside vs outside the wind farm during 2023-2024 was significant ($p=0.049$) with significantly more harbour porpoise detections inside the wind farm.

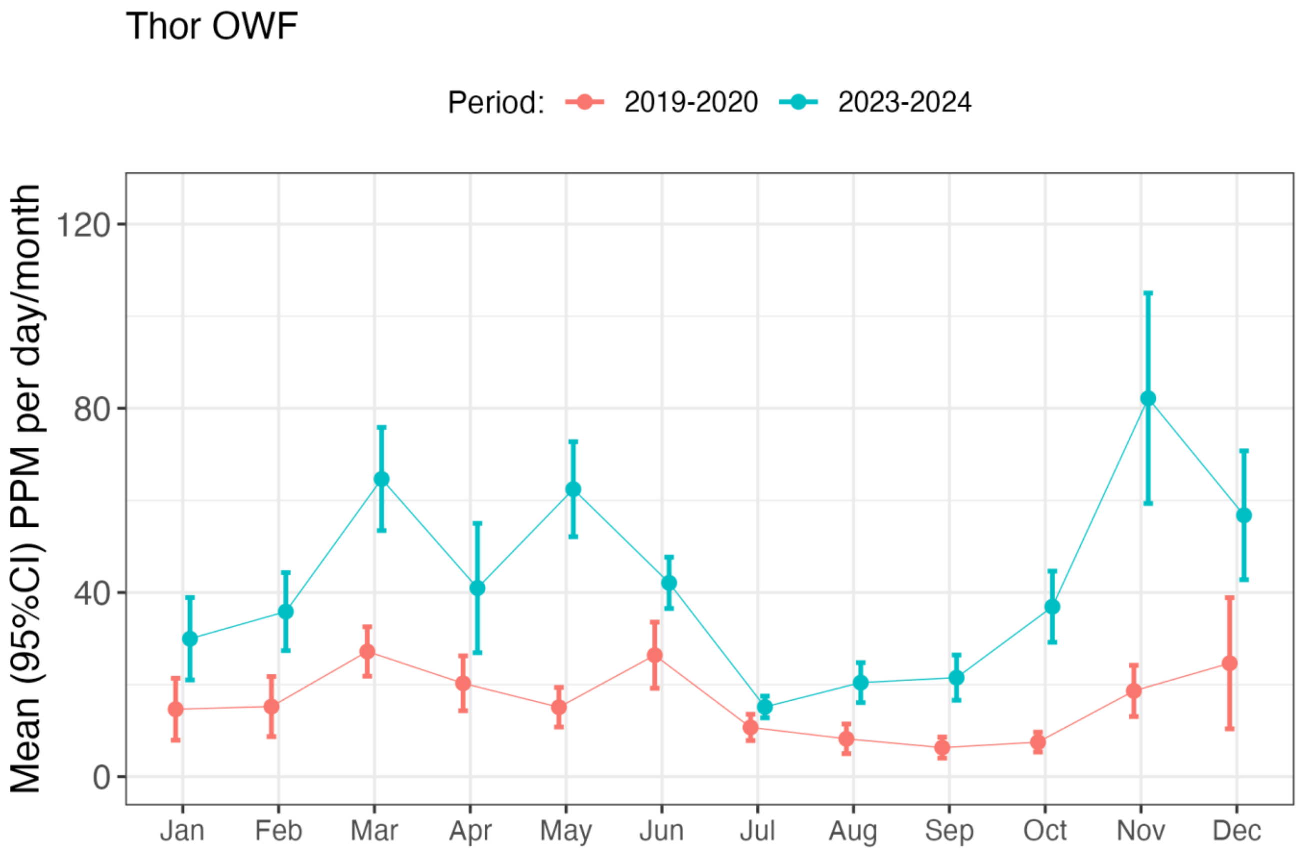

Figure 4-9. Average (95% CI) porpoise positive minutes (PPM) per day across months for the three CPOD stations deployed in the planned Thor OWF area in Dec-19 to Nov-20 and in Apr-23 to Mar-24.

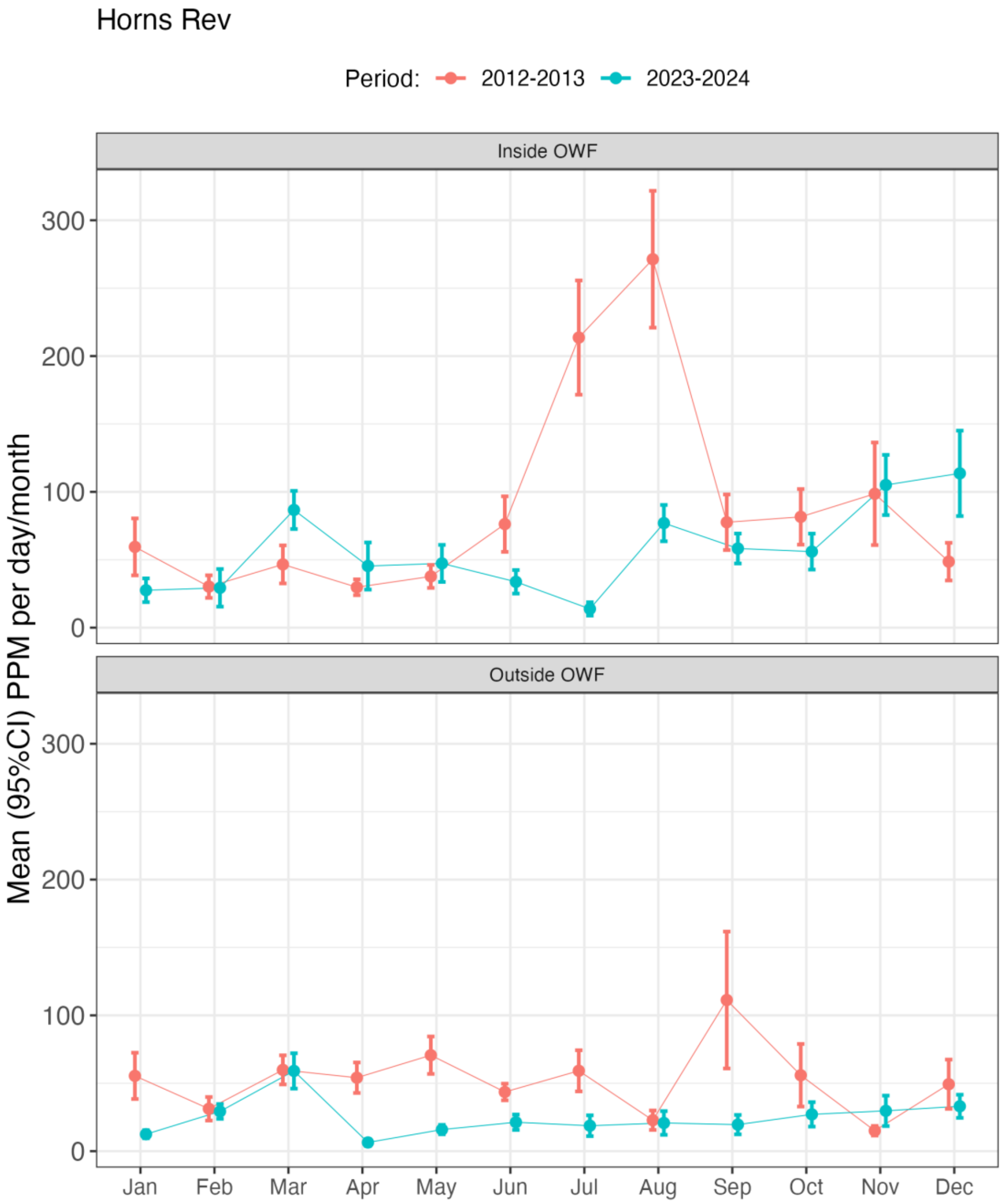

Figure 4-10 Average (95% CI) porpoise positive minutes (PPM) per day and month for three CPOD stations deployed within the Horns Rev 3 Offshore Wind Farm area (HR3) (HR3_1-3, Top panel) and near but outside (HR3_4-6, lower panel) in Dec-12 to Nov-13 and Apr-23 to Nov-23.

4.1.1.4 Comparison of CPOD and FPOD detections

This part of the study were commissioned to Bioconsult SH and details are explained in Voß & Diederichs (2024). Here, only a short summary is given. All text is copied from Voß & Diederichs 2024, but some tables are modified to simplify the results and only include relevant information.

CPODs and FPODs were continuously deployed at 9 monitoring stations between April 2023 and May 2024 to compare detection rates of the two types of Passive Acoustic Monitoring devices (Table 4-3). During the study period, an average of 197 CPOD days per station and 221 FPOD days per station were included. The data were analysed and exported according to the methodology described in section 3.1.1.

Table 4-3 Geographical positions and deployment periods of the deployed FPODs and CPODs, water depth (m). PODs were deployed from April 2023–May 2024 (Modified from Voß & Diederichs 2024).

Station ID	Latitude (°N)	Longitude (°E)	Depth (m)
HR3_1	55.7148	7.6081	-17
HR3_2	55.6485	7.6725	-12
HR3_3/NS23	55.7012	7.7141	-19
HR3_4	55.7348	7.7908	-18
HR3_5	55.7173	7.8519	-16
HR3_6	55.7487	7.901	-18
T2	56.2799	7.5437	-32
T3/NS26	56.2706	7.6946	-31
T4	56.3391	7.6816	-29

In general, harbour porpoise detection rates (analysed as percent Detection Positive Days per month "%DPD/m" and percent Detection Positive Minutes per day, "%DPM/d") of CPODs and FPODs were similar (Figure 4-11Figure 4-9). However, the FPOD generally recorded slightly more detections than the CPOD - irrespectively of the temporal scale. Both the CPOD and FPOD recorded detections on nearly every day. With the CPOD, an average detection rate of 98.4 %DPD/m was calculated, whereas with the FPOD, an average detection rate of 99.1 %DPD/m was calculated (Table 4-4). The correlation test showed that the CPOD detection rate and the FPOD detection rate correlated significantly when using the temporal scale %DPD/m (Table 4-5, Figure 4-12). Furthermore, the t-test showed no significant difference between the two detection rates. However, when analysing the data on a minute basis, an average detection rate of 4.6 %DPM/d was recorded with the CPOD, whereas an average detection rate of 6.0 %DPM/d was recorded with the FPOD (Table 4-4). The correlation test showed that the CPOD detection rate and the FPOD detection rate correlated significantly when using the temporal scale %DPM/d (Table 4-5). However, the t-test showed a significant difference between detection rates of the two devices.

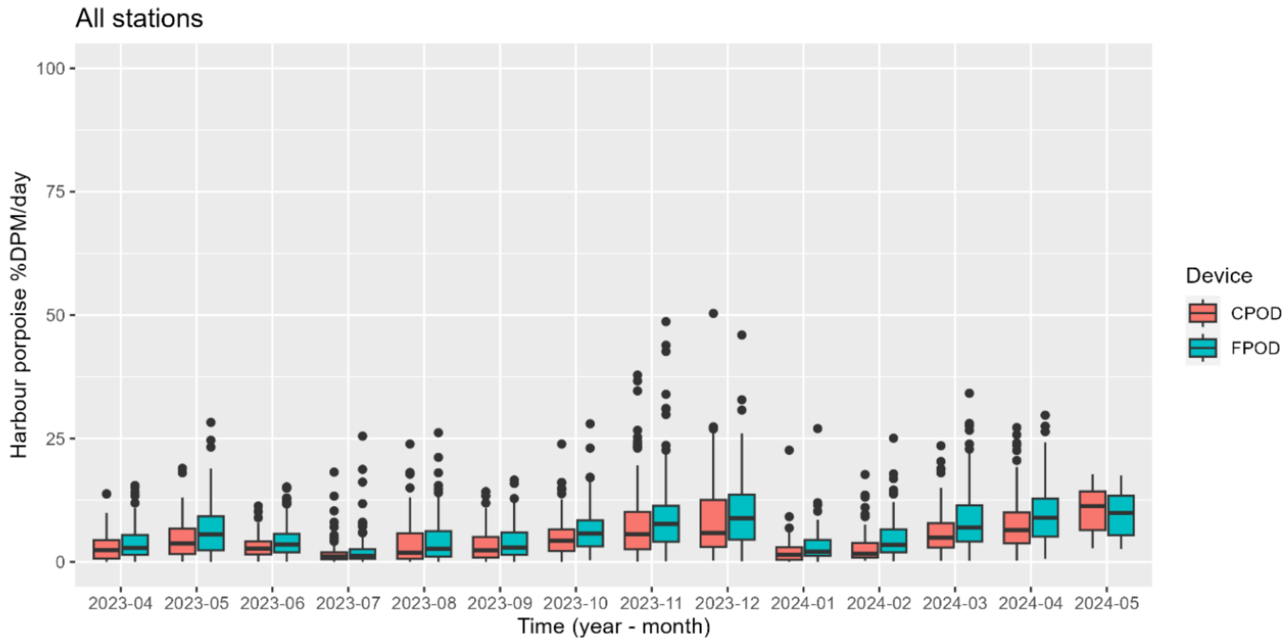

Figure 4-11 Harbour porpoise detection rates using the temporal scale %DPM/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – May 2024) averaged over all stations in the Danish North Sea I survey area; data set adjusted for background noise; only complete recording days and only the two highest data quality classes used (From Voß & Diederichs 2024).

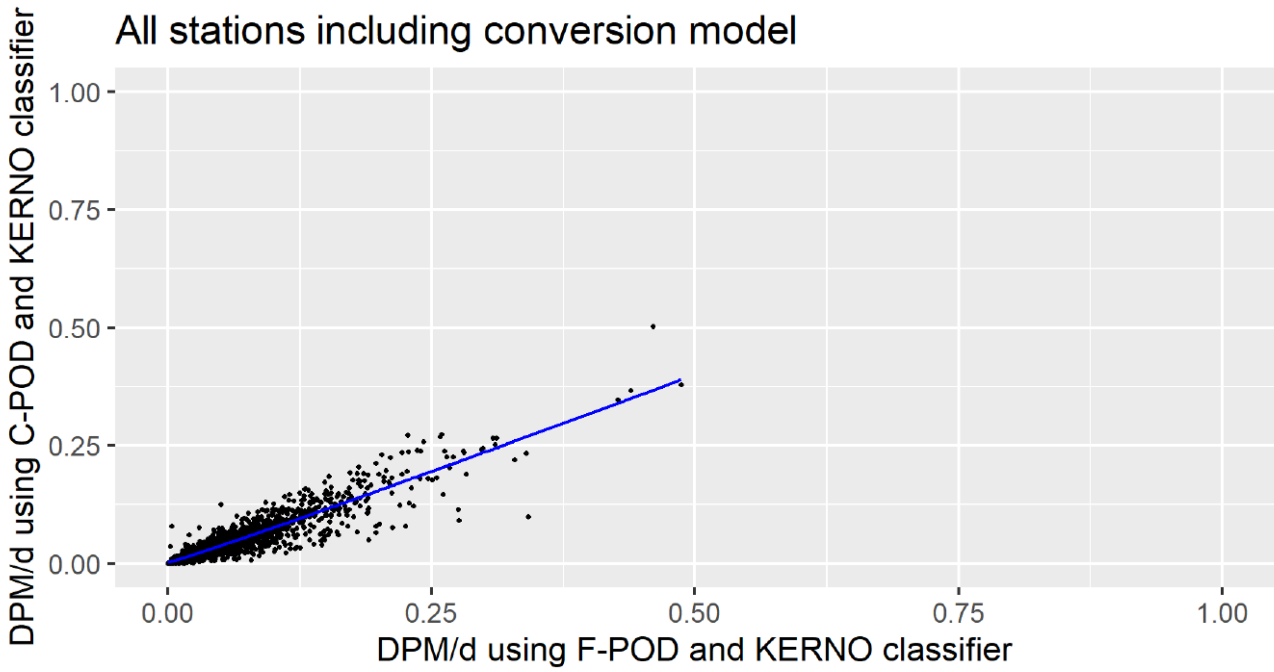

Figure 4-12 Comparing harbour porpoise detection rates using the temporal scale %DPM/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – May 2024) averaged over all stations in the Danish North Sea I survey area; the blue line is a curve fitting using a generalised log-logistic model; the model had a residual standard error of below 0.05 (From Voß & Diederichs 2024).

*Table 4-4 Comparing the detection rates using different temporal scales averaged over all stations in the Danish North Sea: Results of the t-test; signif. codes: '***' = 0.001 (Modified from Voß & Diederichs 2024).*

	Av. CPOD detection rate	Av. FPOD detection rate	t	df	p-value
%DPD/m	98.36	99.12	-1.1	142	0.3
%DPM/d	4.63	5.99	-7.3	3242	4e-13 ***

*Table 4-5 Comparing the detection rates using different temporal scales averaged over all stations in the Danish North Sea I survey area: Results of the correlation test; signif. codes: '***'=0.001. DPD = Detection Positive Day. DPM = Detection Positive Minutes (Modified from Voß & Diederichs 2024).*

	Sample estimate: cor	t	df	p-value
%DPD/month	0.6541	8	85	6e-12 ***
%DPM/day	0.92	96	1669	<4e-16 ***

Both PAM devices thus reported detections at the same time and only the number of detections varied. Furthermore, the CPOD and FPOD data correlated significantly when analysing data at different resolutions meaning that the data are generally comparable. The FPOD generally recorded more porpoise detections than the CPOD. However, there were also some exceptions with more detections at a CPOD than FPOD at one out of nine POD-stations and with short time intervals at single POD-stations, when more detections were recorded by the CPOD.

The differences between the two detection rates, however, varied. At 8 out of 9 stations, the detection rates of FPODs were higher than the detection rates of CPODs. Besides, the detection rates of CPODs and FPODs differed significantly at 6 stations and did not differ significantly at 3 stations. Accordingly, the average difference between the detection rates of CPODs and FPODs does not mean that the FPOD generally records this percentage of detections more than the CPOD.

Overall, the differences in detection rates seems to depend on (1) the temporal scale of data analysis (e. g %DPM/d or %DPD/m), (2) the study area, (3) the POD software used.

4.1.2 Other cetaceans

Of the six SoundTraps (ST600) deployed in each deployment period, all six were retrieved from deployment A, five from deployment B, and while six were retrieved from deployment C, one of those experienced data loss. The SoundTrap deployed at station NS13 during deployment B, like the F-POD, was lost during the deployment. The SoundTrap deployed at station NS6 during deployment C unfortunately experienced flooding, and therefore the data from the deployment was not available. For deployment D, retrieval and deployment dates varied greatly due to weather and personnel complications. Therefore, additional data loss resulted in deployment D from delays in equipment servicing as the batteries became exhausted. Station NS02 from deployment D is presently missing. Data available for this report is summarized in Table 4-6.

Table 4-6 shows the date each ST600 was initialized, and the expected life of the unit based on battery power and memory limitations. Each ST600 was expected to record for approximately 90 days, which requires servicing every three months. Please note that the ST600 at station NS25_A during deployment A and station NS06_B during deployment B were equipped with lower ampere-hour batteries, which had a much shorter life than calculated. For further deployments, those batteries were replaced with higher ampere-hour batteries.

Most of the stations during deployment D also suffered from rig noise, or noise which originates from the mooring itself or from the nearby surface buoy (Figure 4-13). The presence of this interference makes it very difficult to actively search for cetaceans in the soundscape, as the noise is often broadband and therefore can trigger automated detectors causing false positive detections. It can also mask actual odontocete vocal behavior, leading to false negatives.

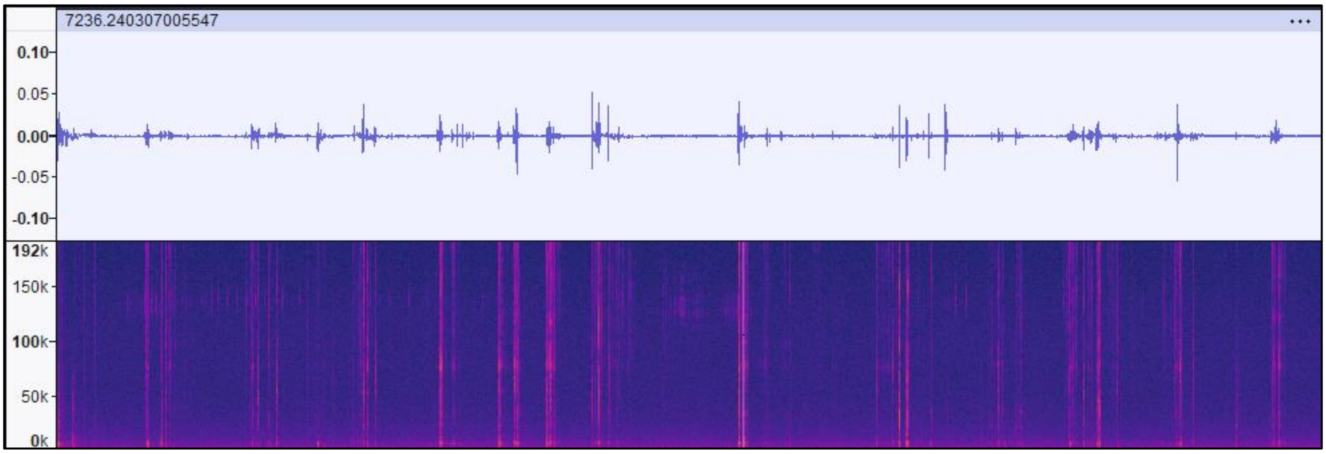

Figure 4-13. Example of rig noise, specifically from a loose chain on the rig, during deployment D at station NS25. The top panel is the linear waveform of the signal, and the bottom is a spectrogram between 0-192 kHz. The window is approximately 7 seconds long. The noise is broadband, and fills up the entire spectrum where present.

