North Sea Energy Island

Satellite tagging of marine mammals
Technical report

Energinet Eltransmission A/S

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Contents

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4	28.6.2024	Marine mammal movements and distribution in relation to the North Sea Energy Island	Line Kyhn (AU) Rune Dietz (AU) Jacob Nabe-Nielsen (AU) Anders Galatius (AU) Jonas Teilmann (AU) Ursula Siebert (TIHO) Dominik A. Nachtsheim (TIHO)	Morten T. Olsen (AU) Maria Wilson (NIRAS)	Annette Møller (NIRAS) Jesper Fredshavn (AU)

Preface

This report was commissioned by Danish Energy Agency (DEA) to the consortium of NIRAS and Aarhus University and constitutes a description of the obtained results from the tagging program of marine mammal species in connection with the planned construction of an Energy Island in the North Sea.

The report builds upon existing knowledge as well as new data and analysis collected and conducted during this program.

The report is divided in seven main chapters and begins with a report summary (chapter 1) followed by introduction and aim of the report (chapter 2). Chapter 3 provides baseline knowledge for each species in the North Sea. Chapter 4 describes the methods, and chapter 5 describes the results of the tagging study. In chapter 6, the results are discussed and chapter 7 provides the conclusion. Hereafter acknowledgements and references are provided. The report ends with an appendix showing all seal tracks.

The work within the consortium was divided so that Line Anker Kyhn, Jonas Teilmann, Rune Dietz, Anders Galatius and Jacob Nabe-Nielsen, Section for Marine Mammal Research, Aarhus University, and Ursula Siebert and Dominik A. Nachtsheim, Stiftung Tierärztliche Hochschule Hannover (TIHO), were the main authors and responsible for the report with Morten Tange Olsen, Section for Marine Mammal Research, responsible for scientific review and Jesper Fredshavn, DCE – Danish Center for Environment and Energy, Aarhus University, 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. Energinet helped write the introductory passus of chapter 2 – introduction and aim.

1. Summary

This report presents the final efforts and results from the tagging program of marine mammals in the North Sea carried out by Aarhus University, Stiftung Tierärztliche Hochschule Hannover (from here onwards 'TiHO') and NIRAS for the Danish Energy Agency (from here onwards DEA). The analysis of the data from tagged harbour and grey seals includes habitat suitability analysis and tortuosity track analysis. The data from TIHO was bought for this project and the fieldwork was carried out under German permits and HSE requirements.

The tagging program intended to tag harbour porpoises, white-beaked dolphins, killer whales, minke whales, harbour and grey seals with satellite transmitters to understand whether the pre-investigation area for the North Sea Energy Island was used for foraging or migration of these species. Data from 27 harbour seals and 15 grey seals instrumented with satellite transmitters in 2022 and 2023 provided information that was used to evaluate use of the pre-investigation area of the North Sea Energy Island in relation to migration and movement patterns of the two seal species. In addition, Aarhus University obtained permission to use data from 33 juvenile grey seals tagged at Helgoland, Germany by TIHO between 2018 and 2022 to improve the data material of the present assessment.

Capture trials of harbour porpoises and white beaked dolphins were limited by number of days with calm water and a lack of dolphins close to shore. It was attempted to tag dolphins with an ARTS - a modified air-gun normally used as a 'line thrower' that allows the scientists to shoots the satellite tag into the dorsal fin. This was attempted during the servicing of the PAM stations in the Energy Island pre-investigation area. However, due to very few observations close to the ship no dolphins or porpoises were tagged.

Killer whales and minke whales were likewise planned to be tagged by shooting the tag into the dorsal fins or back of the animals, however none of the species were observed during the field work.

2. Introduction and aim

With the Climate Agreement for Energy and Industry of the 22nd of June 2020, the majority of the Danish Parliament agreed to establish an energy island in the Danish part of the North Sea as an energy hub with a connection to Jutland as well as interconnectors to neighbouring countries. To establish an environmental baseline for the later environmental permitting processes for the specific projects, a series of environmental pre-investigations have been carried out. This report concerns baseline data and information on marine mammals from the tagging program.

The pre-investigation area for the North Sea Energy Island is located in a part of the Danish North Sea with sparse existing information on marine mammals. This report provides the outcome of a satellite tagging study of marine mammal species in and near the pre-investigation area for the North Sea Energy Island conducted during 2022-23. Calculations and modelling was however performed prior to changing the spatial focus of the area. All calculations and modelling was therefore performed with respect to *the phase 1 area of the proposed plan for the program North Sea Energy Island* (see Figure 2. 1). This term, or the shortened term "*the phase 1 area*", is therefore used from chapter 4 and onwards and represents an area a little smaller than the pre-investigation area (Figure 2. 1). The tagging study is a supplement to the main marine mammal monitoring program for the North Sea Energy Island that includes passive acoustic monitoring (PAM) of cetaceans and aerial survey program of cetaceans and seals. The PAM program provides information on seasonal presence of the cetaceans, but the data will not provide any information on the migration or movements of the cetaceans and seals in or around the pre-investigation area. Similarly, the aerial surveys for cetaceans provide "snapshots" of the presence and numbers of cetaceans and data can be used for density estimation, if a sufficient number of animals of a species is encountered. However, these data neither provide information on migration nor movements of marine mammals in the pre-investigation area for the North Sea Energy Island. The purpose of the tagging program was therefore to supplement the main marine mammal monitoring program for the North Sea Energy Island with movement data from cetaceans and seals in and near the pre-investigation area, and to understand the use of the phase 1 area of the proposed plan for the program North Sea Energy Island for harbour and grey seals. The geographic scope of the tagging program was in and near the pre-investigation area, however marine mammals in general roam much larger areas, which are included in maps as relevant.