Table 4-6. Life of SoundTraps This table shows when each ST600 was turned on before deployment, and from that date the expected duration of the unit (i.e. 90 days). Data started and ended shows the range of actual data available, from the date of deployment to either the date or retrieval or the end of the battery life. Based on the date range, we have calculated how many hours are available for analysis per deployment, and from that number, how many hours were actually included in the subsampled analysis.

Station & deployment	Data started	Data ended	Hours available	Hours analyzed	Percent hours analysed
NS02_A	2023/04/19 00:06:04	2023/07/06 09:51:04	1883	941	50
NS02_B	2023/08/05 16:15:04	2023/10/24 10:00:04	1916	1437	75
NS02_C	2024/01/09 00:45:00	2024/02/06 18:30:00	692	519	75
NS06_A	2023/04/22 00:15:09	2023/07/02 13:00:09	1719	1289	75
NS06_B	2023/08/02 12:31:03	2023/09/07 14:16:03	868	434	50
NS06_D	2024-02-27 00:38:14	2024-04-22 00:23:14	1322	1321	100
NS13_A	2023/04/20 00:52:04	2023/07/14 16:37:04	2058	1538	75
NS13_C	2023/12/03 00:52:04	2024/02/20 22:44:53	1920	1441	75
NS13_D	2024-02-28 01:58:24	2024-04-22 00:43:24	1297	1296	100
NS14_A	2023/04/22 00:00:06	2023/07/20 12:45:06	2150	1073	50
NS14_B	2023/08/02 14:00:04	2023/10/24 13:45:04	1993	993	50
NS14_C	2023/11/30 00:01:53	2024/02/12 16:46:53	1794	892	50
NS14_D	2024-02-27 00:32:05	2024-04-18 00:17:05	1226	1224	100
NS16_A	2023/04/20 00:21:03	2023/07/06 15:06:03	1865	1398	75
NS16_B	2023/08/06 13:43:04	2023/10/20 16:28:02	1805	1798	100
NS16_C	2023/12/03 00:03:02	2024/02/10 14:48:02	1672	836	50
NS16_D	2024-02-2607:41:51	2024/03/13 07:01:51	384	384	100
NS25_A	2023/04/21 00:43:05	2023/05/28 14:28:05	904	677	75
NS25_B	2023/08/07 00:13:00	2023/10/24 02:42:04	1876	1873	100
NS25_C	2023/12/02 00:20:53	2024/02/12 01:05:53	1731	1526	88
NS25_D	2024-02-28 00:55:47	2024-04-21 00:40:47	1274	1274	100

4.1.2.1 Minke Whales

For the Minke whale analysis, 45 minutes per four hours for all data were analyzed between April 2023-April 2024. The rebuilt, beta detector did not detect any occurrences of minke whale pulse trains. This does not imply that minke whales do not use this area, only that they do not regularly produce the most readily identifiable signal in our waters, or that the tool is not functioning properly as it is still in beta development. However, while reviewing the 'Whistle & Moan Detector' output for delphinids, which overlaps in frequency range with the minke whale pulse train, no pulse trains were detected.

4.1.2.2 Delphinid Analysis

Detections were tallied for both white-beaked dolphins and uncategorized delphinids. Across all stations and deployments, there were a total of 158 detection positive snapshots, which resulted in 110 detection positive hours. Within these data, there were only six instances of dolphin acoustic activity that could not be confidently associated with white-beaked dolphins, though they did occur close in time to white-beaked dolphin acoustic events. There was one uncategorized delphinid at station NS06 during deployment A, one at NS02 during deployment A, one at NS13 during deployment D, and three at NS14, during deployments A, C, and D. These stations are the most northern and western stations with broadband recordings. Only two snapshots/hour were associated with unknown delphinids. Due to the low number of unclassified detections, all descriptions of dolphin positive hours hereafter refer to white-beaked dolphin detections.

Detection positive hours (DPH) were generated for white-beaked dolphin events, based on the hours available for analysis per station and deployment and the 158 detection positive snapshots. The ratio of detection positive days (DPD) was higher at the most northwestern stations in the study area, though no station recorded detection positive days more than 20% (Figure 4-14).

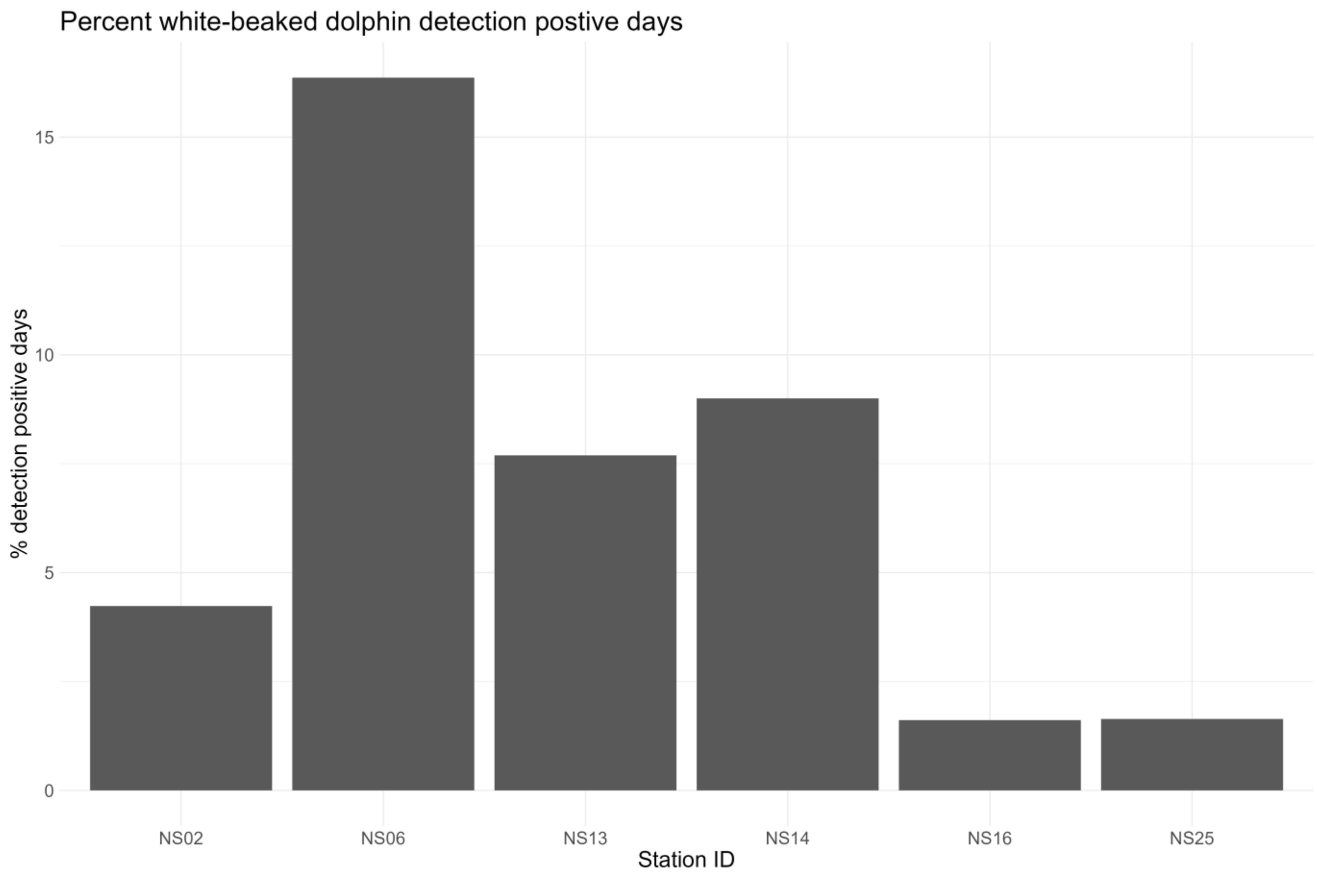

Figure 4-14 Percent dolphin positive days across deployments A–C across all stations.

From the hours included in this analysis, less than 1% contained instances of white-beaked dolphin acoustic activity (Figure 4-15). The highest acoustic detections were observed at NS13 in July 2023. However, the confidence interval of 1.2% at station NS13 indicated a large variability of acoustic detections of white-beaked dolphins for that particular month. All stations showed similar patterns of acoustic detections (except Station NS25) in early summer months following a drop during autumn months and another rise in the winter. The northwestern stations in general had slightly higher acoustic detections than their southeastern counterparts, suggesting a higher presence in the offshore marine environment.

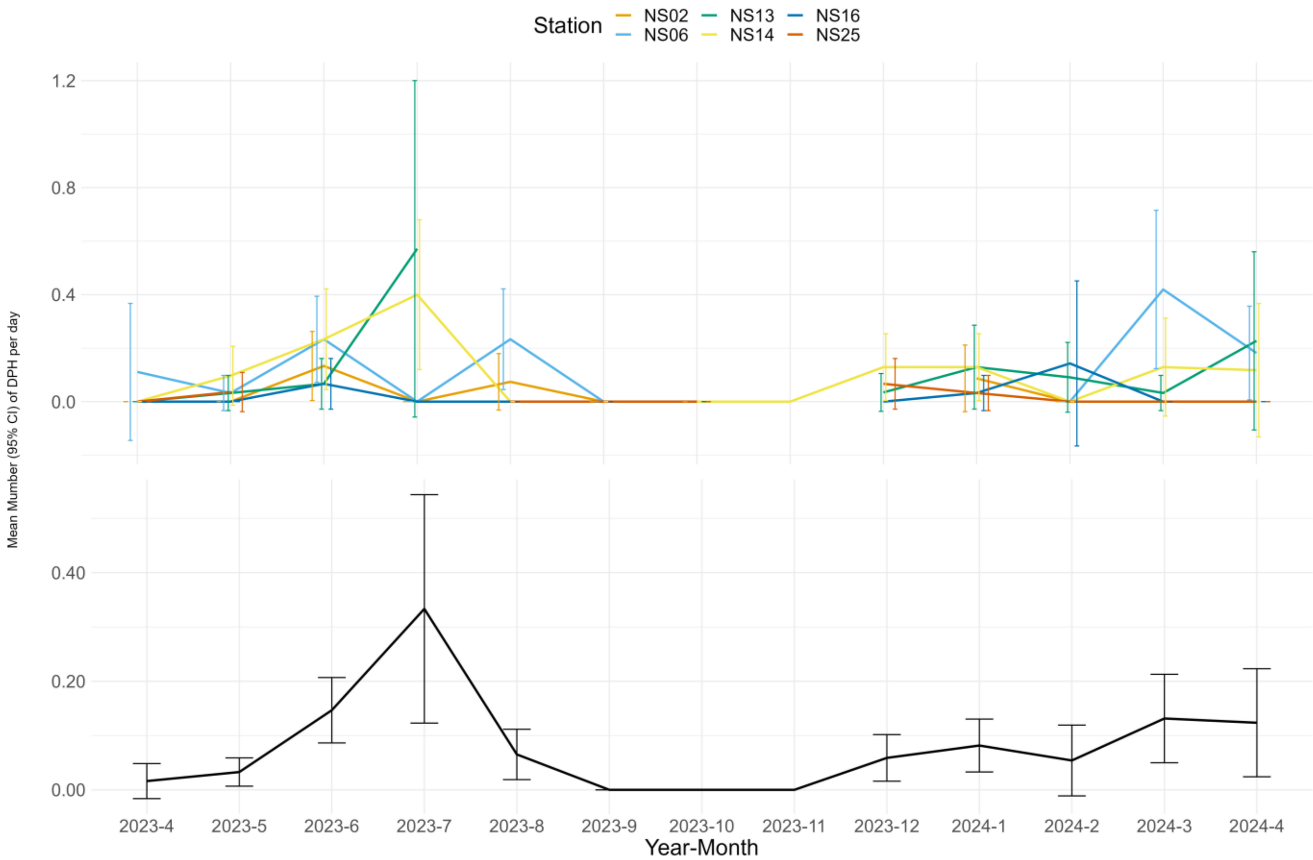

Figure 4-15 Average detection positive hours (DPH) for white-beaked dolphins per month in the study area for the entire survey, presented with 95% confidence intervals. Top Panel shows these data by month and station, while the bottom panel shows these data across all stations for the full survey period.

Generally, even with the limited detections we had within the survey area, there were twice as many detection positive snapshots at night (n=106) than during the day (n= 52). When looking at the diurnal patterns of dolphin activity, snapshots provide a more detailed overview as to the length of activity than detection positive hours. Globally, dolphin groups are more acoustically active at night, including dolphins in the North Atlantic (Cascão et al, 2020; Cohen et al., 2023). Danish white-beaked dolphins demonstrated similar trends during the North Sea Energy Island monitoring program in an adjacent area 2021–2023, however with much higher levels (Kyhn et al, 2024a). Figure 4-16 shows a high presence of bioacoustics activity throughout the night, with a sharp increase in the predawn hours, with some activity during the day. This activity coincides with what is known about acoustic activity from tagged white-beaked dolphins in Iceland, where all presumed foraging activity occurred between 01:30 and 07:00 UTC on 3 August 2006, when ambient light levels were low (n=1) (Rasmussen et al. 2013).

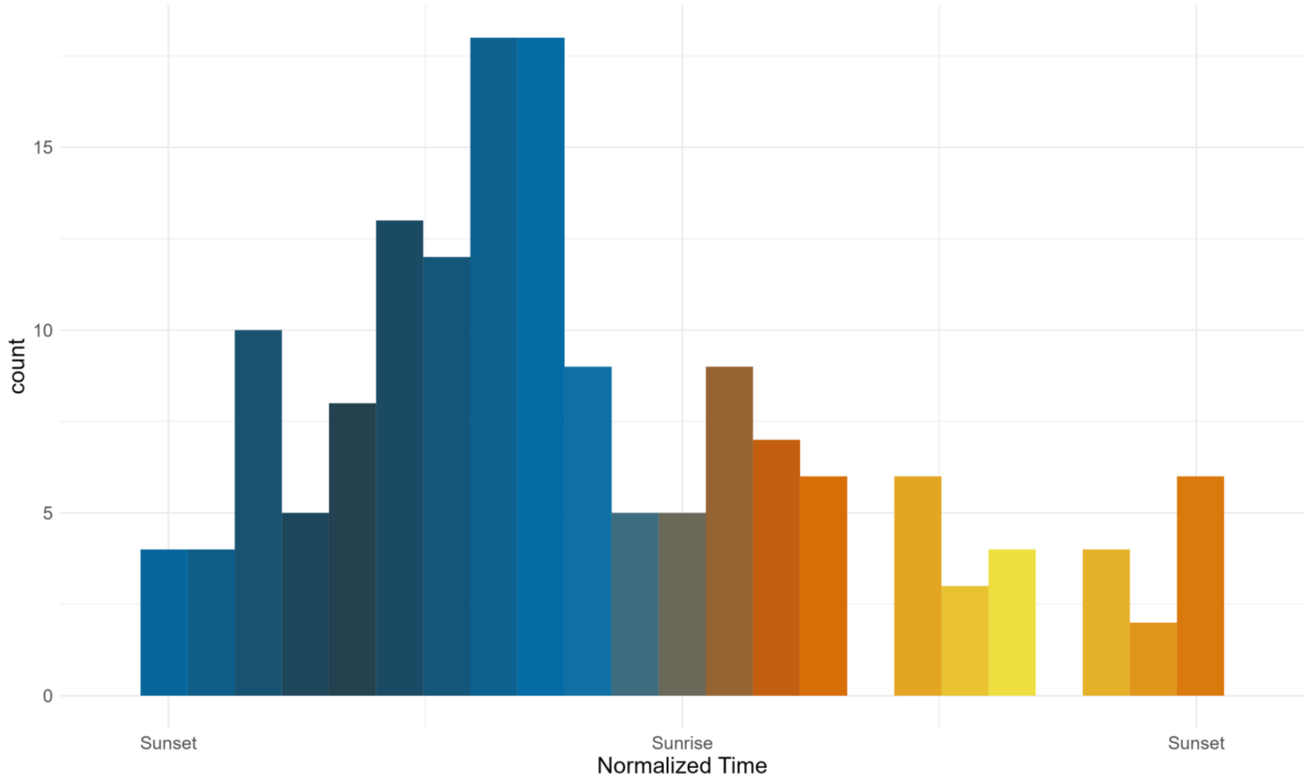

Figure 4-16 Diurnal pattern of detection positive snapshots (DPSS) for white-beaked dolphins at all stations against normalized time (sunset-sunrise: -1 - 0; sunrise-sunset: 0 - 1).

4.2 Aerial surveys of harbour porpoise

Four aerial surveys were planned during 2023, but due to poor weather in fall 2023 only three surveys were carried out. This was on 12th of May, 14th of June and 2nd of August 2023. It was therefore decided to move the missing fall survey to the fall of 2024.

Harbour porpoise aerial survey 12th May 2023

On the survey 12th May 2023, all transects were covered except for the part of the transects that crosses the Horns Rev 3 Offshore Wind Farm. The plane was not allowed to fly at 600 feet when crossing the wind farm and had to increase the flight height. Consequently, these parts are excluded on all surveys (Table 4-7). Observations were conducted in Beaufort Sea State 1-3, but on this survey 77% were conducted in Sea State 1 or 2. Beaufort Sea State is a definition of wave height and used here to determine when the waves were too high (when above 2) for observing harbour porpoises. The subjectively assessed sightability for each observer is displayed in Figure 4-17. Here, merely 38% of the effort was conducted in either good or moderate conditions. The sightability was particularly poor in the western part of the survey area, which for example can be reduced due to strong glare. Variation in sightability is included and adjusted for in the Distance sampling analysis when calculating the abundance.

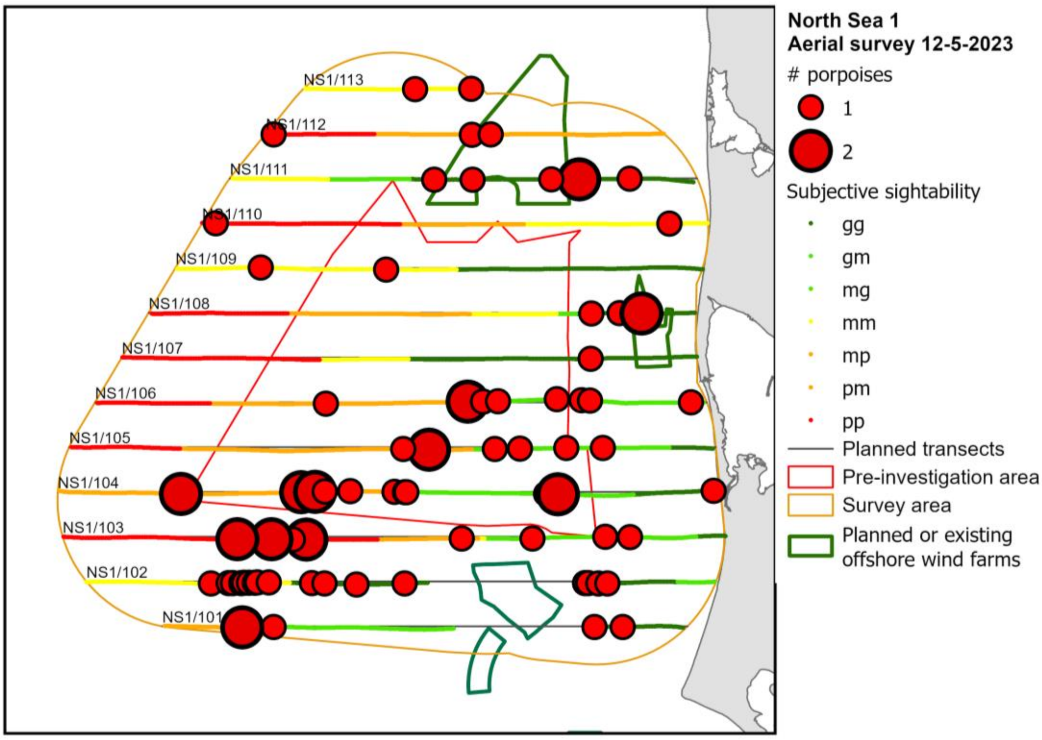

Figure 4-17 Harbour porpoise observations during the aerial survey on the 12th of May 2023. The size of the dots indicates the group size at each observation. The observer assessed sightability is indicated in colours from green to red for each observer side of the plane (g=good, m=moderate, P=poor).

Table 4-7 Data and results from the three aerial surveys conducted during the North Sea I survey in 2023. CV = Coefficient of Variation. Total length of planned transects is 1084 km.

Survey date	Completed effort with good or moderate sightability (km)	Abundance (95% Confidence Interval)	Density (95% Confidence interval)	Mean group size	No. harbour porpoises (incl. calves)	No. calves	Calf ratio	CV
12/05/2023	848	4814 (2771–7935)	0.63 (0.36–1.04)	1.14	73	0	0%	0.26
14/06/2023	855	22,206 (14,924–31,182)	2.91 (1.95–4.08)	1.31	311	32	10.30%	0.19
02/08/2023	862	3572 (1968–6155)	0.47 (0.26–0.81)	1.35	68	14	20.60%	0.3

In total, 73 adult harbour porpoises were observed (*Table 4-7*). There were no observations of calves, defined by a much smaller individual next to a large individual. It was not possible to determine if any of the porpoises seen in pairs were a mother with a large and nearly weaned calf. The harbour porpoise observations were distributed across the aerial survey area. The abundance of harbour porpoises in the survey area was estimated to 4814 harbour porpoises (95% CI = 2771–7935; CV = 0.26). The average density within the area was 0.63 individuals/km^2 (95% CI = 0.36–1.04).

Aerial harbour porpoise survey 14th June 2023

On the 14th June 2023 survey, there were optimal survey conditions and 92% of transects were covered in Sea State 1. The subjectively assessed sightability for each observer is displayed in Figure 4-18. Here, 98% of the effort was conducted in either good or moderate conditions, while 2% were conducted with lower sightability. Variation in sightability is included and adjusted for in the Distance sampling analysis for calculating the abundance. Due to military activity, the western part of the four most southern transects could not be covered.

During this survey, 311 harbour porpoises were observed in total and 32 of these were calves (small animal next to a large animal), which gave a mother-calf pair ratio of 10.3% (Table 4-7). A study in German waters near Sylt (Sonntag et al., 1999) described a calving area based on two aerial surveys one year apart where they found a calf ratio of 10–17%. This area was confirmed as breeding area in later surveys (Gilles et al., 2009; Gilles et al., 2011; Gilles et al., 2016). The observations were distributed in most of the survey area but with few in the coastal waters on top of and south of the Vesterhav Syd wind farm. The turbines were piled into the seabed during the early spring of 2023 and multiple construction vessels were still in the area (Figure 4-18). Throughout the survey, many large schools of fish were seen at the surface making the water appear to "boil". It was not possible to determine the species, but it appears likely that these fish could be contributing to the high level of harbour porpoise observations.

The abundance of harbour porpoises in the survey area was estimated to 22,206 harbour porpoises (95% CI = 14,924–31,182; CV = 0.19) with a density of 2.91 individuals/km^2 (95% CI = 1.04–3.16) (Table 4-7). This is 4.6 times as many as compared to the May survey. For comparison, the densities from the Danish national aerial surveys in Skagerrak and the Southern North Sea was respectively 0.54 individuals/km^2 on average for the period 2017–2021 and maximum 0.85 individuals/km^2 in 2017 for Skagerrak, and on average 0.75 individuals/km^2 (2011–2021) and maximum 1.22 individuals/km^2 in 2014 in the southern North Sea. In German North Sea waters, however, similar and higher densities than the North Sea I survey area have been estimated particularly at the German Dogger Bank (Nachtsheim, 2021) indicating that there may be several high-density areas (or hot spots) in the North Sea and that the North Sea I survey area may be one of them. The density of 2.91 porpoises per km^2 is the highest ever detected in the Danish North Sea.

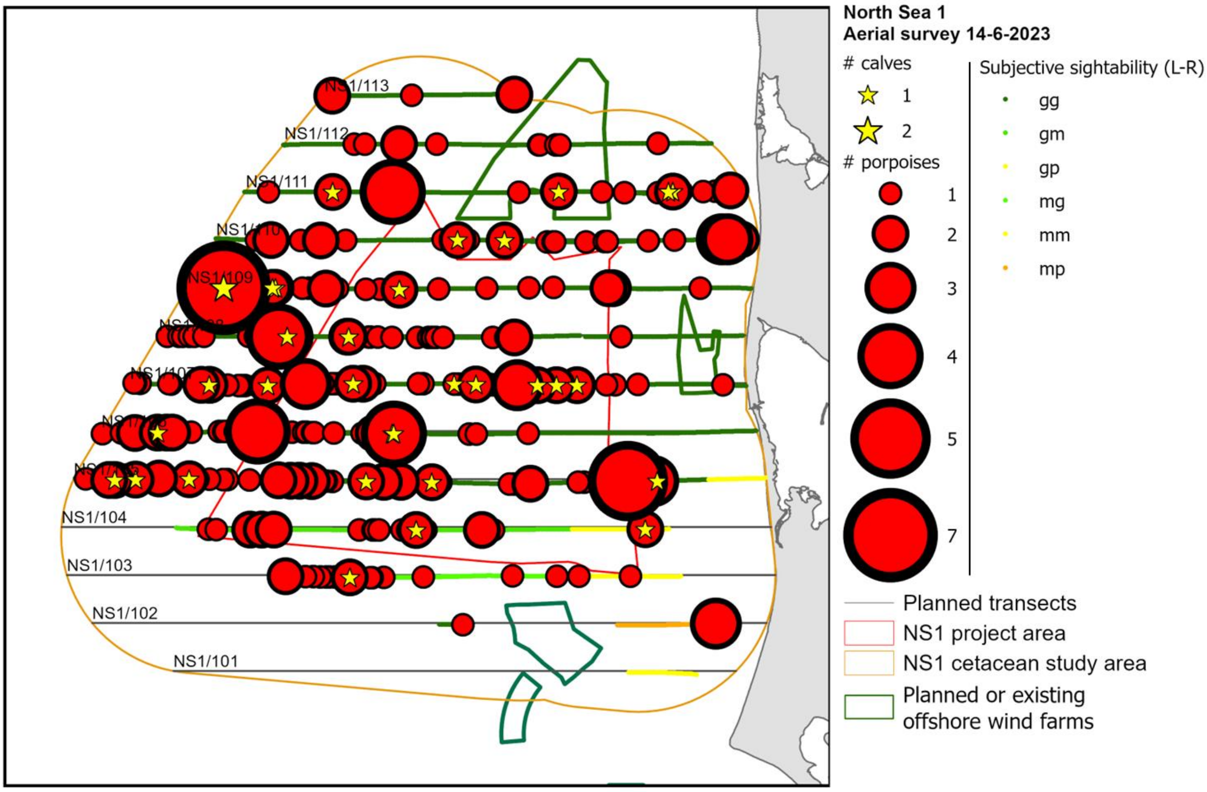

Figure 4-18 Harbour porpoise observations during the aerial survey on 14th June 2023. The size of the dot indicates the group size at each observation and a star indicates one or more harbour porpoise calves. The observer assessed sightability is indicated in colours from green to red for each observer side of the plane (g=good, m=moderate, P=poor).

Aerial harbour porpoise survey 2nd of August 2023

On the 2nd of August 2023 survey, the weather was overall good and 75 % of transects were covered in Sea State 1 or 2. Furthermore, 60% of the effort was conducted in Good or Moderate sightability (Figure 4-19). During this survey, 68 harbour porpoises were observed in total and 14 of these were calves (small animal next to a large animal), which gives a mother-calf pair ratio of 20.6% (Table 4-6).

The abundance of harbour porpoises in the survey area was estimated to 3,572 harbour porpoises (95% CI = 1,968–6,155; CV = 0.30) with a density of 0.47 individuals/km^2 (95% CI = 0.26–0.81) (Table 4-7). This is comparable to the porpoise abundance and density estimated in May 2023, but six times less than the abundance and density estimated for the June 2023 survey.

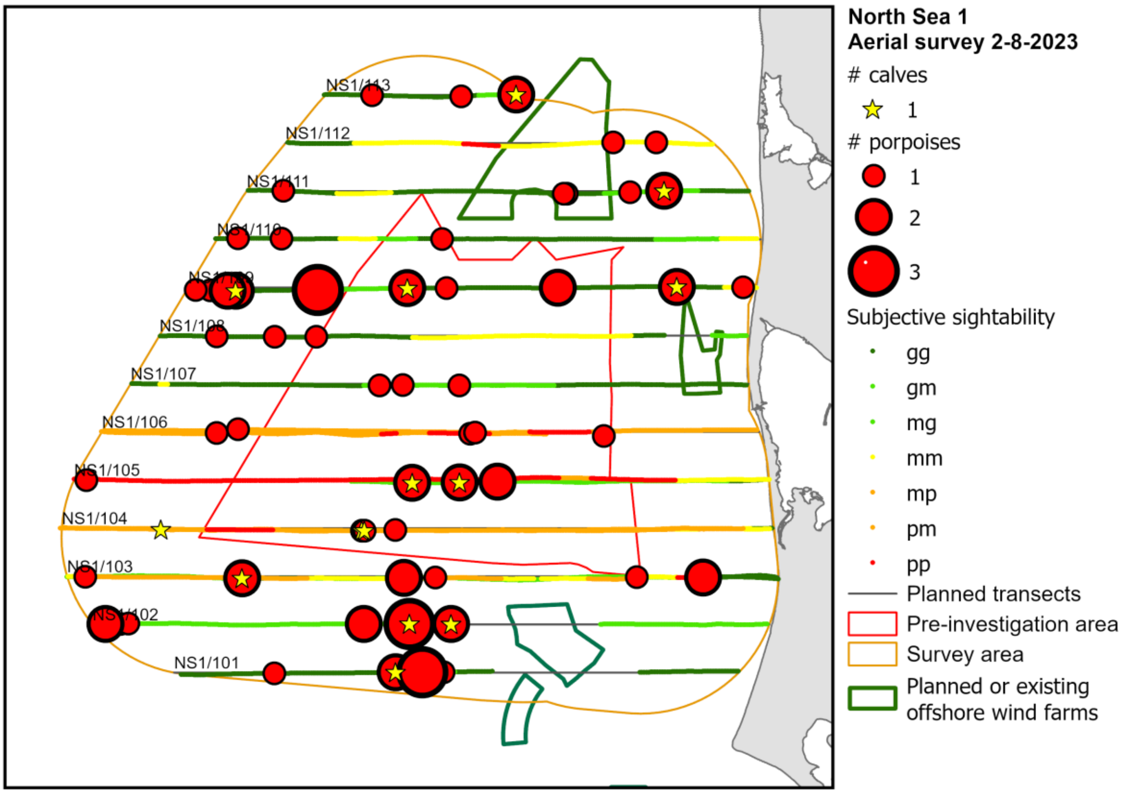

Figure 4-19 Harbour porpoise observations during the aerial survey on 2nd August 2023. The size of the dot indicates the group size at each observation and a star indicates one or more harbour porpoise calves. The observer assessed sightability is indicated in colours from green to red for each observer side of the plane (g=good, m=moderate, P=poor).

4.3 Aerial surveys other cetaceans

Other marine mammals were observed during the marine mammal surveys, but also during the bird surveys. Altogether, six bird surveys and three marine mammal surveys were conducted between April 2023 and March 2024, providing data on other cetaceans in the area. In total, seven minke whales, 10 white beaked dolphins of which one was a calf, 2 common dolphins and 2 unidentified whales were observed (Figure 4-20). Some of the whales were observed “off effort” i.e. not on the planned transects, but within few kilometres off the survey area. They have been included here since they are so close to the survey area that it is likely that they would also use the survey area.

The number of observations of white-beaked dolphins confirm that this species utilises the area regularly during summer and perhaps more sporadically during winter where only 1 white-beaked dolphin was observed (November). However, since the majority of surveys were conducted in the spring and summer, more surveys are needed to confirm this. The seven minke whales were observed between March and July 2023 (1 in March and 6 in June–July) suggesting that this is mainly a Spring-Summer habitat for minke whales. For further information on whales see chapter 4.1.2 on wideband recordings of cetaceans. For the bird surveys, the plane is kept at a survey height of 200 feet vs 600 feet during marine mammal surveys. For larger whales and dolphins, where the main aim is to note whether they are present in the area, the results from both types of surveys are usable.

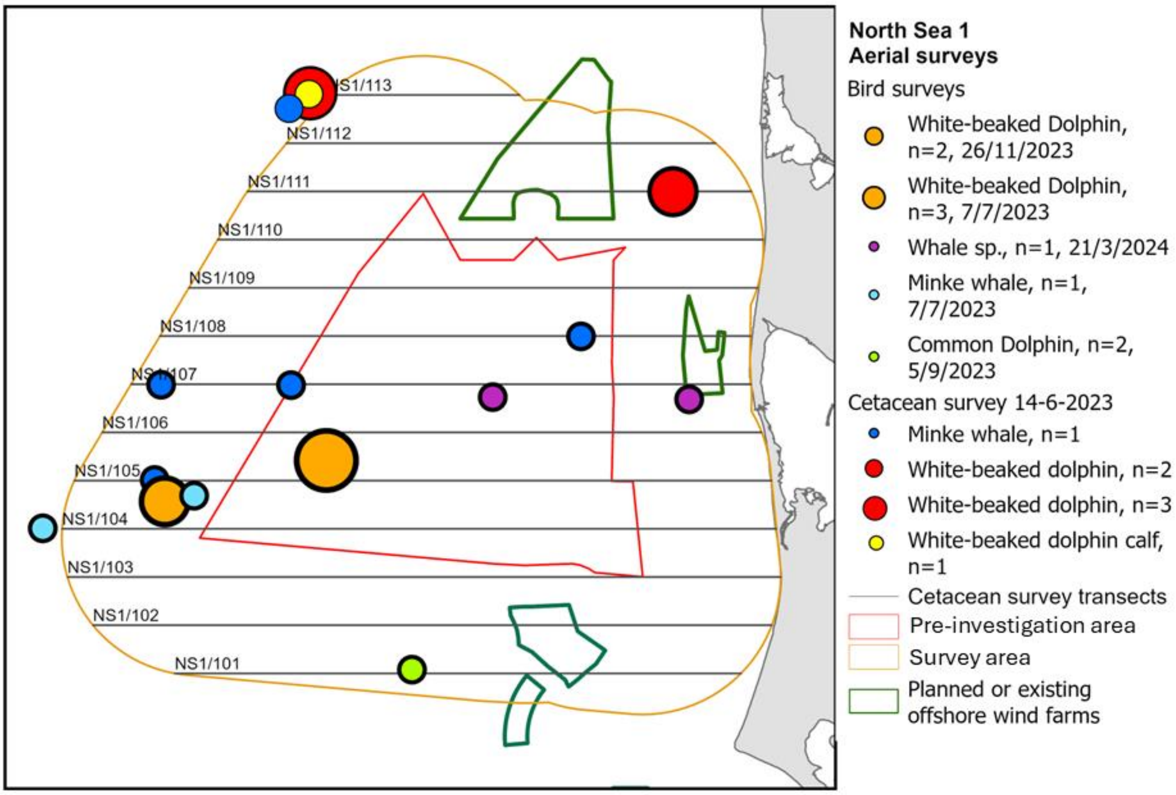

Figure 4-20 Observations of cetaceans other than harbour porpoises during bird and cetacean surveys from April 2023 to March 2024.

4.4 Underwater noise

Monitoring of underwater noise follows a stepwise pattern, where the first focus is the collection of baseline data on ambient noise and noise from turbines in operation, to be used as input for soundscape modelling; second is collection of high-resolution mapping of harbour porpoise presence around individual turbines and the soundscape modelling itself; third is the overlay of soundscape maps and fine-scale data with harbour porpoise abundance mapping.

4.4.1 Noise monitoring

Calibrated and quality assured decidecade band levels were obtained from six monitoring stations inside and around the project area (table 4-6). Overall statistics of the noise spectra are shown in Figure 4-21, which will be used in calibrating/validating the noise propagation model and for future impact assessments. The median spectra (purple lines in Figure 4-21) have pronounced peaks between 50 and 125 Hz, consistent with spectra from areas with high levels of ship noise. The sharp decrease for frequencies below 50 Hz is caused by the shallow waters, as the long wavelengths of the lower frequencies cannot physically propagate in shallow water. The apparent increase in noise above 10 kHz is due to the self-noise of the sound recorders, which means the recordings are limited at lower levels by the electronic noise in the recorder, and not by the ambient noise. This means that lower levels than indicated in the figure did occur above 10 kHz, but could not be recorded due to self-noise.

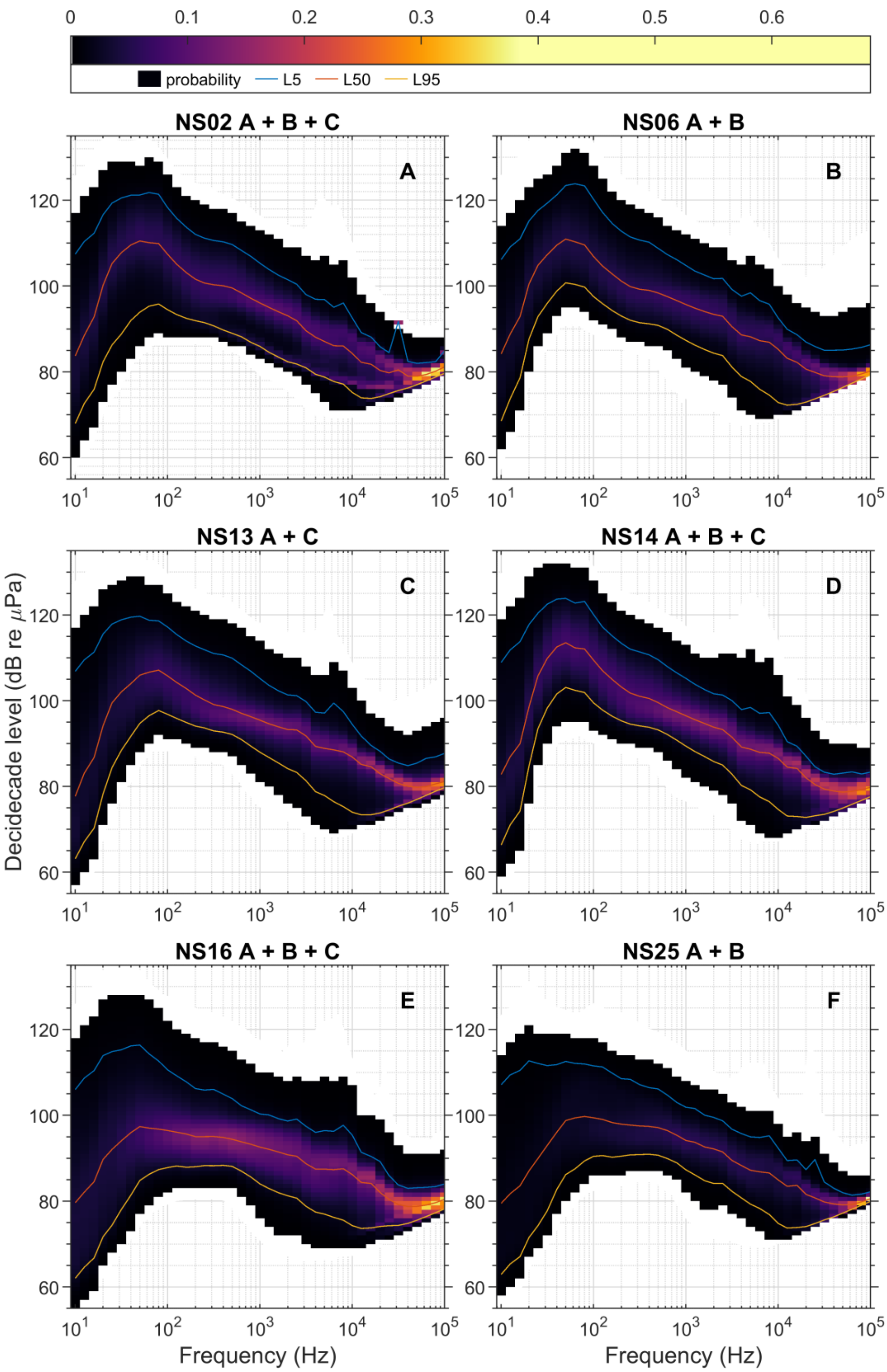

Figure 4-21 Statistical representation of decidecade frequency spectra of the ambient noise recordings from the six dedicated noise monitoring stations and the three deployment periods A, B and C. Distributions were created from sequential 1 second averages of the noise level within each decidecade band. The colour coding shows the probability of occurrence (density function) of the different sound pressure levels within each frequency band, with lighter colours representing higher probability of occurrence. The red line represents the median (L_{50}), yellow and blue line the lower and upper 5th percentiles, L_{95} and L_5, respectively.

Results from three selected frequency bands are shown in Figure 4-22 (63 Hz), Figure 4-23 (125 Hz) and Figure 4-24 (2 kHz) as detailed examples. The three bands (63 Hz, 125 Hz and 2 kHz), are recommended by the HELCOM manual for noise monitoring (HELCOM, 2018). The figures indicate monthly medians and selected percentiles for the months with available data for each station. Levels are generally stable across stations and time, with a few exceptions. The possible causes behind exceptions, such as the generally lower levels on station NS02 during deployment C have not been investigated.