The North Sea Energy Island *pre-investigation area*, *extended survey area* and *the phase 1 area of the proposed plan for the program North Sea Energy Island* is shown in Figure 2. 1. The pre-investigation area is the area covered by the survey permit for North Sea Energy Island. It is also the geographical scope of the technical baseline reports. The phase 1 area is where the first phase of North sea Energy Island is planned according to the Plan for Programme North Sea Energy Island. The extended survey area is the maximum area covered by the technical report on marine mammals, and corresponds to the phase 1 area plus a 15 km buffer zone.

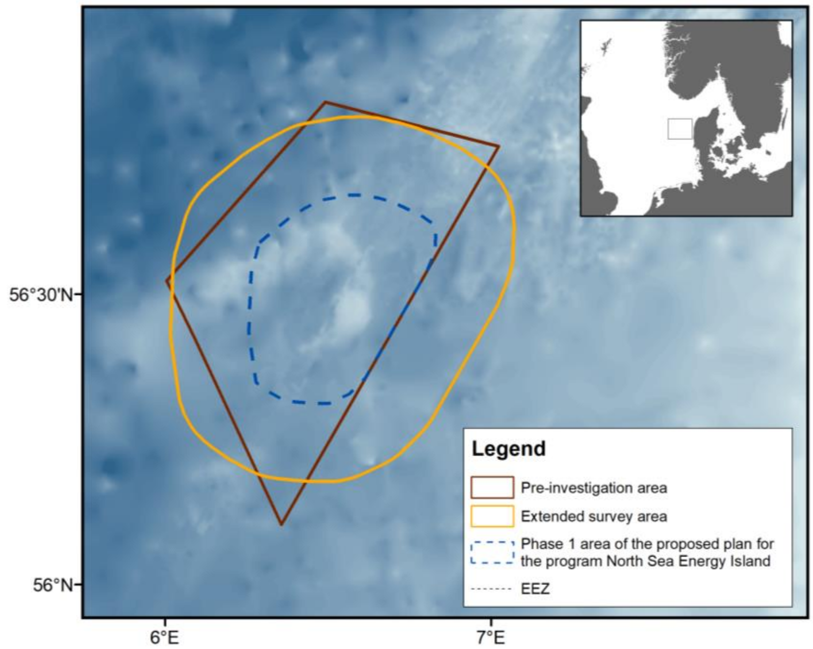

Figure 2. 1. Pre-investigation area, extended survey area and the phase 1 area of the proposed plan for the program North Sea Island.

Aiming at improving the baseline description of marine mammals (i.e. information on distribution, abundance and migration) with information on use of the pre-investigation area for future concession owners EIAS's, the marine mammal monitoring program was expanded with this planned satellite tagging study of harbour seals, grey seals, harbour porpoise, white beaked dolphins, killer whales and minke whales in the North Sea in spring 2022. However, only information from the two seal species were obtained.

3. Baseline species description

In the following chapters, baseline information is provided on relevant species in the North Sea.

3.1 Seals

There are two species of seals in the North Sea; harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*). Baseline information on the two species is covered in the following two chapters

3.1.1 Harbour seal (*Phoca vitulina*)

The harbour seal is widespread along coasts throughout the northern hemisphere in the temperate and subarctic zone (Teilmann and Galatius, 2018). The distribution in the northeast Atlantic Ocean extends from the British Isles over Iceland up to Svalbard and the Barents Sea as well as from northern France in the English Channel area into the North Sea and Baltic Sea at Kalmarsund. Harbour seals are widespread in Danish waters, except in the Baltic Sea around Bornholm (Søgaard et al., 2018). On the basis of genetics and migration data, four geographically separated populations are identified within Danish waters: the Wadden Sea population (shared with Germany and the Netherlands), the Inner Limfjord population, the Kattegat population (shared with Sweden) and the western Baltic Sea population (shared with Sweden) (Olsen et al., 2014). The population of harbour seals in Denmark started to increase, when it was protected in 1976 and seal reserves were established. Harbour seals have since been affected by PDV (Phocine Distemper Virus) epidemics in 1988 and 2002, where up to half of the individuals in the four Danish populations died (Dietz et al., 1989; Härkönen et al., 2006). In 2007, harbour seals were affected by algae toxins and Klebsiella infections (Mollerup et al., accepted) and in 2014 harbour seals in the Limfjord, the Kattegat and the Wadden Sea populations were affected by a bird flu epidemic (Søgaard et al., 2018; Bodewes et al. 2015; Zohari et al. 2014). In recent years, population growth has stagnated in the Wadden Sea, Kattegat and Limfjord populations. The highest national Danish count was in 2017 and has since been decreasing (Hansen and Høgslund, 2021).