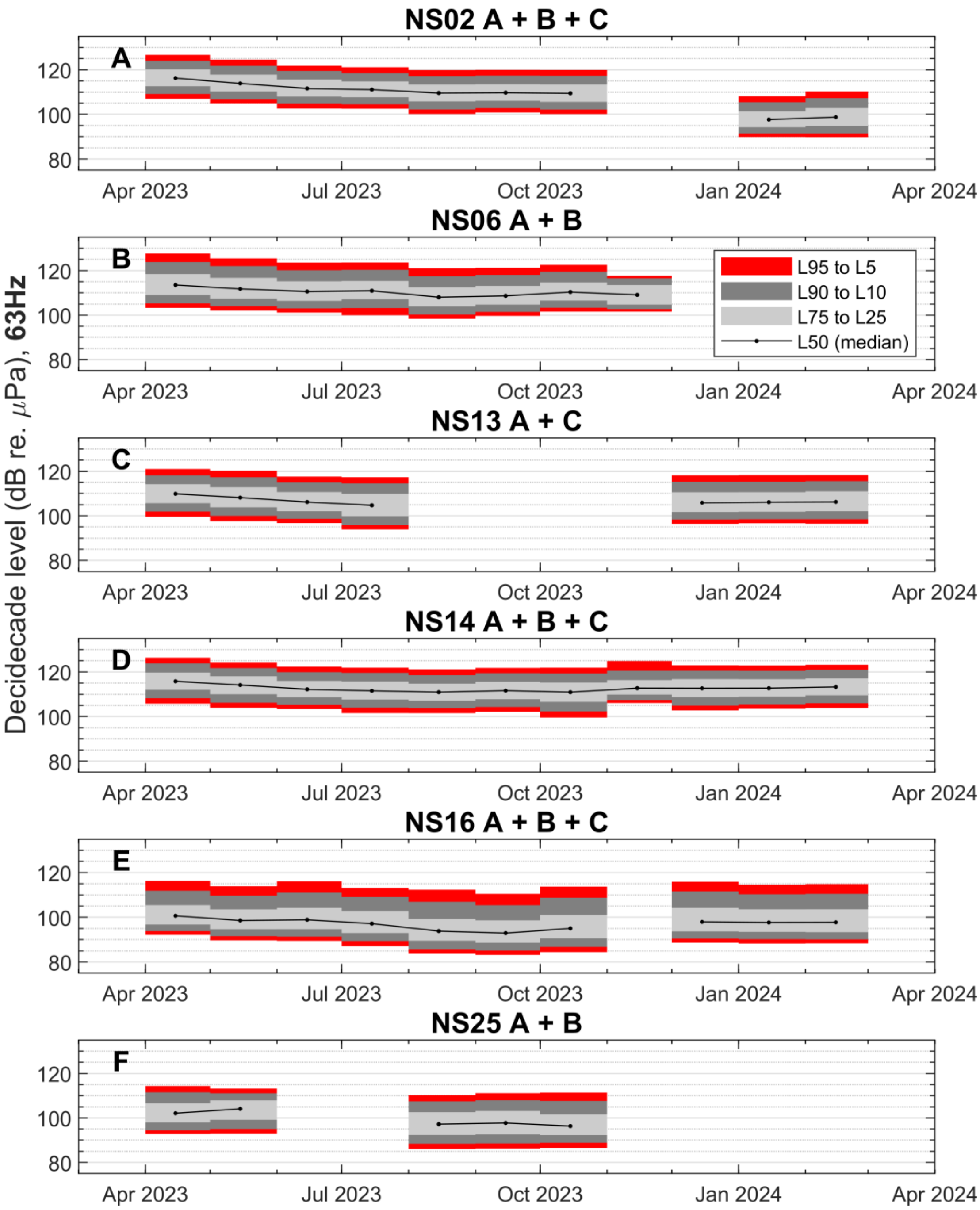

Figure 4-22 Monthly statistics of the 63 Hz decidecade band from the noise recordings at the six dedicated monitoring stations. For each month selected exceedance levels are indicated by the coloured bands. The solid line indicates the monthly median (L_{50}).

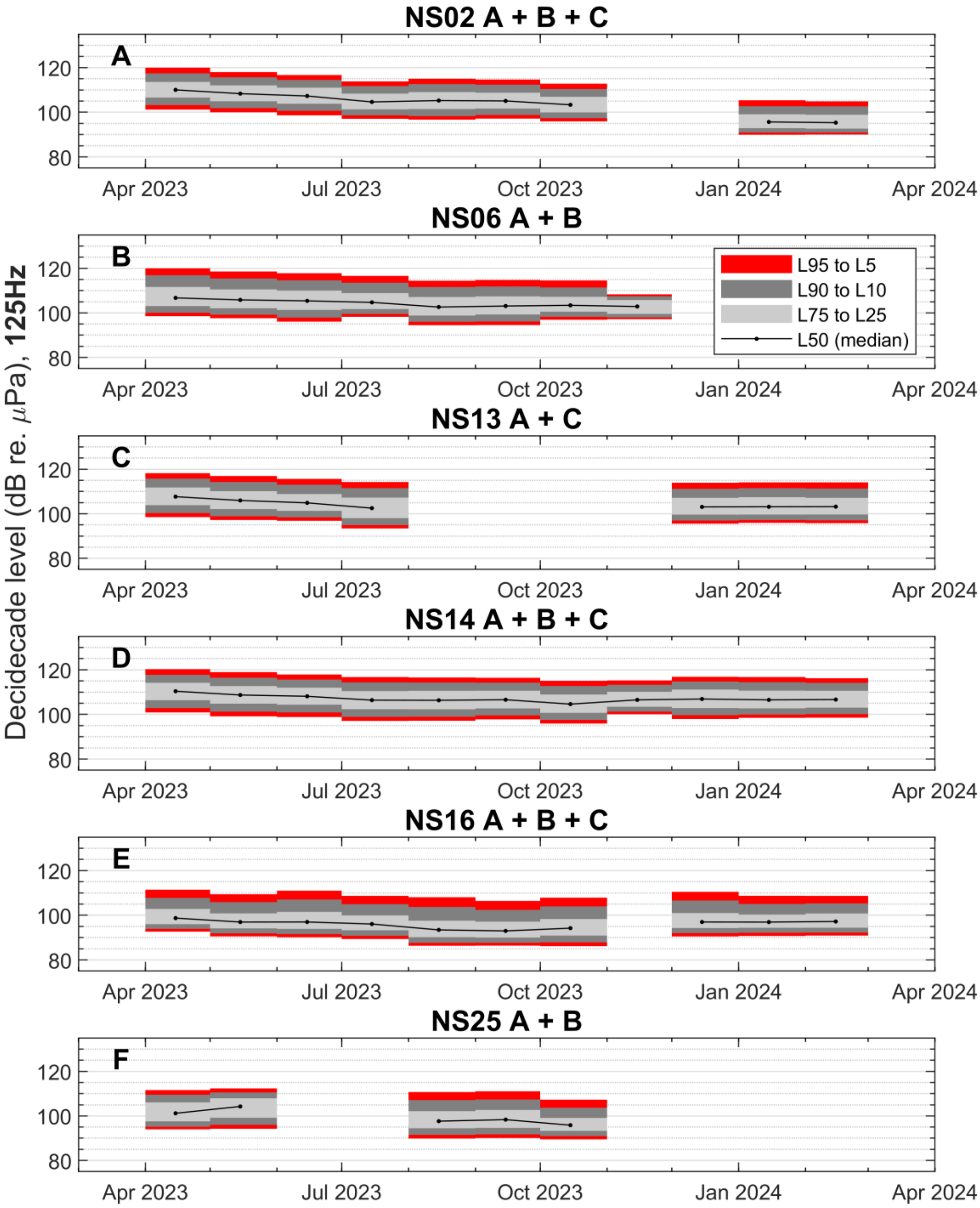

Figure 4-23 Monthly statistics of the 125 Hz decidecade band from the noise recordings at the six dedicated monitoring stations. For each month selected exceedance levels are indicated by the coloured bands. The solid line indicates the monthly median (L_{50}).

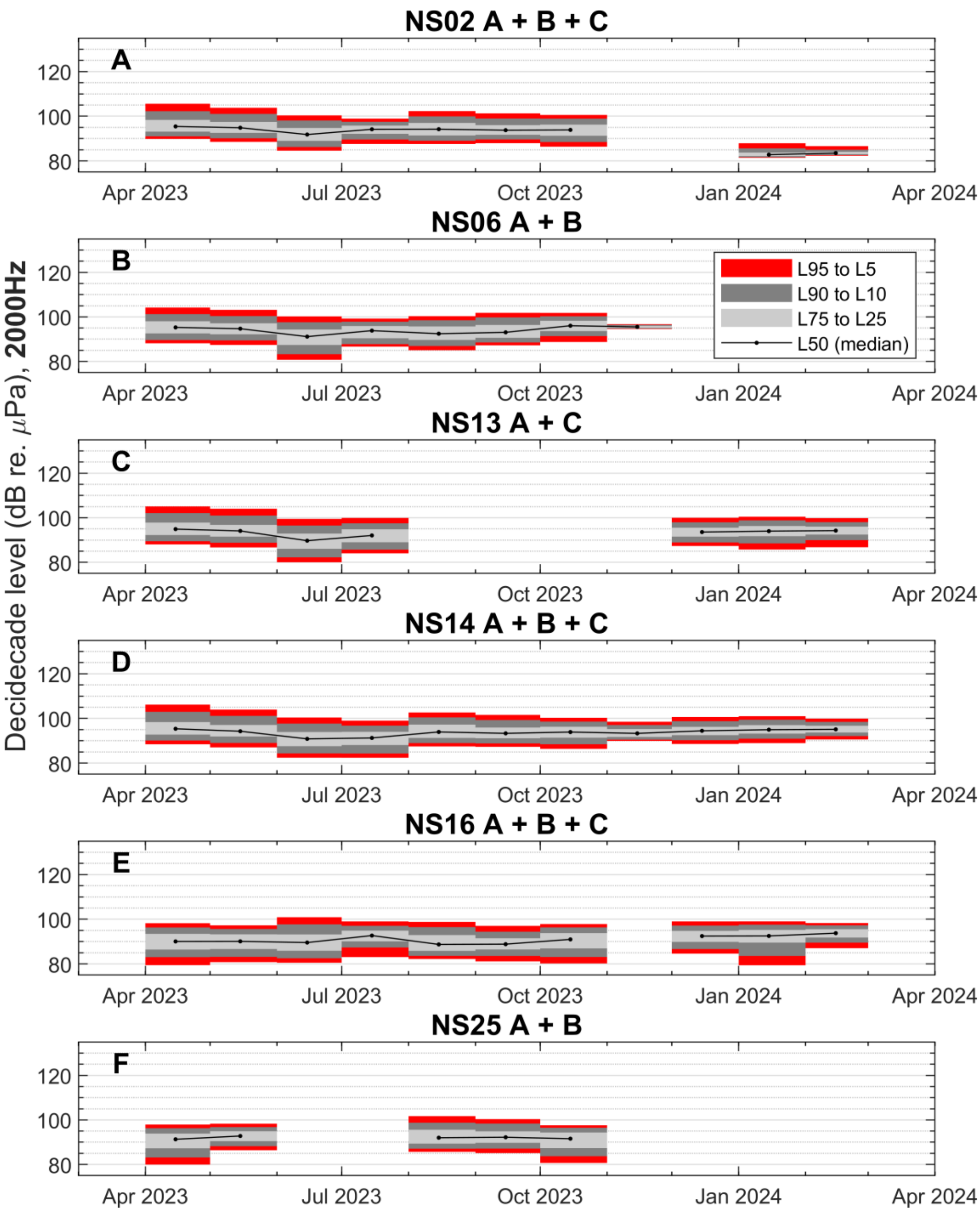

Figure 4-24 Monthly statistics of the 2 kHz decidecade band from the noise recordings at the six dedicated monitoring stations. For each month selected exceedance levels are indicated by the coloured bands. The solid line indicates the monthly median (L_{50}).

4.4.2 Turbine noise

Noise recorders were placed close to individual turbines in two existing wind farms, in order to measure the noise from operational turbines. The turbines were selected to represent the largest turbines in operation in Danish waters and of two different types: one with gear box (Horns Reef 3) and one with direct drive technology (Kriegers Flak). Deployment and data collection is indicated in Table 4-8.

Table 4-8 Obtained recordings of turbine operational noise. The difference in recording distance between the two sites adds a small bias to the results, with the recordings at Kriegers Flak expected to be a few dB higher than the recordings at Horns Reef 3, simply because the recorder was closer. This difference is difficult to correct for without proper modelling of sound propagation, but is not expected to exceed 4 dB and likely less than this[3].

Wind farm	Turbine ID	Latitude (Decimal degrees)	Longitude (Decimal degrees)	Distance from turbine	Turbine type	Nominal capacity	Data collection period
Kriegers Flak	10O	55.0197	12.8180	98 m	Siemens Gamesa SG 8.0-167 DD	8.4 MW	2023/06/20–2023/09/26
Horns Reef 3	F08	55.6566	7.7040	152 m	Vestas V164	8.3 MW	2023/11/26–2024/01/09

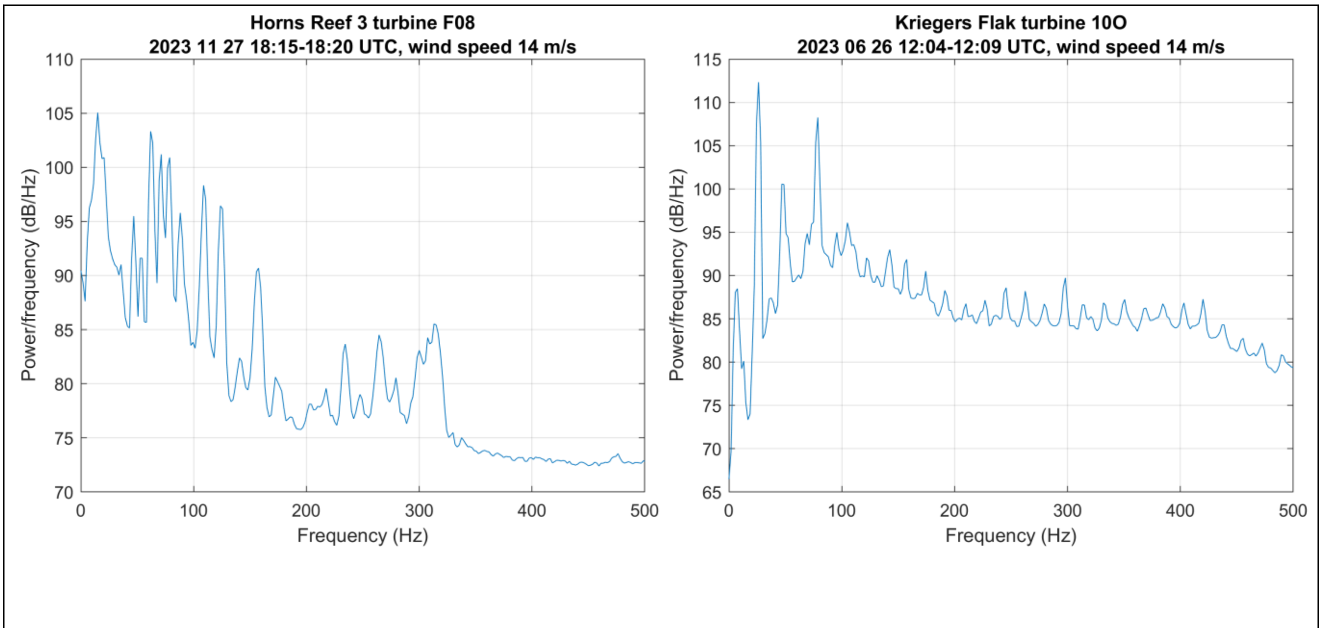

Figure 4-25 Power density spectra (Welch average) of the 5 minute sample recordings shown in Figure 4-21. Down sampled to 1,920 Hz sample rate from the original recording at 192 kHz sample rate. FFT size 1024, Hann window, 50% overlap, analysis bandwidth 1.9 Hz.

Noise recordings were analyzed in decidecade bands from 10 Hz to 80 kHz, with a 10 minute time resolution ($L_{p,ddec,10min}$). This time resolution was selected to match the time resolution of wind speed data, obtained from the operator of the wind farms (Vattenfall) as 10 minute averages. The wind data allowed the analysis to be broken up by wind speed in bins of 1 m/s from 0 m/s to 25 m/s. For each wind speed interval, the decidecade spectrum was computed. Examples are shown in Figure 4-25. Figure 4-26 shows a waterfall plot of all frequency spectra,

[3] For a point source in a free field, the sound pressure level 98 m from the source is expected to be 3.8 dB higher than at 156 m ($= 20\log_{10}\left(\frac{156}{98}\right)$), but in practice it is likely less, due to the reflections from sea surface and sea floor. Note also that the measurement precision of the instruments is ± 1 dB.

broken up by wind speed classes. Individual relationships between wind speed and decidecade level are shown for the lower frequency bands and selected higher frequency bands in Figure 4-29 and Figure 4-30.

Recordings from Kriegers Flak were dominated by ship noise from the nearby shipping lane, visible in the spectra in the bands between 63 Hz and 1000 Hz and identifiable as ship noise because levels are unaffected by wind speed. Clearly visible in the recordings are also two strong tonal peaks in the 25 Hz and 80 Hz bands, respectively. These peaks are most pronounced at wind speeds above approximately 10 m/s. Below 10 m/s the frequency of the peaks appears variable, and they are absent at the lowest wind speeds, where the turbine is not rotating.

Recordings from the turbine at Horns Reef 3 are much less contaminated by ship noise, visible as a lower noise floor. Numerous and very variable peaks are present in the spectra below 500 Hz, attributable to the turbine and likely originating in the gear box. The dominant peaks increased in amplitude with increasing wind speed. Not enough measurements were available at wind speeds (0–1 m/s) low enough for the turbine to be stopped Figure 4-27.

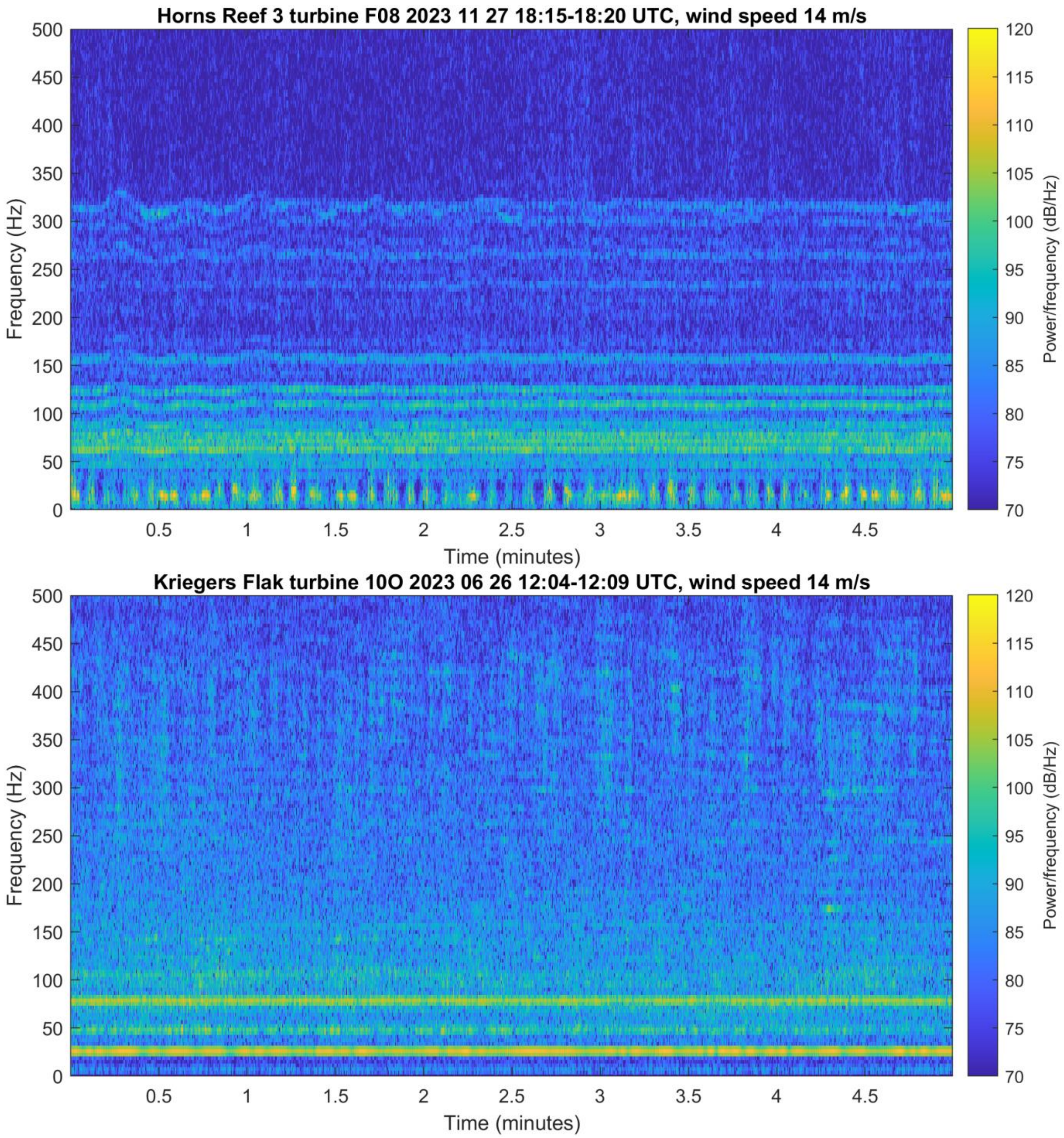

Figure 4-26 Spectrograms of 5-minute samples of noise recordings from a turbine with gearbox (Horns Reef 3, Vestas V164, 8.3 MW) and a turbine with direct drive (Siemens Gamesa 8.0 167-DD, 8.4 MW), both recorded at a wind speed of 14 m/s (10 minute average) and at a distance of approximately 100 m from the foundation. Down-sampled to 1920 Hz sample rate from the original recording at 192 kHz sample rate. FFT size 512, overlap 87.5%, Hann window.

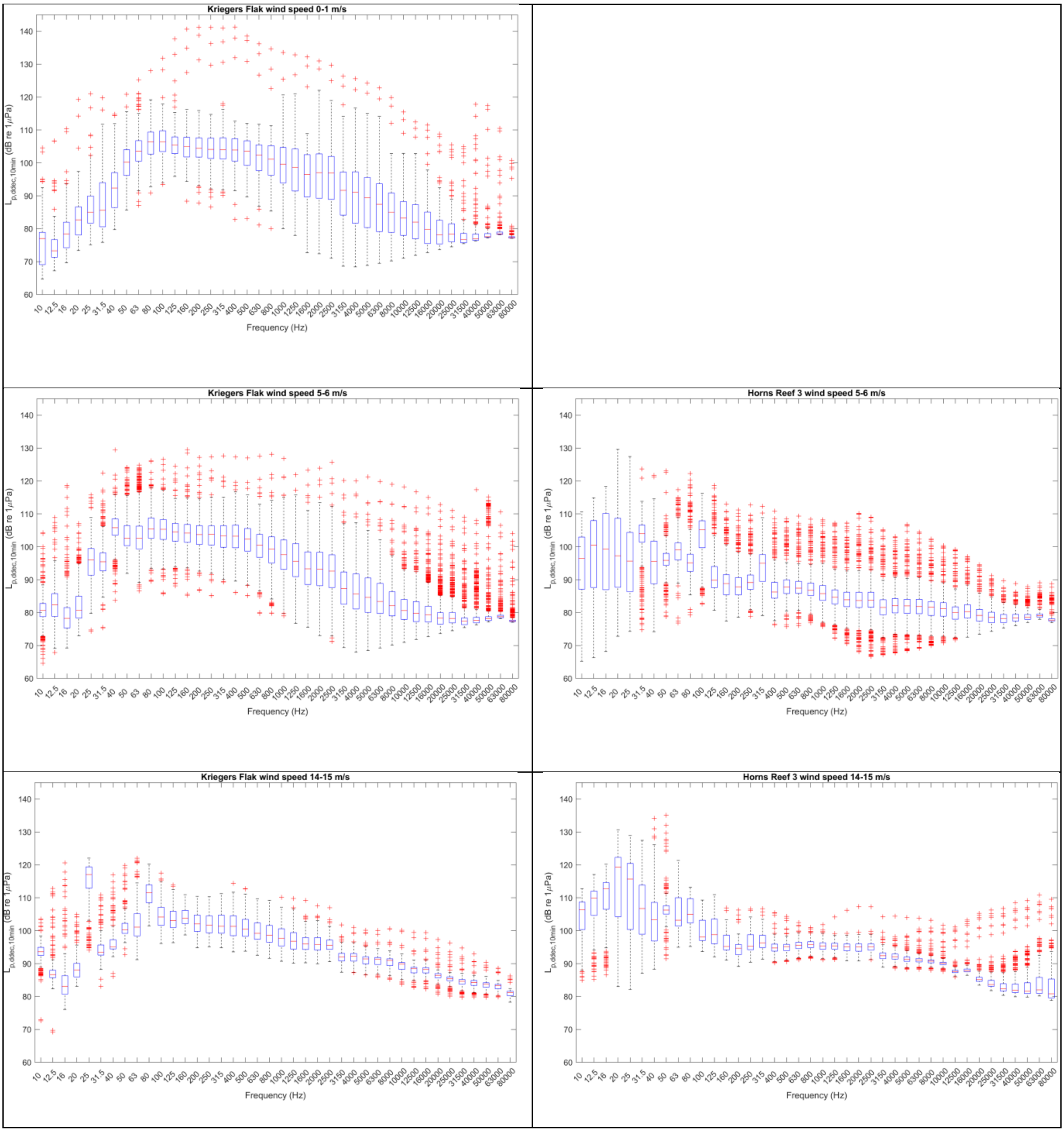

Figure 4-27 Left: Decidecade frequency spectra of wind turbine noise recorded from an 8.4 MW direct drive turbine at Kriegers Falk (left) at three different wind speeds. The top panel is the spectrum when the turbine is not turning, middle panel is at low wind speed, just above cut-in speed (= when the blades start rotating and generating power) and bottom panel is at high wind speed, where the turbine is likely operating at full nominal capacity. Note the pronounced peaks at 25 Hz and 80 Hz in the turbine noise from Kriegers Flak at high wind speed. Right: Similar spectra for an 8.3 MW turbine with gear box in Horns Reef 3 offshore wind farm. Insufficient data were available for the lowest wind speeds. Note the generally elevated levels at the lowest frequencies (below 100 Hz) compared to the spectra from Kriegers Flak.

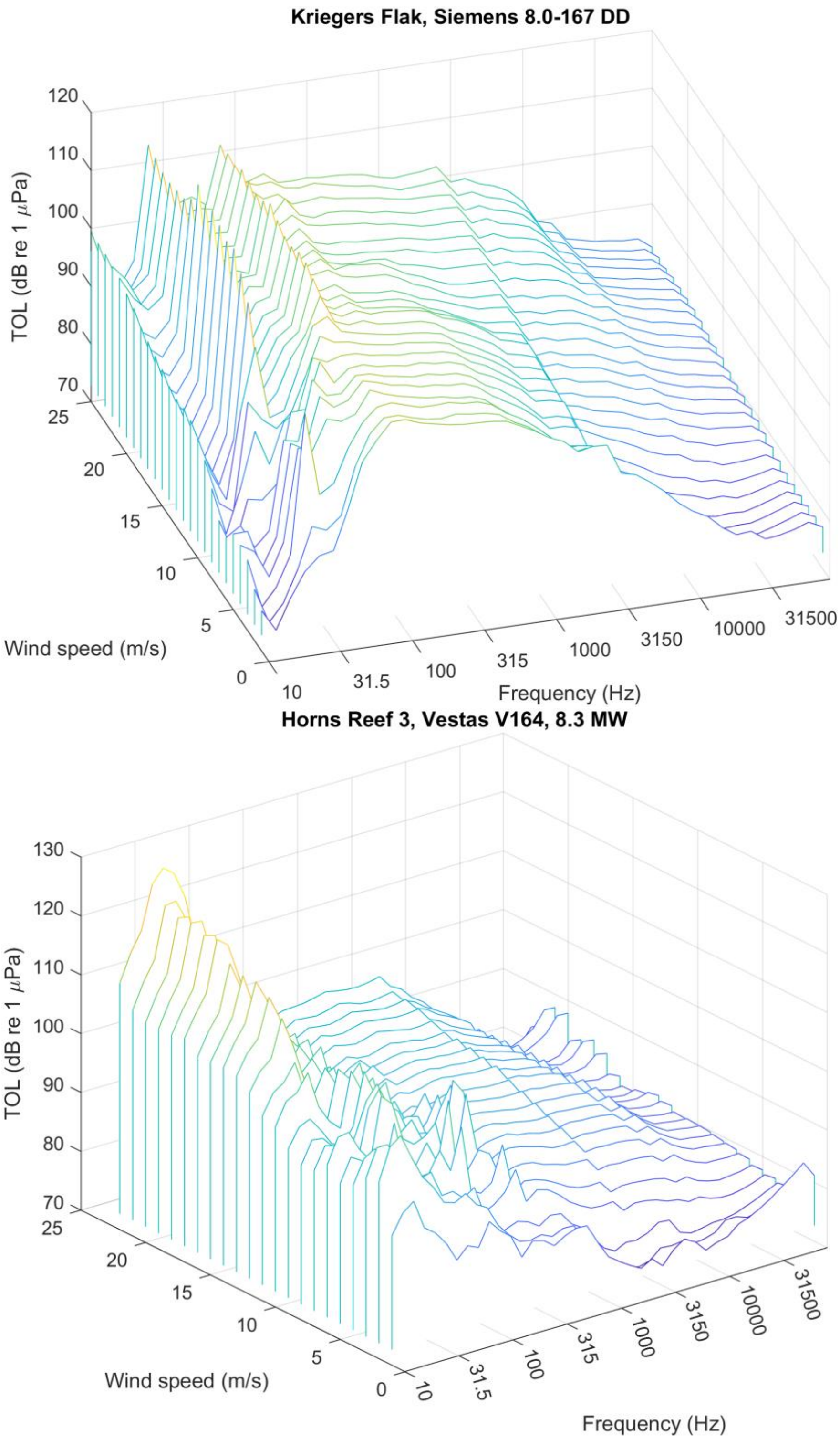

Figure 4-28 Top: Median decidecade frequency spectra of wind turbine noise recorded from an 8.4 MW direct drive turbine at Kriegers Flak at different wind speeds. Note the peaks of the turbine noise at 25 Hz and 80 Hz, absent or variable at lowest wind speeds; the contribution from ships in the bands between 63 Hz and 1 kHz, unaffected by the increase in wind speed; and the increasing contribution of wind noise at higher wind speeds in the bands up to 10 kHz. Bottom: Median decidecade frequency spectra of wind turbine noise recorded from an 8.3 MW turbine with gear box in Horns Reef 3 at different wind speeds. Note the variable peaks of the turbine noise at frequencies below 500 Hz, increasing with wind speed; and the increasing contribution of wind noise at frequencies up to 10 kHz.

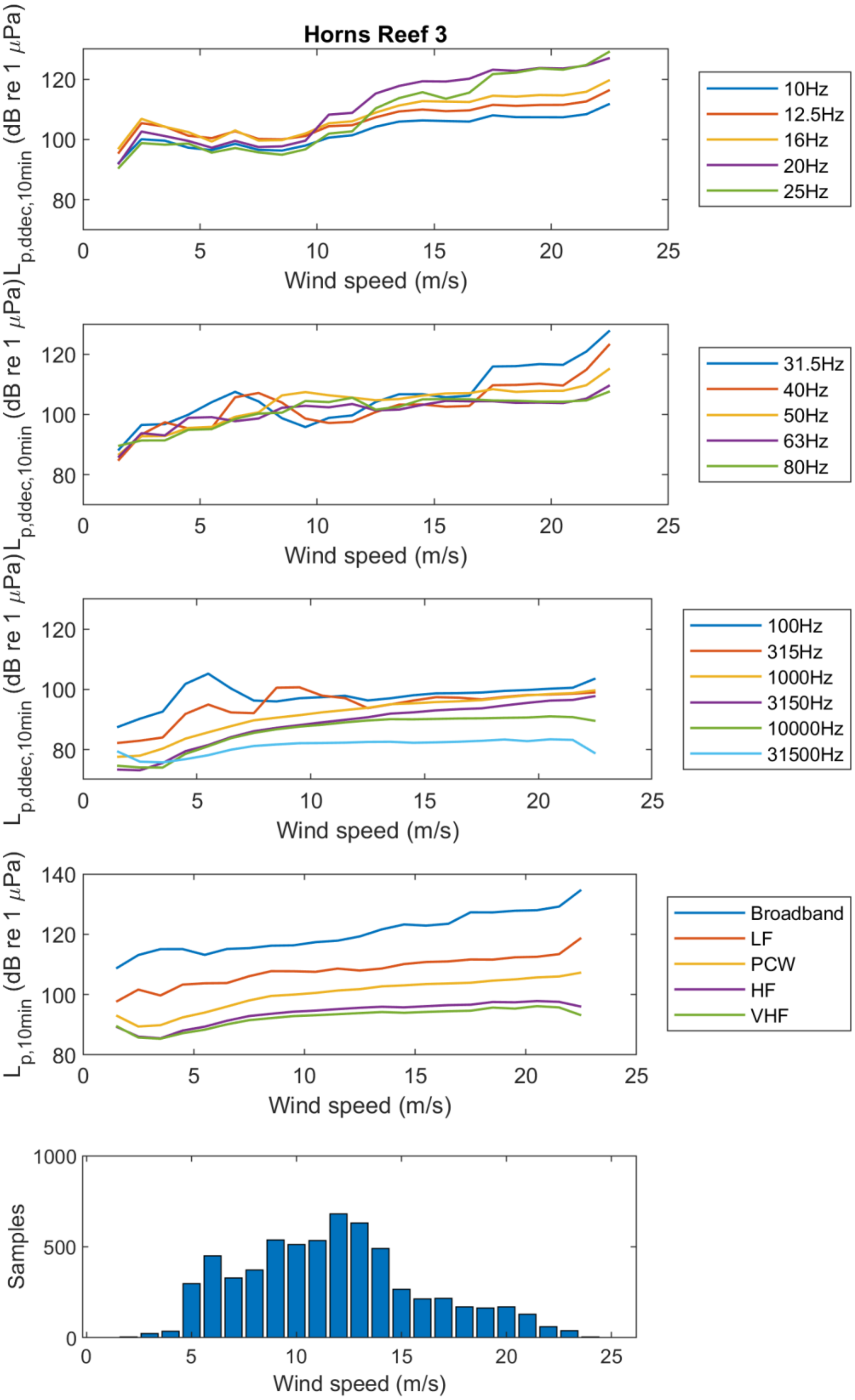

Figure 4-29 Relationship between wind speed and sound pressure level recorded from a Vestas V164-8.0 MW turbine with gear-box in Horns Reef 3. Top three subplots indicate decidecade levels in different frequency bands. Fourth subplot indicate the combined (total) sound pressure level at different wind speeds, given both as broadband (unweighted) and weighted sound pressure levels according to different functional hearing groups of marine mammals. Bottom bar graph indicates the number of 10-minute intervals available for each wind speed class.

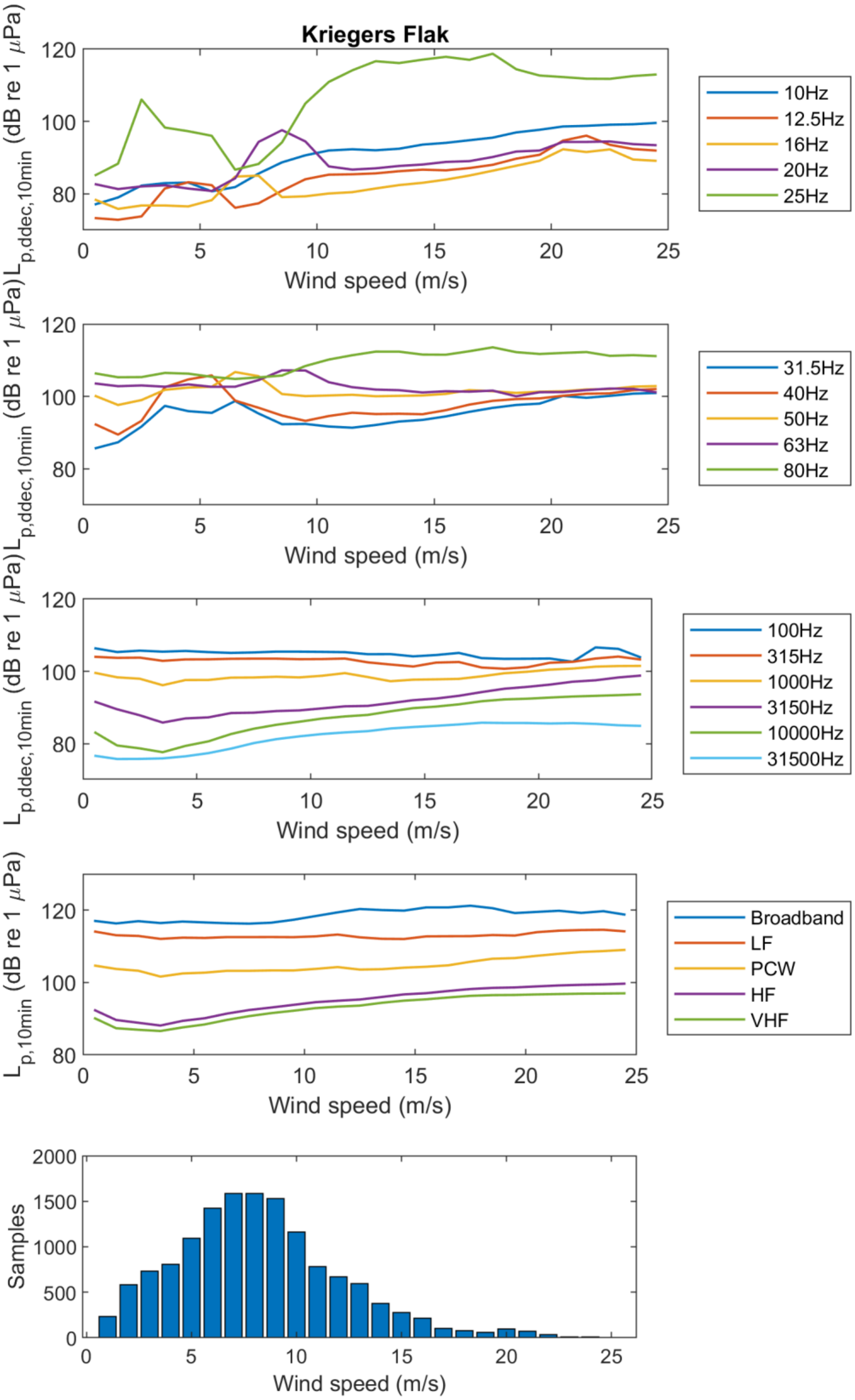

Figure 4-30 Relationship between wind speed and sound pressure level recorded from a Siemens-Gamesa 8.0-167 8.4 MW direct drive turbine at Kriegers Flak. Top three subplots indicate decidecade levels in different frequency bands. Fourth subplot indicate the combined (total) sound pressure level at different wind speeds, given both as broadband (unweighted) and weighted sound pressure levels according to different functional hearing groups of marine mammals. Bottom bar graph indicates the number of 10-minute intervals available for each wind speed class.

4.4.3 Harbour porpoise presence near operating turbines

The first deployment in 2023 resulted in about 24 hours of recordings. While this proved that the general recording methodology worked, the amount of data collected was insufficient, and a second deployment with new recorders with higher endurance was conducted in 2024. Below are the results from analysis of these recordings presented.

Harbour porpoise signals were found in recordings from both recorders and an overview is given in Table 4-9. The selection criteria for including a minute as porpoise positive were that a click should be recorded on all of the four channels and with a signal-to-noise ratio (SNR) of all clicks of 10 dB or more. This is a significantly stricter criterion than those used on the single-channel systems (C-PODs, F-PODs etc.), which then leads to significantly lower detection rates. Thus, the detection rates of 1–6% porpoise positive minutes (PPM) per day are much lower than the rates of up to 20% PPM per day reported from the F-PODs deployed inside the wind farm (Figure 4-4), but because the detection criteria are different, the lower rates found in the array recordings cannot be used to conclude that there are fewer harbour porpoises close to the turbine, compared to further away, but still inside the wind farm.

Table 4-9 Overview of the recordings obtained during the deployment in March 2024. For each hour of recordings, the number of minutes containing porpoise clicks on all four channels of the recording is indicated. For accurate positioning to be possible, clicks must be recorded on both arrays.

Porpoise positive minutes per hour (SoundTrap 5729 4-channel array)

Date	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
20 Mar 2024													0	6	0	0	0	0	0	0	0	0	0	0
21 Mar 2024	0	0	4	1	1	0	0	1	0	0	2	0	0	0	0	0	3	3	0	1	0	0	0	1
22 Mar 2024	4	3	2	1	0	0	0	0	0	0	3	0	0	0	0	0	0	4	4	0	0	0	0	2
23 Mar 2024	0	1	0	0	1	11	6	0	4	0	3	0	0	0	8	9	12	0	10	7	2	4	4	0
24 Mar 2024	4	3	0	0																				

Hour of day (time zone: Europe/Copenhagen)

Colour scale: 0, 2, 4, 6, 8, 10, 12; NaN

Porpoise positive minutes per hour (SoundTrap 5948 4-channel array)

Date	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
20 Mar 2024														29	0	0	0	0	0	3	0	3	0	4
21 Mar 2024	0	3	12	14	4	2	2	27	14	7	18	0	0	10	0	0	10	5	0	2	0	9	1	9
22 Mar 2024	14	3	7	5	1	2	0	3	0	1	11	15	0	2	1	1	0	13	19	0	0	1	0	16
23 Mar 2024	1	6	0	0	5	15	20																	

Hour of day (time zone: Europe/Copenhagen)

Colour scale: 0, 5, 10, 15, 20, 25; NaN

Individual segments of porpoise clicks were identified in the recordings and bearings determined from the time-of-arrival differences between the clicks recorded on the four different hydrophones. The bearing estimates form fragmented line segments corresponding to the bearing to nearby harbour porpoises together with numerous outliers that are likely the result of imprecise detection times of low SNR clicks or detections of reflections rather than the direct signals. One example of a recording with two sequences of harbour porpoise clicks, separated by about 3 seconds, is shown in Figure 4-31. The top panel shows the received amplitude of the echolocation clicks, which display a characteristic repetitive variation up and down, consisting with the sideways scanning behaviour observed in echolocating porpoises. As the animal turns its head from side to side, in order to ensonify the space in front of it with its narrow sound beam, a receiver in a fixed location (such as PAM equipment), will observe the sound beam repeatedly scanning across the hydrophone, causing the sinusoidal-like amplitude modulation. The bottom panel shows the bearing to the sound source determined on a click-by-click basis from the time-of-arrival differences on the four hydrophones of the array. The first sequence has several outliers, likely caused by errors in the localization algorithm due to a low signal-to-noise ratio. The main part of the data points falls along a gradually changing line, however, consistent with a swimming animal, where the bearing to the array changes gradually over the few seconds the encounter lasts. At around time mark 21:27:23 there is a discontinuity in the trace, which can either be due to the inherent precision of the localization[4], or – less likely – a second animal close to the first. The second click train, starting at time marker 21:27:29, has a bearing that is a natural continuation of the bearings from the first event. This suggests that both trains originate from the same animal, which moved in an arch from 270 degrees to 180 degrees relative to the array within the 12 second duration.

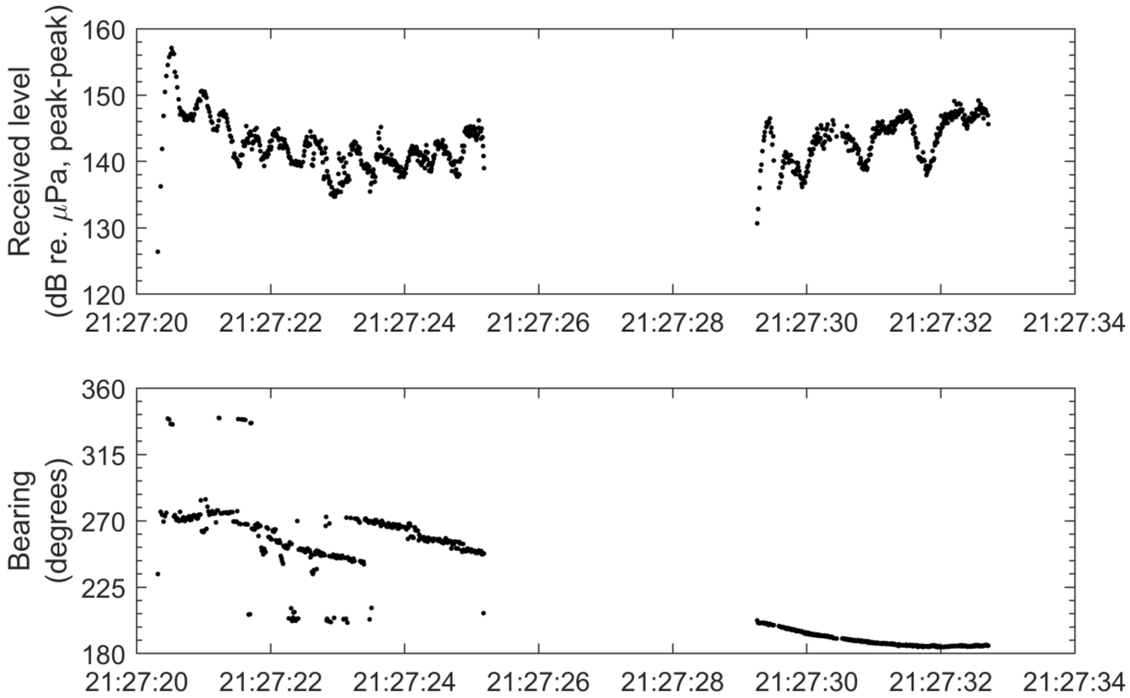

Figure 4-31 Example of recording of two sequences of several hundred harbour porpoise clicks. Top panel shows the received sound pressure level at the top hydrophone. Bottom panel shows the bearing from the array to the vocalizing harbour porpoise.

While recordings from a single array can only provide direction to the porpoise, not distance, it is possible to estimate distance if one bearing can be determined from each of the two arrays at the same time, or at least not further apart in time to justify that the error caused by the animal moving slightly between bearing estimates can be ignored. Such a positioning with cross-bearings from the two arrays were done for the March 2024 deployment data, where click trains separated by less than 5 seconds on the two arrays were combined. A total of 120 events were identified with this criterion and they are all plotted in Figure 4-33.

[4] The outliers tend to fall at discrete distances from the main body of the data points. This is due to the characteristics of the porpoise clicks (see Figure 3-7), where errors in determining time-of-arrival differences tend to occur at integer steps of the period of the 130 kHz signal, i.e. the best match between two channels is found with an offset of an integer number of wave cycles from the true time-of-arrival difference.

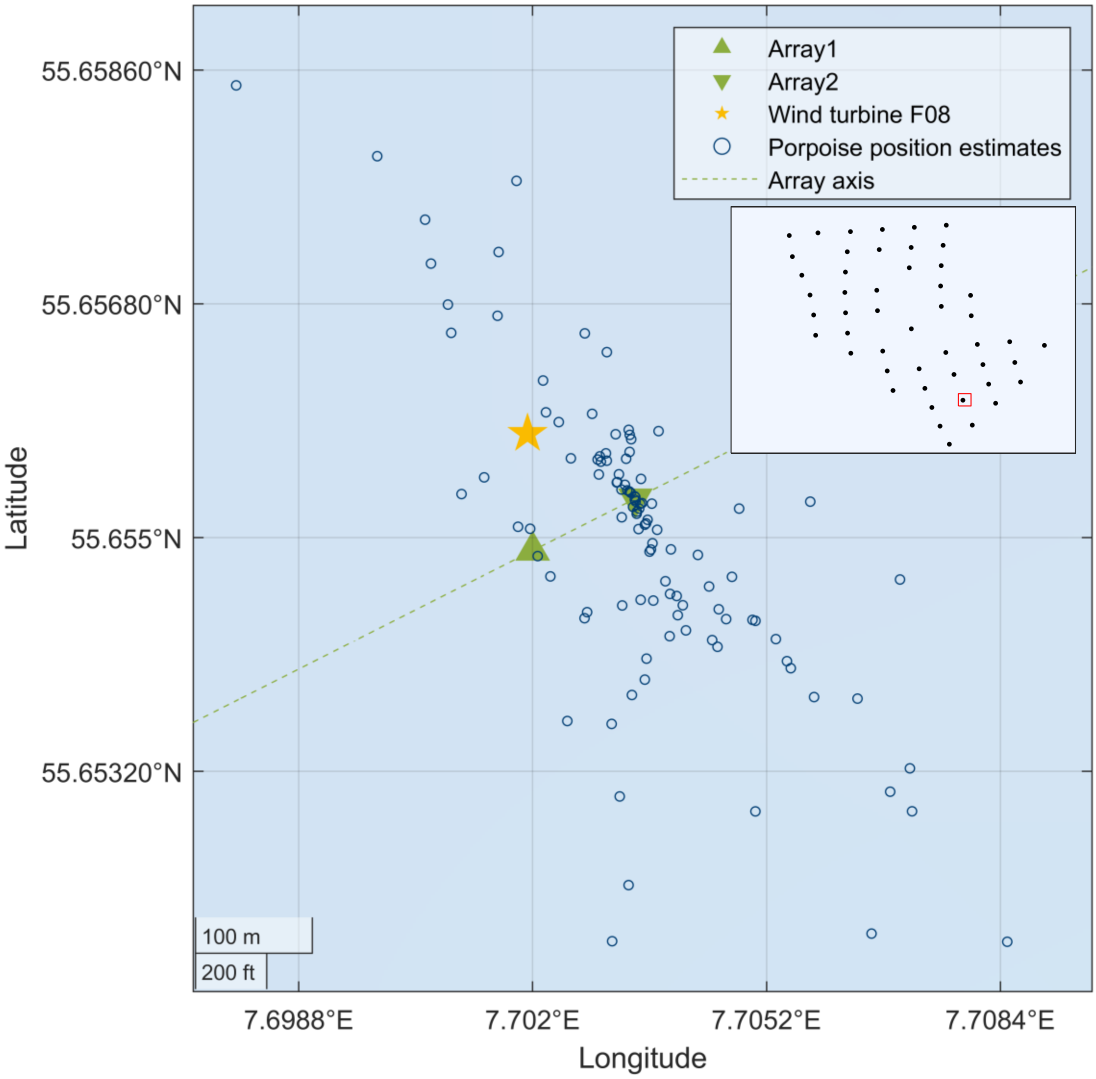

Figure 4-32 Map of the array and wind turbine positions together with the porpoise position estimates. The map grid has a 200 m spacing. This map shows 110 out of the total of 120 porpoise position estimates from the deployment in March 2024. Insert shows the Horns Reef 3 wind farm with the position of the main map indicated by the red rectangle.

The results show that consistent bearings can be assigned to the porpoise clicks in our recordings, which is the requirement for determining the position of the animals relative to the turbine (Figure 4-32). Porpoises were positioned very close to the arrays, but also to the turbine. The distance from the turbine to each data point is summarized in the histogram in Figure 4-34. There appears to be a clustering of positions around the eastern array and along a line running approximately NW-SE through this array and east around the turbine. Upon recovery of the arrays it was discovered that the eastern array had toppled over during deployment and had been slightly deformed under its own weight. This deformation was included in the localization algorithm but may have resulted in a bias towards certain bearings in the analysis[5]. It is also a possibility that porpoises have a preferred

[5] All array configurations have variable precision in localization, depending on the angle of incidence. For each pair of hydrophones, the precision is highest along the midline perpendicular to the point between the two hydrophones, whereas the precision deteriorates substantially towards the line running through the two hydrophones, the so-called 'end-fire' positions.

route when swimming past the turbine. Porpoises are known to use structures on the seabed as 'land marks' in their navigation (Verfuss et al. 2005) and may even have used our array as such a land mark.

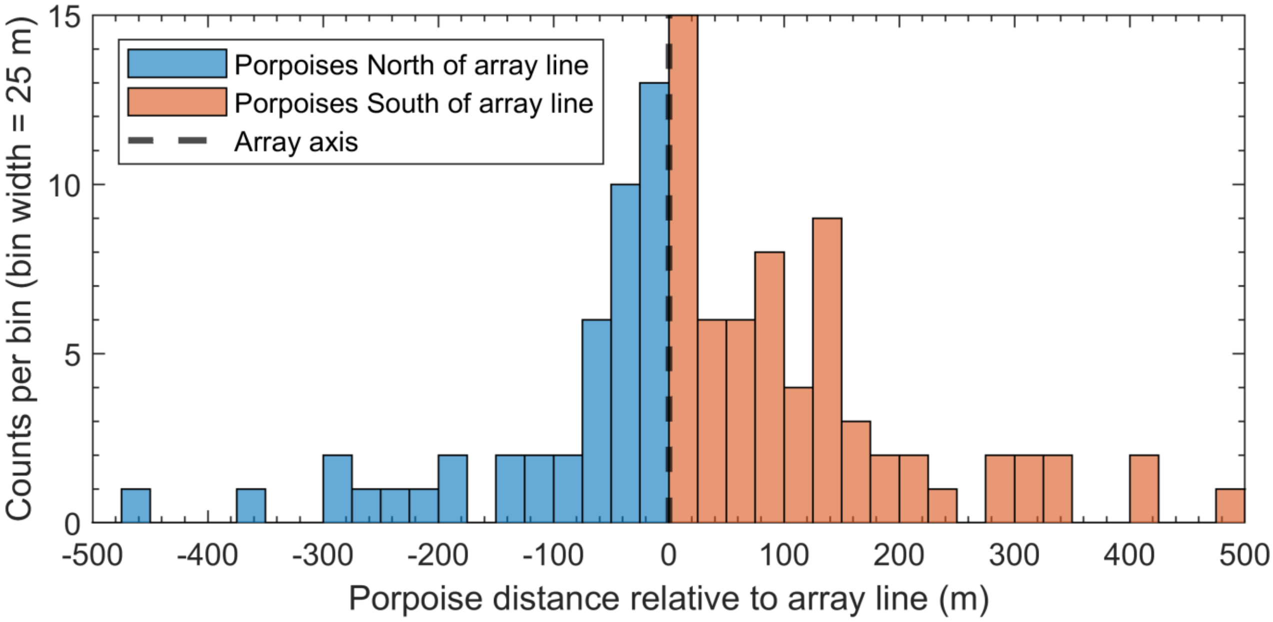

Figure 4-33 Histogram showing porpoise distribution relative to the axis going through the two array positions. Distances to positions North of the array line (same side as the wind turbine) are shown in blue and plotted with negative distance values, and positions South of the array line are shown in red with positive values. Histogram bin width is 25 m. 11 out of 120 data points exceed the ±500 m distance limit of the x-axis.

The estimated porpoise positions are generally within ranges of a few hundred meters from the two arrays (>80% are within 300 m, and >90% are within 500 m), which agrees with the expectation that porpoise clicks are detectable over maximum ranges up to approximately a kilometer depending on the click source level and detection threshold (DeRuiter et al. 2010). A simple approach to testing whether porpoises are attracted/deterred from the turbine is to evaluate the number of positions obtained on either side of the line running through the two arrays. In such an analysis one would expect localization errors to be symmetrical around this line, meaning that we should expect the same number of positions on either side of the array if the distribution of porpoises is unaffected by the presence of the turbine. From the histogram showing porpoise distributions north or south of the array line, there might seem to be a tendency towards fewer porpoises around 100 m north of the array line compared to the same distance south of the line (Figure 4-33). However, the limited number of samples prevents a robust analysis of this. A chi-squared two-sample test of the number of observations on either side of the line did not reject the null hypothesis that the overall porpoise distribution is the same on both sides of the line ($p = 0.48$). This conclusion is likely limited by low statistical power due to the low number of observations but until further data are collected, the conclusion is that no change in porpoise density could be documented close to the turbine.

4.4.4 Noise exposure maps

Underwater noise exposure maps, separated into contributions from current sources. Modelling was conducted for the 125 Hz decidecade band, which is a standard frequency band for modelling for the Marine Strategy

Framework Directive criterion D11C2. It can also be used as a proxy for estimating responses to ship noise, in line with the methodology used for the HELCOM HOLAS 3 assessment.

Four monthly statistical maps were produced for April 2023, July 2023, October 2023 and January 2024 representing each season. Each map layer represents the statistics of the noise in the 125 Hz decidecade band, as described in section 3.3.4. Two maps were used for each month, one expressing the 5% exceedance level (L_5, equal to the upper 5th percentile) and one expressing the 10% exceedance level (L_{10}). The original plan was to use the median i.e. the 50% exceedance level, but the noise levels estimated to disturb harbour porpoises was at all times below 20% and so only 5% and 10% were included. The maps should therefore be interpreted so that the level indicated in each grid cell (approximately 100–200 m x 100–200 m rectangles) was exceeded in 5% and 10% respectively, of the individual snap shots modelled for that particular month.

The 5% and 10% exceedance level noise layers are shown in Figure 4-34 and 4-35, respectively. The main dominant feature is the shipping lane, running SW to NE in the outer, western edge of the survey area. There is some variation across the seasons, with noise from vessel traffic related Hvide Sande port in the middle of the eastern area appearing in Summer (July) and Autumn (October) and higher noise levels in the shipping lane in spring (April).

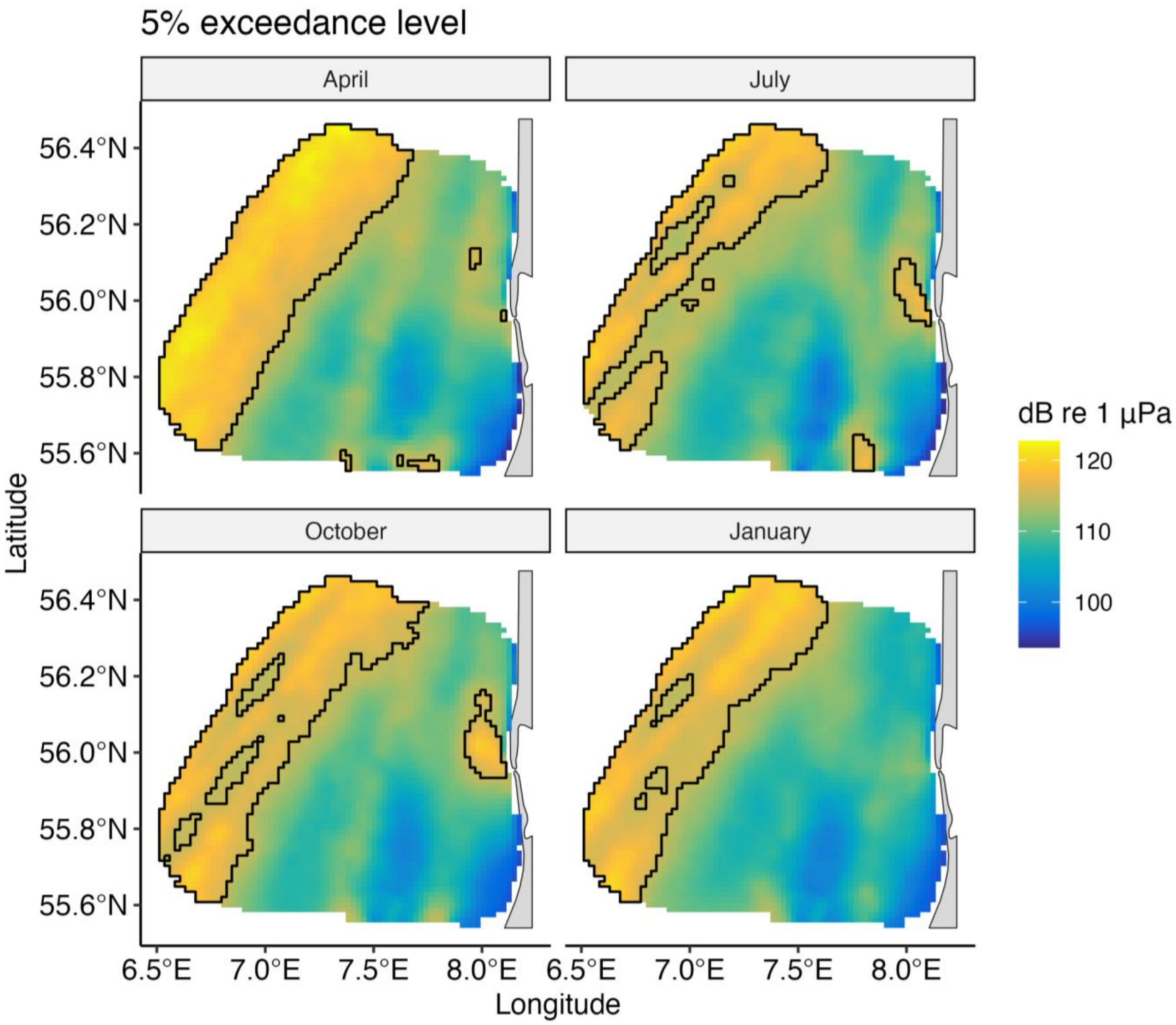

Figure 4-34 Maps of the 5% exceedance level in the 125Hz decidecade frequency band for April 2023, July 2023, October 2023 and January 2024 representing the four seasons. The sound pressure level ($L_{p,125Hz\ ddec}$, unit dB re 1 µPa/decidecade) measured on a short time scale of a few seconds (the temporal scale of the individual snap shots modelled every hour of the month) in each point of the map is expected to be equal to or higher than the level corresponding to the colour 5% of the time. The map therefore represents the loudest events that occur in the survey area for the four months. The overlayed black polygons represents parts of the map where sound pressure levels ($L_{p,125Hz\ ddec}$) exceed 115 dB re 1 µPa) (i.e., the noise level above which harbour porpoises are expected to respond) 5% of the time, indicating that reactions to the noise is expected to occur on average 5% of the time.

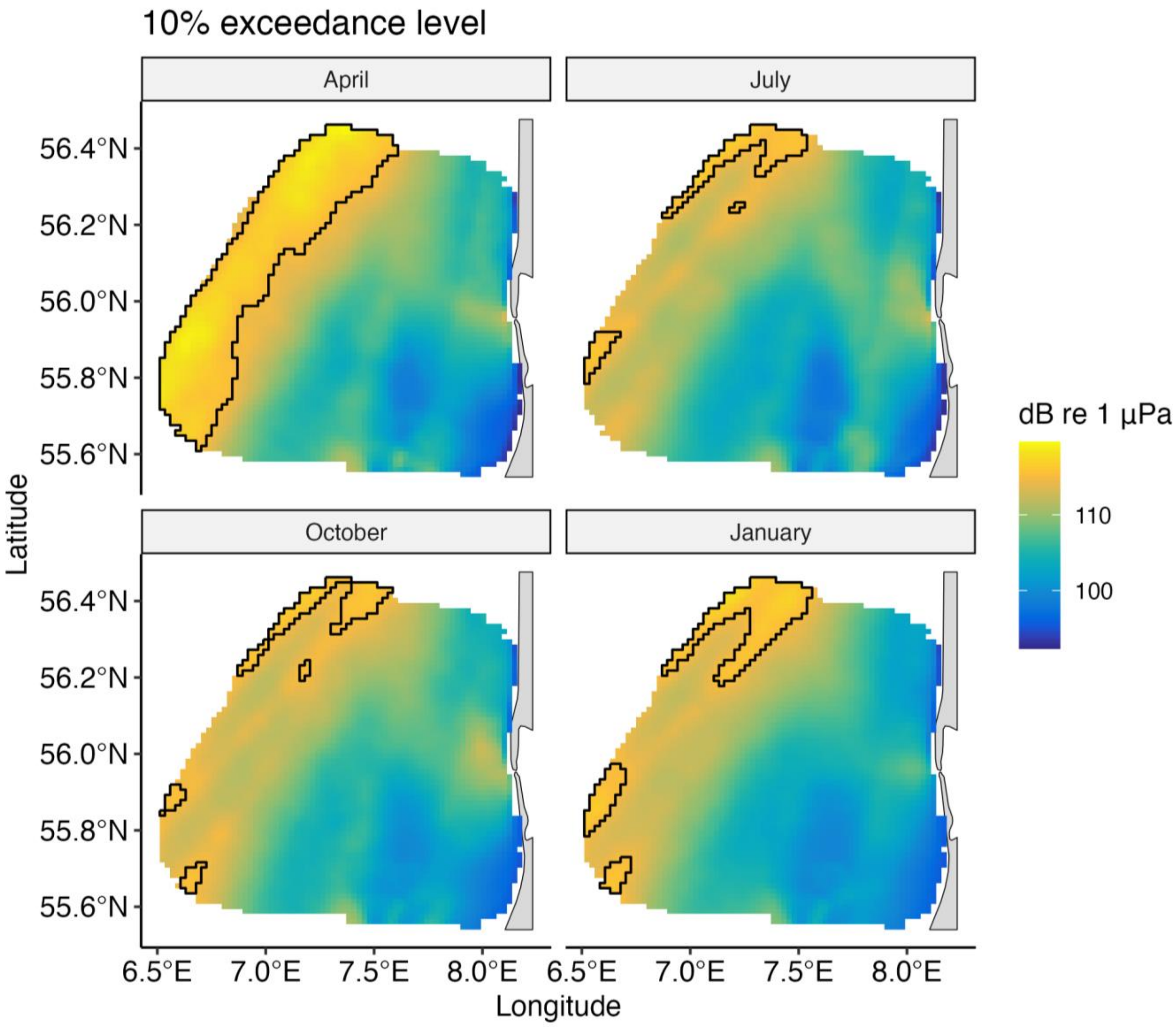

Figure 4-35 Maps of the 10% exceedance level in the 125Hz decidecade frequency band for April 2023, July 2023, October 2023 and January 2024 representing the four seasons. The sound pressure level ($L_{p,125Hz\ ddec}$, unit dB re 1 µPa/decidecade) measured on a short time scale of a few seconds (the temporal scale of the individual snap shots modelled every hour of the month) in each point of the map is expected to be equal to or higher than the level corresponding to the colour 5% of the time. The map therefore represents the loudest events that occur in the survey area for the four months. The overlayed black polygons represents parts of the map where sound pressure levels ($L_{p,125Hz\ ddec}$) exceed 115 dB re 1 µPa) (i.e., the noise level above which harbour porpoises are expected to respond) 10% of the time, indicating that reactions to the noise is expected to occur on average 10% of the time.

4.4.5 Overlaying model

The eight underwater noise exposure maps for the survey area (Figure 4-34 and 4-35) were overlayed with the comparable four monthly distribution maps of harbour porpoises based on the collected PAM data (Figure 4-7). This enables the area where animals may respond to underwater noise and vibrations to be assessed. Following the Faulkner et al. (2018) guidelines, the steps to evaluate the impact of underwater noise on marine life include:

I. identifying noise exposure criteria (i.e., the noise level above which animal responses are expected), and
II. compute “effect zones” (i.e. the combination of noise model prediction and noise exposure criteria).

The monthly predicted harbour porpoise distribution was thus overlayed with a map of the effect zones based on a noise exposure criterion of 115 dB re 1 µPa in the 125 Hz decidecade band (Tougaard et al., 2023), see section 3.3.5 above. Within this effect zone, harbour porpoises are expected to be exposed to noise levels sufficiently high to induce behavioural reactions in the animals 5% of the time. We used effect zones corresponding to the 125Hz frequency band - 5% exceedance level (i.e., the level exceeded 5% of the time, see "3.3.1 Noise monitoring") and 10% exceedance level, respectively (4-36 and 4-37).

The maps indicate that there is little variation across the seasons in the area where noise exceeds the 115 dB level particularly at the 5% level and that the area above the criterion level mainly coincides with areas with a relatively high porpoise density (>120 PPM per day) for both the 5% and the 10% exceedance level in summer (July) and winter (January). This is supported by the extracted quantities (median of the average PPM per day and per 1.5km^2) of the monthly overlayed maps inside the threshold area (Table 4-10). The extracted values indicate that while there is little difference for the 5% level, the risk of behavioural reactions is highest in spring (April) at the 10% level, as there is the largest number of animals exposed to levels above 115 dB. Note that the exceedance levels correspond to harbour porpoises being exposed above the criterion level 5% and 10% of the time, respectively, so most of the time porpoises inside the polygons will be exposed to levels below where they are expected to react to the noise.

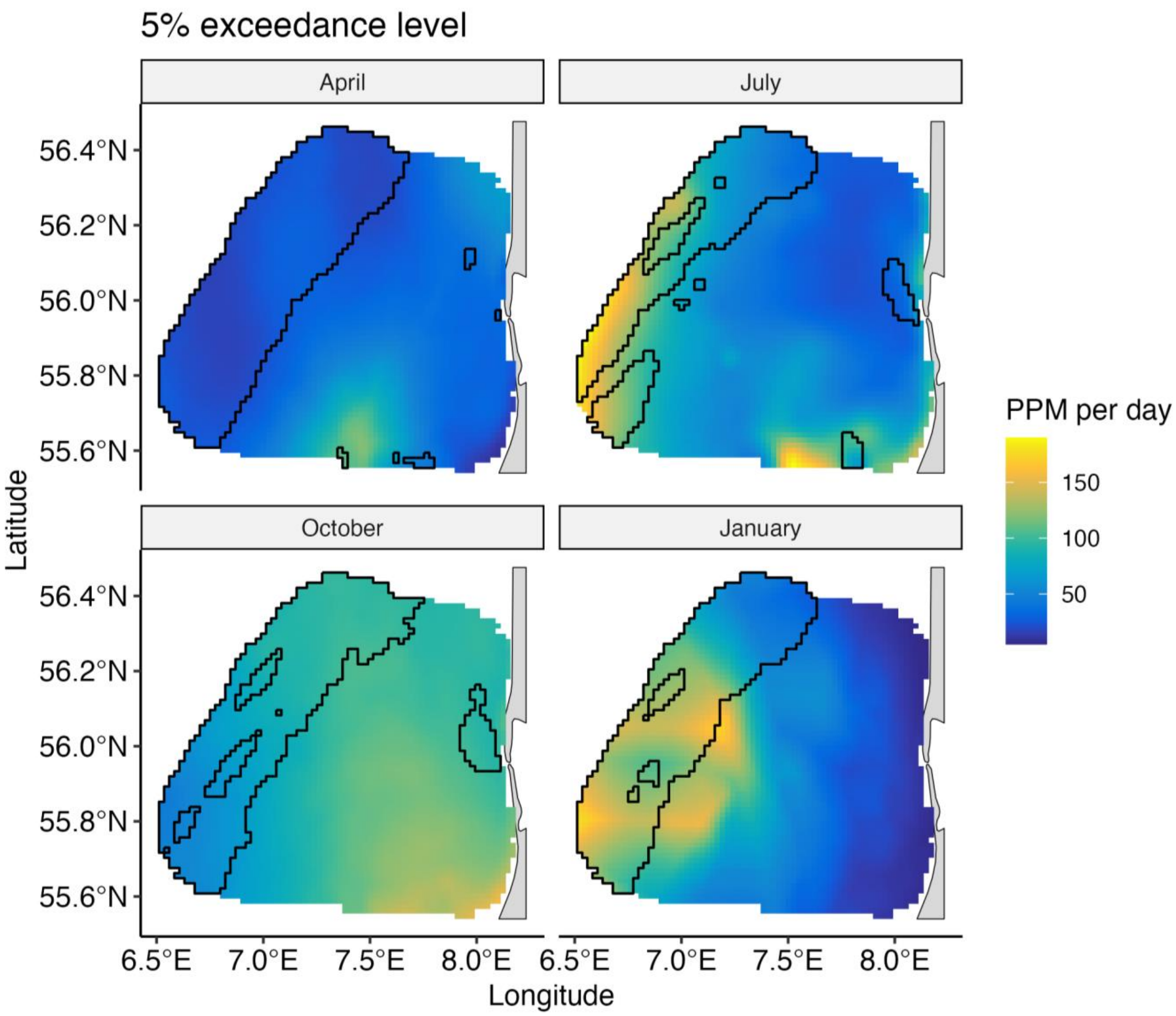

Figure 4-36 Overlayed PAM model with the area of expected impact from noise (the 5% exceedance level in the 125Hz decidecade frequency band) on harbour porpoises (≥ threshold value, black lined polygon) PPM is 'Porpoise Positive Minutes', and high values (yellow) indicate areas where porpoises are predicted to occur more frequently.

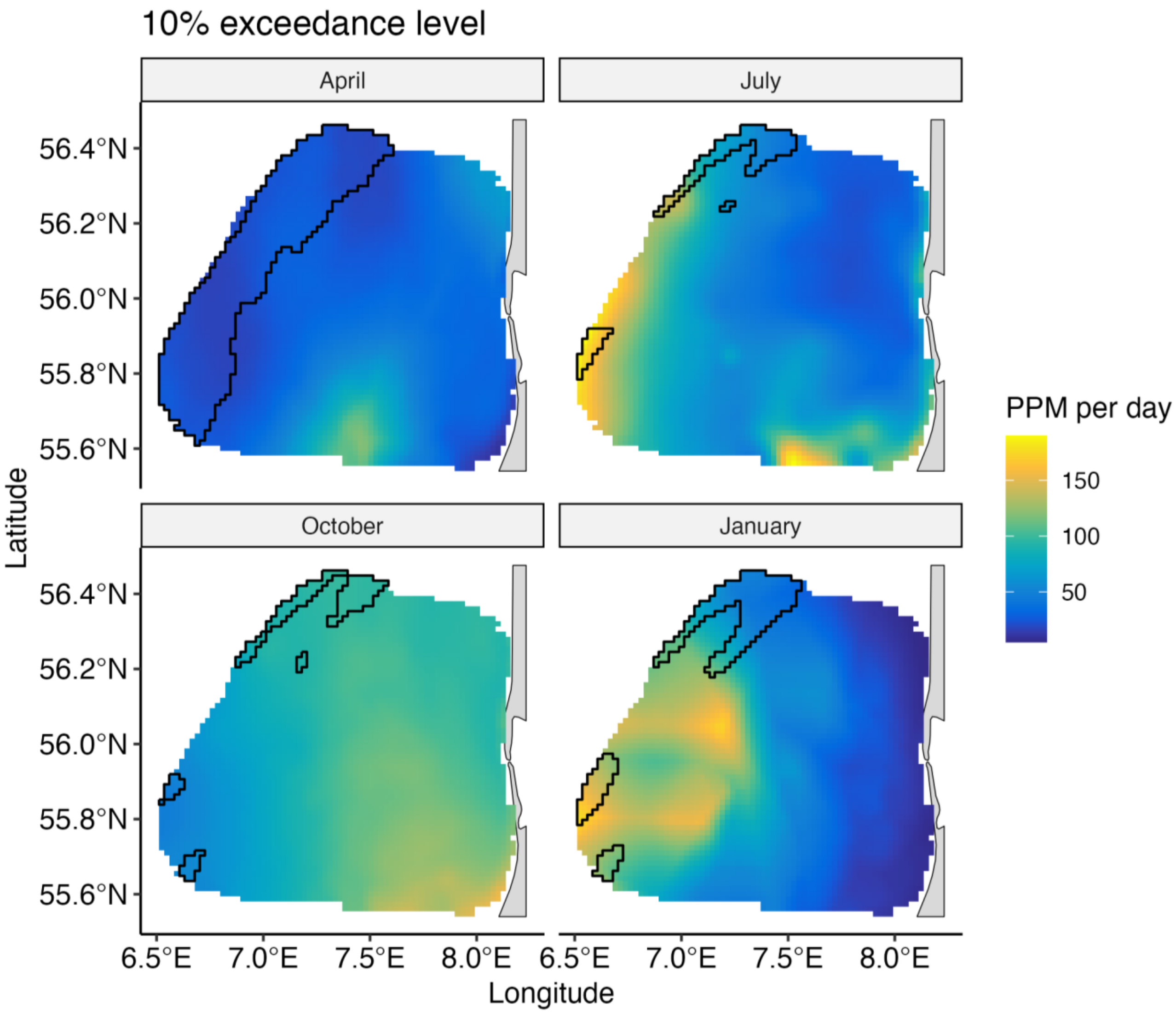

Figure 4-37 Overlayed PAM model with the area of expected impact from noise (the 10% exceedance level in the 125Hz decidecade frequency band) on harbour porpoises (≥ threshold value, black lined polygon) PPM is 'Porpoise Positive Minutes', and high values (yellow) indicate areas where porpoises are predicted to occur more frequently.

Table 4-10 Quantities of harbour porpoise density extracted from inside the threshold areas from the 5% and 10% exceedance level maps (see figure 4-35 and 4-36). The area is the total area inside the threshold area.

	Mean (PPM per day)		**Area (km²)**	
Month	5% exceedance level	10% exceedance level	5% exceedance level	10% exceedance level
April 2023	22	22	2983	1935
July 2023	89	68	1937	336
October 2023	88	94	2665	345
January 2024	117	64	2416	656

5. Conclusion from 1st year's survey

5.1 Harbour porpoise

Prior to the present monitoring program, harbour porpoise presence in the North Sea I survey area has only been assessed during the four SCANS surveys conducted during July–August (1994, 2005, 2016 and 2022). These surveys were broad scale snap shots and only had sporadic parts of a few transect lines in or near the survey area (Hammond et al., 2002; Hammond et al., 2013; Hammond et al., 2021; Gilles et al. 2023). Therefore, no data is available to assess the development in abundance of harbour porpoises in the survey area. The results of the four published SCANS surveys suggest that the harbour porpoise population as a whole is stable in the North Sea.

The data collected in the PAM survey of the 1st year baseline study shows that harbour porpoises were present at all 42 stations in the North Sea I survey area throughout the year, but with large variation between the daily detection levels at all stations and seasons. In general, results from the passive acoustic monitoring showed that on a monthly temporal scale, there is little variation across the year, but substantial variation between individual days detected on most stations. Spatial distribution of harbour porpoise detections (average PPM per day per month) for the winter (Sep–Feb) and summer (Mar–Aug) also showed no clear patterns except that the coastal areas may have lower densities overall compared to the stations further offshore.

The monthly models of PPM per day also showed considerable spatial and temporal variation in harbour porpoise presence in the survey area. The models explained on average 50.68% of the deviation in the data, which is considered very high for such models. Of the explanatory variables, PPM per day generally declined with increasing distance from sandeel spawning grounds and the dynamic forcing variables: mixed layer thickness, sea surface salinity, temperature, height and current velocity explained most of the variation in the data. Furthermore, they all correlated with PPM per day in a non-linear fashion that differed between months likely due to seasonal changes in environmental conditions and thus prey availability in the area.

The comparison of harbour porpoise detections over time in the planned Thor Offshore Wind Farm showed that the mean PPM per day was significantly higher in 2023–2024 compared to 2019–2020. At the Horns Rev 3 Offshore Windfarm (which commenced operation in 2019), the mean PPM per day was significantly higher in 2012-2013 compared to 2023-2024 at the stations both inside and outside the wind farm area. Interestingly, the difference in mean PPM per day between inside and outside the wind farm during 2012-2013 (i.e. prior to the construction of the OWF) was not statistically significant while the difference in mean PPM per day between inside and outside the wind farm during 2023-2024 was significant with significantly more harbour porpoise detections inside the wind farm, indicating that the construction of the wind farm has improved the habitat for harbour porpoises. This result should be taken with caution until data from 2024-2025 becomes available.

The comparison of CPOD and FPOD detection rates, showed that levels of detections on CPODs and FPODs were similar but with the FPOD generally recording slightly more than the CPOD.

The aerial surveys were conducted from May to August 2023. Data also showed large variation between survey days with the June survey having a 4–5 times higher estimate of abundance compared to the May and August survey. On the June survey, the sea surface was very calm and throughout the survey area large schools of fish were observed indicating that the prey abundance was the major driver for the high density of porpoises. The density estimated for the June survey (2.91 porpoises per km^2) is the highest ever detected in the Danish North Sea. The observed calf ratios in both June (10.30%) and especially August (20.60%) indicate that the North Sea I survey area may be an important breeding area for harbour porpoises in the North Sea.

Both PAM and aerial survey data illustrate that there are extensive variation in porpoise density in the survey area between days. It is likely that variations in prey availability is a major driver for this finding. Another possible explanation could be the influence of geophysical surveys. At the time of writing this version of the report, however, the results of the project examining the effects of geophysical surveys on PAM data was not completed. It can therefore only be speculated that some of the variation in PAM data can be attributed to the presence of geophysical surveys using USBL, which can cause avoidance responses in harbour porpoise. Aerial surveys represent snap shots in time as the survey plane covers the area over a single day only. It is therefore expected that there can be large differences between survey dates, but also between the two methods.

5.2 White-beaked dolphin

To date, the only studies examining presence of dolphins in the North Sea are the four SCANS aerial distance sampling surveys conducted in July–August (1994, 2005, 2016 and 2022) (Hammond et al., 2002; Hammond et al., 2013; Hammond et al., 2021; Gilles et al., 2023) and the North Sea Energy Island survey program in 2022-2023 conducted in the northeastern Danish North Sea (Kyhn et al., 2024a). The present study provides the first data on dolphin presence in the eastern North Sea off the southern Danish coast.

White-beaked dolphins were observed during aerial surveys for both marine mammals and birds. The PAM data did reveal some detections of white-beaked dolphins and other delphinids in the data evaluated for this report. Even with relatively few white beaked dolphin detection, there was a peak of detection positive hours (DPH) in summer (July), coinciding with the calving, nursing and mating period for white-beaked dolphins. This corresponds well to the white-beaked dolphin mother-calf pairs observed during the cetacean aerial survey on 14th of June 2023. Most of the detections were recorded on the northwestern stations, or within the deeper waters along the shelf, which is consistent with our knowledge of their habitat use (Kinze, 2009). Most of the bioacoustic activity was captured during nighttime hours, indicating that the animals may be using the shelf waters within the study area for feeding. Although it is not possible to make any assessments on their annual development with these limited data, due to the low detection rate it is unlikely that this region constitutes an important part of the animal's habitat.

5.3 Minke whales

The presence of minke whales in the North Sea has only been documented during the four July-August SCANS surveys (1994, 2005, 2016 and 2022) (Hammond et al., 2002; Hammond et al., 2013; Hammond et al., 2021; Gilles et al. 2023) and during the North Sea Energy Island survey program (Kyhn et al., 2024a). There is no data to assess the development of the species in the survey area.

During the aerial survey program, six minke whales were observed in the area in June and July 2023. This is not enough data to evaluate the status of the area for minke whales, but only enough to confirm that they are present in the area in the summer months. No minke whales were detected in the acoustic data. This should however not be seen as evidence of absence, but more that the species may not be vocal in this part of the North Sea, or that the analyses was not based on the right signals.

5.4 Seals

Seals were not part of the survey program for the North Sea I area but information from existing data and published scientific reports and articles are presented. See section 3.2 for a review on occurrence and distribution at haul-outs.

5.4.1 Seal use of the North Sea I project area

The habitat suitability maps show that both species of seals are predominately found close to the places where they haul out, and that the likelihood of encountering seals is relatively high in the North Sea I survey area. This corresponds to the pattern obtained by observing the filtered satellite tracking data although the habitat suitability map for harbour seals suggests that the North Sea I survey area is more frequently used than a visual inspection of the satellite tracking data would indicate. This is related to the high number of seals on haul-out sites in the Wadden Sea. The available tagging data of harbour seals also indicate that the North Sea I survey area is mainly used by seals from the Wadden Sea and not the Limfjord. For a stronger baseline dataset on seals, it is recommended to focus on the haul-out sites in the Wadden Sea and supplement the existing data.

5.5 Noise

The noise monitoring from April 2023 to March 2024 were analyzed and are now available as baseline data for subsequent impact assessments and projects. Substantial concern has been raised about the contribution from geophysical survey ships in the project area in 2023 and the associated likely disturbance on harbour porpoises. This likely contribution from survey systems and associated equipment, most notably the underwater telemetry system USBL, was not quantified in the analysis presented here. The contribution from USBLs and survey systems is likely to only be detectable when survey ships are within some kms from the recording stations and therefore only detectable for a low percentage of the total recording time of each recorder. The contribution is therefore not evident in the monthly statistics presented here but requires a dedicated analysis. This is done in a separate study.

Underwater noise from two operating wind turbines, one with and one without gearboxes, were obtained. These recordings show that overall noise levels and frequency content are in line with what is to be expected from extrapolation of existing data from other turbines (Bellmann et al. 2023). The noise for both turbine types is only audible above ambient noise at low frequencies, below 1 kHz. As seals, and in particular harbour porpoises have poor hearing at these low frequencies, the audibility of the noise is low for these species. For harbour porpoises, the range of audibility is predicted similar to what has been suggested previously (Tougaard et al. 2022), i.e. a few hundred meters maximum.

Localization of porpoises within 100–200 m of operating turbines were successfully achieved and now that the methodology has been shown to work these will be supplemented with additional data obtained in the fall of 2024. The result for the fall deployment will be included in the report of the NSI second year survey. Preliminary analysis of the available data could not show an effect of the turbine on porpoises (neither attraction, nor deterrence), but the statistical power was low. The additional data obtained in year two will be amended and increase the statistical power of the analysis.

6. Data and knowledge gaps

6.1 Influence on PAM results of geophysical surveys in the investigation area

The data collection for the baseline survey of North Sea I are supposed to be unaffected by any anthropogenic impact related to the pre-investigation or construction of the wind farm. This may, however, not be the case as extensive geophysical surveys were carried out in the survey area from April to November 2023. Energinet has contracted NIRAS and AU as subcontractors to undertake a study to assess the geophysical surveys' potential impacts on the baseline data and examine how the effect can be excluded if necessary.

6.2 Lack of data on seal distribution in the survey area

It is important to note that the habitat suitability maps for the North Sea I survey area are based on a relatively small sample of tagged seals, and that it would have been preferable to tag more seals closer to the area of interest to improve the predictions for this area. Particularly, both grey and harbour seals tagged at locations in the Danish Wadden Sea would be desirable. Additionally, the data may be skewed in terms of sex (mostly males) and age (mostly adult harbour seals, mostly juvenile grey seals) and thus not representative of the population. TIHO only tagged juvenile grey seals less than a month of age, and their results are therefore representative of naïve juvenile grey seal pups, adapting to the marine environment and developing their foraging skills. For the North Sea Energy Island survey program, mainly adult harbour seals were tagged. TIHO tagged grey seals at Helgoland in January–February, whereas for the AU/NIRAS tagged grey seals of mixed age in March 2023, May 2022 and September 2022 and at Thyborøn for the North Sea Energy Island survey program, providing data throughout the annual cycle from the latter area.

7. Referencer

Andersen, J. H., Bendtsen, J., Hammer, K. J., Therese Harvey, Knudsen, S. W., Murray, C. J., Carstensen, J., Petersen, I. K., Sveegaard, S., Tougaard, J., Edelvang, K., Egekvist, J., Olsen, J., Vinther, M., Al-Hamdani, Z., Jensen, J. B., Leth, J. O., Kaae, B., Olafsson, A. S., McClintock, W., Burt, C., and Yocum, D. (2020). "ECOMAR: A data-driven framework for ecosystem-based Maritime Spatial Planning in Danish marine waters. Results and conclusions from a development and demonstration project. ," (Copenhagen), p. 83.

Bellmann, M., Müller, T., Scheiblich, K., and Betke, K. (2023). "Erfahrungsbericht Betriebsschall - Projektübergreifende Auswertung und Bewertung von Unterwasserschallmessungen aus der Betriebsphase von Offshore-Windparks, itap Bericht Nr. 3926, gefördert durch das Bundesamt für Seeschifffahrt und Hydrographie, Fördernummer 10054419.," (Oldenburg).

Berggren, P. 1994. Bycatches of the harbour porpoise (Phocoena phocoena) in the Swedish Skagerrak, Kattegat and Baltic Seas; 1973-1993. Rep Int Whal Comm Spec Issue. 15:211-215.

Braulik, G. T., et al. (2023). Phocoena phocoena (amended version of 2020 assessment). The IUCN Red List of Threatened Species 2023: e.T17027A247632759.Cascão, I., Lammers, M. O., Prieto, R., Santos, R. S., & Silva, M. A. (2020). Temporal patterns in acoustic presence and foraging activity of oceanic dolphins at seamounts in the Azores. Scientific reports, 10(1), 3610.

Camphuysen, K.C.J., and A. Kropp. 2011. Maternal care, calf-training and site fidelity in a wild harbour porpoise in the North Sea. Lutra Journal of the Dutch Mammal Society. 54.

Cohen, R. E., Frasier, K. E., Baumann-Pickering, S., & Hildebrand, J. A. (2023). Spatial and temporal separation of toothed whales in the western North Atlantic. Marine Ecology Progress Series, 720, 1-24.

Cosentino, M., Marcolin, C., Griffiths, E. T., Sánchez-Camí, E., & Tougaard, J. (2024). Dolphin and porpoise detections by the F-POD are not independent: Implications for sympatric species monitoring. JASA Express Letters, 4(3).

Cunningham, L., Baxter, J.M., Boyd, I.L., Duck, C.D., Lonergan, M., Moss, S.E., McConnell, B., 2009. Harbour seal movements and haul-out patterns: implications for monitoring and management. Aquat Conserv 19, 398-407.

Delefosse, M., M.L. Rahbek, L. Roesen, and K.T. Clausen. (2017). Marine mammal sightings around oil and gas installations in the central North Sea. J. Mar. Biol. Ass. UK. 98:993-1001.

DeRuiter, S. L., Hansen, M., Koopman, H. N., Westgate, A. J., Tyack, P. L., & Madsen, P. T. (2010). Propagation of narrow-band-high-frequency clicks: Measured and modeled transmission loss of porpoise-like clicks in porpoise habitats. *The Journal of the Acoustical Society of America*, *127*(1), 560-567.

Dietz R., Teilmann J., Andersen S.M., Riget F. and Olsen M.T. 2013. Movements and site fidelity of harbour seals (Phoca vitulina) in Kattegat, Denmark, with implications for the epidemiology of the phocine distemper virus. ICES Journal of Marine Science, 70(1), 186-195.

Dyndo, M., Wiśniewska, D. M., Rojano-Doñate, L., and Madsen, P. T. (2015). "Harbour porpoises react to low levels of high frequency vessel noise," Sci. Rep. 5, 11083, doi.org/10.1038/srep11083

Faulkner, Rebecca C., Adrian Farcas, and Nathan D. Merchant. 'Guiding Principles for Assessing the Impact of Underwater Noise'. Edited by Manuela González-Suárez. Journal of Applied Ecology 55, no. 6 (15 November 2018): 2531–36. https://doi.org/10.1111/1365-2664.13161.

Frankish, Caitlin Kim, Christ A. F. de Jong, Jakob Tougaard, Jonas Teilmann, Rune Dietz, Alexander M. von Benda-Beckmann, Bas Binnerts, and Jacob Nabe-Nielsen. 'Effect of Ship Noise on the Behaviour of Harbour Porpoises (Phocoena Phocoena)'. Marine Pollution Bulletin 197 (2023). https://doi.org/10.1016/j.marpolbul.2023.115755.

Galatius A., Brasseur S., Hamm T., Jeß A., Meise K., Meyer J., Schop J., Siebert U., Stejskal O., Teilmann J., Thøstesen C. B. (2023) Survey Results of Harbour Seals in the Wadden Sea in 2023. Common Wadden Sea Secretariat, Wilhelmshaven, Germany.

Galatius, A., O.E. Jansen, and C.C. Kinze. (2013). Parameters of growth and reproduction of white-beaked dolphins (Lagenorhynchus albirostris) from the North Sea. Marine Mammal Science. 29:348-255.

Gallagher, C. A., Grimm, V., Kyhn, L. A., Kinze, C. C., & Nabe-Nielsen, J. (2021). Movement and seasonal energetics mediate vulnerability to disturbance in marine mammal populations. American Naturalist, 197(3), 296-311. https://doi.org/10.1086/712798

Gilbert, J. R., G. T. Waring, K. M. Wynne and N. Guldager (2005). Changes in abundance of harbor seals in Maine, 1981-2001. Marine Mammal Science 21(3): 519-535.

Gilles, A., Authier, M., Ramirez-Martinez, M., Araujo, NC., Blanchard, H., Carlström, J., Eira, J., Doremus, C., Fernandez-Maldonado, G., Gelhoed, C., Kyhn, L. A., Laran, S., Nachtsheim, D. A., Panigada, S., Pigeault, R., Sequeira, M., Sveegaard, S., Taylor, N. L., Owen, K., ... Hammond, P. S. (2023). Estimates of cetacean abundance in European Atlantic waters in summer 2022 from the SCANS-IV aerial and shipboard surveys. Stiftung Tierärztliche Hochschule Hannover. https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Eksterne_udgivelser/20230928_SCANS-IV_Report_FINAL.pdf

Gilles, A., Scheidat, M. & Siebert, U. (2009). Seasonal distribution of harbour porpoises and possible interference of offshore wind farms in the German North Sea. s.l.: Marine Ecology Progress Series 383: 295-307.10.3354/meps08020.

Gillespie, D., Gordon, J., McHugh, R., McLaren, D., Mellinger, D. K., Redmond, P., Thode, A., Trinder, P., and Deng, X. Y. (2008). "PAMGUARD: Semiautomated, open source software for real-time acoustic detection and localisation of cetaceans," Proceedings of the Institute of Acoustics 30, 9pp-9pp,

Gillespie, D., Palmer, L., Macaulay, J., Sparling, C., and Hastie, G. (2021). "Harbour porpoises exhibit localized evasion of a tidal turbine," Aquatic Conservation: Marine and Freshwater Ecosystems, doi.org/10.1002/aqc.3660

Granquist, S.M., Hauksson, E., 2016. Seasonal, meteorological, tidal and diurnal effects on haul-out patterns of harbour seals (Phoca vitulina) in Iceland. Polar Biol 39, 2347-2359.

Griffiths, E.T., Kyhn, L.A., Sveegaard, S., Marcolin, C., Teilmann, J. and Tougaard., J. (2023). Acoustic detections of odontocetes in Skagerrak. Investigation of clicks and whistles from delphinids at Gule Rev and Store Rev. Aarhus University, DCE – Danish Centre for Environment and Energy, 22 pp. Scientific Report No. 539http://dce2.au.dk/pub/SR539.pdf

Hansen J.W. & Høgslund S. (red.) 2024. Marine områder 2022. NOVANA. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 184 s. - Videnskabelig rapport fra DCE nr. 592. https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Videnskabelige_rapporter_500-599/SR592.pdf

Hamilton, C.D., Lydersen, C., Ims, R.A., Kovacs, K.M., 2014. Haul-out behaviour of the World's northernmost population of harbour seals (Phoca vitulina) throughout the year. Plos One 9.

Hammond et al. (2021). Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys. Survey report.

Hammond, P.S., K. Macleod, P. Berggren, D.L. Borchers, L. Burt, A. Cañadas, G. Desportes, G.P. Donovan, A. Gilles, D. Gillespie, J. Gordon, L. Hiby, I. Kuklik, R. Leaper, K. Lehnert, M. Leopold, P. Lovell, N. Øien, C.G.M. Pax-ton, V. Ridoux, E. Rogan, F. Samarra, M. Scheidat, M. Sequeira, U. Siebert, H. Skov, R. Swift, M.L. Tasker, J. Teil-mann, O. Van Canneyt, and J.A. Vázquez. (2013). Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biological Conservation. 164:107-122.

Hammond, P.S., P. Berggren, H. Benke, D.L. Borchers, A. Collet, M.P. Heide Jørgensen, S. Heimlich, A.R. Hiby, M.F. Leopold, and N. Øien. (2002). Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. Journal of Applied Ecology. 39:361-376.

Hansen J.W. & Høgslund S. (red.) 2021. Marine områder 2020. NOVANA. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 192 s. - Videnskabelig rapport fra DCE nr. 475. http://dce2.au.dk/pub/SR475.pdf.

Harvey, J.T., Goley, D., 2011. Determining a correction factor for aerial surveys of harbor seals in California. Mar Mammal Sci 27, 719-735.

HELCOM (2018). "HELCOM Guidelines for monitoring continuous noise," (HELCOM secretariat, Helsinki), p. 9.

HELCOM (2023). "Continuous low frequency anthropogenic sound (HELCOM pre-core indicator report)," (Helcom Secretariat, Helsinki).

Hiby, L. (1999). The objective identification of duplicate sightings in aerial survey for porpoise. s.l.: Marine mammal survey and assessment methods. Balkema, Rotterdam: 179-189.

Hiby, L. and Lovell, P. (1998). Using aircraft in tandem formation to estimate abundance of harbour porpoise. s.l.: Biometrics: 1280-1289.

Huber, H.R., Jeffries, S.J., Brown, R.F., DeLong, R.L., VanBlaricom, G., 2001. Correcting aerial survey counts of harbor seals (Phoca vitulina richardsi) in Washington and Oregon. Mar Mammal Sci 17, 276-293.

Härkönen, T., Dietz, R., Reijnders, P., Teilmann, J., Harding, K., Hall, A., Brasseur, S., Siebert, U., Goodman, S.J., Jepson, P.D., Rasmussen, T.D., Thompson, P., 2006. The 1988 and 2002 phocine distemper virus epidemics in European harbour seals. Dis Aquat Organ 68, 115-130.

Härkönen, T., Heide-Jørgensen, M.P., 1990. Comparative life histories of east atlantic and other harbor seal populations. Ophelia 32, 211-235.

ISO (2017). "18405:2017 Underwater acoustics - terminology," (International Organization for Standardization, Geneva).

Kinneging, N., and Tougaard, J. (2021). "Assessment North Sea. Report of the EU INTERREG Joint Monitoring Programme for Ambient Noise North Sea (Jomopans)," (Rijkswaterstaadt, The Hague, Netherlands), p. 23.

Kinze, C. C. (2009). White-beaked dolphin: Lagenorhynchus albirostris. In Encyclopedia of marine mammals (pp. 1255-1258). Elsevier.

Kiszka, J. and G. Braulik (2018). Lagenorhynchus albirostris. The IUCN Red List of Threatened Species 2018: e.T11142A50361346.

Knudsen, V. O., Alford, R. S., and Emling, J. W. (1949). "Underwater ambient noise," Journal of Marine Research 7, 410-429

Kyhn ,L.A., Galatius, A., Sveegaard, E., van Beest, F., Marcolin, C. Dietz, R., Teilmann, J., Nabe-Nielsen, J., Siebert, U., Nachtsheim, D. 2024a. Results of the two year monitoring program for marine mammals in connection with the construction of the North Sea Energy Island. Technical report. Energinet Eltransmission A/S. Lockyer, C. 2003. Harbour porpoises (Phocoena phocoena) in the North Atlantic: Biological parameters. NAMMCO Sci. Publ. 5

Kyhn ,L.A., Dietz, R., Nabe-Nielsen, J., Galatius, A., Teilmann, J., Siebert, U., Nachtsheim, D. 2024b. Marine mammal movements and distribution in relation to the North Sea Energy Island. Technical report. Energinet Eltransmission A/S.

London, J.M., Hoef, J.M.V., Jeffries, S.J., Lance, M.M., Boveng, P.L., 2012. Haul-out behavior of harbor seals (Phoca vitulina) in Hood Canal, Washington. Plos One 7.

Lonergan, M., Duck, C., Moss, S., Morris, C., Thompson, D., 2013. Rescaling of aerial survey data with in-formation from small numbers of telemetry tags to estimate the size of a declining harbour seal population. Aquat Conserv 23, 135-144.

MacGillivray, A., and de Jong, C. (2021). "A Reference Spectrum Model for Estimating Source Levels of Marine Shipping Based on Automated Identification System Data," Journal of Marine Science and Engineering 9, 369-, doi.org/10.3390/jmse9040369

Malinka, C. E., Gillespie, D. M., Macaulay, J. D. J., Joy, R., and Sparling, C. E. (2018). "First in situ passive acoustic monitoring for marine mammals during operation of a tidal turbine in Ramsey Sound, Wales," Mar. Ecol. Prog. Ser. 590, 247-266, doi.org/10.3354/meps12467

Meeus, J. (1991) Astronomical Algorithms. Willmann-Bell, Inc

Mellinger, D. K., Carson, C. D., & Clark, C. W. (2000). Characteristics of minke whale (Balaenoptera acutorostrata) pulse trains recorded near Puerto Rico. Marine Mammal Science, 16(4), 739-756.

MERIDIAN. 2020. “Ketos: Acoustic signal detection and classification with deep neural nets.” Institute for Big Data Analytics, Dalhousie University, Canada.

Nachtsheim, D., Unger, B., Martínez, N.R., Mehrwald, K., Siebert, S., Gilles, A. (2021). Monitoring of marine mammals in the German North and Baltic Sea in 2020. Institute for Terrestrial and Aquatic Wildlife Research (ITAW), University of Veterinary Medicine Hannover, Büsum, Germany. 7 pp.

Olesiuk, P.F., Bigg, M.A., Ellis, G.M., 1990. Recent trends in the abundance of harbor seals, Phoca vitulina, in British Columbia. Can J Fish Aquat Sci 47, 992-1003.

Olsen, M.T., Andersen, L.W., Dietz, R., Teilmann, J., Härkönen, T., Siegismund, H.R., 2014. Integrating genet-ic data and population viability analyses for the identification of harbour seal (Phoca vitulina) populations and management units. Mol Ecol 23, 815-831.

Olsen, M.T., Galatius, A., Härkönen, T., 2018. The history and effects of seal-fishery conflicts in Denmark Marine Ecology Progress Series 595.

Popescu, M., Dugan, P. J., Pourhomayoun, M., Risch, D., Lewis III, H. W., & Clark, C. W. (2013). Bioacoustical periodic pulse train signal detection and classification using spectrogram intensity binarization and energy projection. arXiv preprint arXiv:1305.3250.

Rasmussen, M. H., Akamatsu, T., Teilmann, J., Vikingsson, G., & Miller, L. A. (2013). Biosonar, diving and movements of two tagged white-beaked dolphin in Icelandic waters. Deep Sea Research Part II: Topical Studies in Oceanography, 88, 97-105.

Reid, J.B., P.G.H. Evans, and S.P. Northridge. (2003). Atlas of cetacean distribution in north-west European waters, Peterborough, U.K.

Ries, E.H., Hiby, L.R., Reijnders, P.J.H., 1998. Maximum likelihood population size estimation of harbour seals in the Dutch Wadden Sea based on a mark-recapture experiment. J Appl Ecol 35, 332-339.

Risch, D., Castellote, M., Clark, C. W., Davis, G. E., Dugan, P. J., Hodge, L. E., ... and Van Parijs, S. M. (2014). Seasonal migrations of North Atlantic minke whales: novel insights from large-scale passive acoustic monitoring networks. Movement Ecology, 2(1), 1-17.

Risch, D., Clark, C. W., Dugan, P. J., Popescu, M., Siebert, U., & Van Parijs, S. M. (2013). Minke whale acoustic behavior and multi-year seasonal and diel vocalization patterns in Massachusetts Bay, USA. Marine Ecology Progress Series, 489, 279-295.

Risch, D., Wilson, S. C., Hoogerwerf, M., Van Geel, N. C., Edwards, E. W., & Brookes, K. L. (2019). Seasonal and diel acoustic presence of North Atlantic minke whales in the North Sea. Scientific Reports, 9(1), 3571.

Scheidat, M., Gilles, A., Kock, K.-H. & Siebert, U., (2008). Harbour porpoise *Phocoena phocoena* abundance in the southwestern Baltic Sea. s.l.: Endangered Species Research 5 (2-3): 215-223.10.3354/esr00161.

Sharpe, M. and P. Berggren (2023). *Balaenoptera acutorostrata* (Europe assessment). The IUCN Red List of Threatened Species 2023 e.T2474A219011809.

Simpkins, M.A., Withrow, D.E., Cesarone, J.C., Boveng, P.L., 2003. Stability in the proportion of harbor seals hauled out under locally ideal conditions. Mar Mammal Sci 19, 791-805.

Sonntag, R.P., H. Benke, A.R. Hiby, R. Lick, and D. Adelung. (1999). Identification of the first harbour porpoise (*Phocoena phocoena*) calving ground in the North Sea. Journal of Sea Research. 41:225-232.

Sveegaard, S., Teilmann, J., Tougaard, J., Dietz, R., Mouritsen, K. N., Desportes, G., & Siebert, U. (2011). High-density areas for harbor porpoises (*Phocoena phocoena*) identified by satellite tracking. Marine Mammal Science, 27(1), 230-246. https://doi.org/10.1111/j.1748-7692.2010.00379.x

Søndergaard, N.-O., A. H. Joensen and E. B. Hansen (1976). Sæler i Danmark. Danske Vildtundersøgelser 26.

Tougaard, J., Ladegaard, M., Griffiths, E. & Marcolin, C. 2023. Vurdering af tilstanden i de danske havområder for havstrategidirektivets deskriptor 11. Kriterierne D11C1 impulsstøj og D11C2 vedvarende lavfrekvent støj. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 92 s. - Videnskabelig rapport nr. 568

Teilmann, J., F. Larsen, and G. Desportes. (2007). Time allocation and diving behaviour of harbour porpoises (*Phocoena phocoena)* in Danish and adjacent waters. J.Cet.Res.Managem. 9:201-210.

Teilmann, J., Stepien, E.N., Sveegaard, S., Dietz, R., Balle, J.D., Kyhn, L.A., Galatius, A., 2020. Sælers bevægelsesadfærdsmønstre i Limfjorden og de omkringliggende åer: Analyser af adfærd af spættede sæler mærket med satellitsender i Limfjorden i relation til åer med havørredproduktion, Teknisk rapport fra DCE - Nationalt Center for Miljø og Energi. Aarhus Universitet, DCE - Nationalt Center for Miljø og Energi, Aarhus, p. 28.

Thompson, P.M., Harwood, J., 1990. Methods for estimating the population size of common seals, Phoca vitulina. J Appl Ecol 27, 924-938.

Thompson, P.M., Tollit, D.J., Wood, D., Corpe, H.M., Hammond, P.S., Mackay, A., 1997. Estimating harbour seal abundance and status in an estuarine habitat in north-east Scotland. J Appl Ecol 34, 43-52.

Tougaard, J. (2021). Thresholds for behavioural responses to noise in marine mammals. Background note to revision of guidelines from the Danish Energy Agency, (Roskilde).

Tougaard, J., Hermannsen, L., & Madsen, P. P. T. (2020). How loud is the underwater noise from operating offshore wind turbines? The Journal of the Acoustical Society of America, 148(5), 2885–2893. https://doi.org/10.1121/10.0002453

Tougaard, J., Ladegaard, M., Griffiths, E. & Marcolin, C. 2023. Vurdering af tilstanden i de danske havområder for havstrategidirektivets deskriptor 11. Kriterierne D11C1 impulsstøj og D11C2 vedvarende lavfrekvent støj. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 92 s. - Videnskabelig rapport nr. 568

Verfuss, U. K., Miller, L. A., and Schnitzler, H. U. (2005). Spatial orientation in echolocating harbour porpoises (*Phocoena phocoena*), J. Exp. Biol. 208, 3385-3394

Voß, J., A. Diederichs (2024): Energinet LOT1: Passive Acoustic Monitoring of harbour porpoises in the Danish North Sea. BioConsult SH, Husum. 49 p.

Wahlberg, M., Schack, H. B., Wilson, M., Bejder, L., and Madsen, P. T. (2008). Particle acceleration noise generated by boats, Bioacoustics 17, 148-150

Watts, P., 1996. The diel hauling-out cycle of harbour seals in an open marine environment: correlates and constraints. J Zool 240, 175-200.

Knudsen, V. O., Alford, R. S., and Emling, J. W. (1949). Underwater ambient noise, Journal of Marine Research 7, 410-429

Wisniewska, D. M., Johnson, M., Teilmann, J., Rojano Doñate, L., Shearer, J., Sveegaard, S., Miller, L. A., Siebert, U., & Madsen, P. T. (2016). Ultra-High Foraging Rates of Harbor Porpoises Make Them Vulnerable to Anthropogenic Disturbance. Current Biology, 26(11), 1441-1446. https://doi.org/10.1016/j.cub.2016.03.069

Wisniewska, D. M., Johnson, M., Teilmann, J., Siebert, U., Galatius, A., Dietz, R., and Madsen, P. T. (2018). High rates of vessel noise disrupt foraging in wild harbour porpoises (*Phocoena phocoena*), Proc. R. Soc. B 285, doi.org/10.1098/rspb.2017.2314

Yochem, P.K., Stewart, B.S., Delong, R.L., Demaster, D.P., 1987. Diel haul-out patterns and site fidelity of harbor seals (*Phoca vitulina richardsi*) on San Miguel Island, California, in autumn. Mar Mammal Sci 3, 323-332.