The harbour seal is listed on the EU Habitats Directive annex II, which means that it should be protected by the designation of special areas of conservation. For seals, these areas are primarily placed in connection with important haul-outs on land.

3.1.1.1 Harbour seals in the North Sea

The closest resting places ('haul-out sites') to the pre-investigation area in the North Sea are in the western Limfjord and in the Danish Wadden Sea. Individuals from the Limfjord have been tagged with satellite transmitters and have regularly visited the pre-investigation area in the North Sea (Kyhn et al., 2021). Prior to the current study only a small number of seals had been tagged at Thyborøn (2019: n=3, 2020: n=5), and a larger number of harbour seals were tagged in the Inner Limfjord (2017: n=3; 2018: n=1; 2019: n=10; 2021: n=9; 2022: n=10). However, these seals only migrated outside of the Limfjord to a small extent (Teilmann et al. 2020; Bay Breiner 2023; Dietz et al. in prep.). Hence, the existing data were not considered sufficient and a tagging program of 20 harbour seals was proposed by Aarhus University and NIRAS. As for the previous tagging conducted at Rømø in the Wadden Sea (n=10) in 2002, these seals to a large extent migrated northwest towards the pre-investigation area (Tougaard et al. 2008), but being more than 20 years old these data may not be representative for the situation in the 2020s. Tagging conducted in Holland from 2007-2020 indicated that although the harbour seals from this area migrate northward from the Dutch shores into the North Sea, the harbour seals do not enter the pre-investigation area of the Energy Island (Brasseur and Aarts pers. comm.). Also harbour seals tagged in the German part of the Wadden Sea moved northwest, but not as far offshore as the pre-investigation area (Vance et al. 2021). Harbour seals from the Kattegat and the Baltic area rarely move into the North Sea region and hence this seal management unit is not likely to be affected by the planned Energy Island (Dietz et al. 2012; 2015; in prep).

3.1.1.2 Vulnerable periods for harbour seals in the North Sea

Harbour seals give birth to their young pups on land in May-June. The fur of the newborn pup is water repellent like the older seals, making it able to follow the mother into the water without significant heat loss. Harbour seals use the haul-out sites for lactation for 3-4 weeks after parturition. In the period July-August the seals moult and are vulnerable on their haul-outs during this period. Mating takes place in the water in late June to early August where male harbour seals maintain territories near the haul-outs and females are attracted by underwater calls or 'patrol' for females ready to mate (Boness, 2006). Thus, all combined, harbour seals are most vulnerable around the haul-out areas in the period 1 May to 1 September. The species is listed in Appendix II and VI under the Habitats Directive. Harbour seals are listed as Least Concern by IUCN (Lowry 2016). 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.

3.1.2 Grey seal (*Halichoerus grypus*)

The grey seal is widespread in the temperate and subarctic parts of the North Atlantic (Bowen, 2016). On the basis of genetic studies, the grey seal is divided into three subpopulations 1) East coast of North America, 2) around the British Islands, Iceland and the Norwegian coast and 3) the Baltic Sea (Fietz et al., 2016; Graves et al., 2008). The grey seal was common and widespread in Danish waters until the 19th century, where hunting caused its decline (Olsen et al., 2018). It was breeding until approx. 1900 on the Danish coastlines. After being extinct as a breeding species for more than 100 years, the grey seal re-immigrated to Danish waters around the year 2000 and since then up to 10 pups have been observed annually along the entire Danish coastline. It now occurs regularly and in increasing numbers in the Wadden Sea, Kattegat and the Baltic Sea (Søgaard et al., 2018; Galatius et al. 2020; Hansen and Høgslund 2022).

The grey seal is listed on the EU Habitats Directive annex II, which means that they should be protected by the designation of special areas of conservation. For seals, these areas are primarily placed in connection with important haul-outs on land.

3.1.2.1 Grey seals in the North Sea

The grey seals in the pre-investigation area belong to the North Sea population. The number of grey seals occurring in the western Limfjord and Danish Wadden Sea has been increasing in the past five years. However, very few pups are born in the Danish Wadden Sea (<3) and none have been recorded in the Limfjord. In the Wadden Sea, 300 individuals and 3 pups were counted in 2020, while 50 grey seals were observed resting in the western Limfjord (Hansen and Høgslund 2022). The occurrence of grey seals in Danish waters of the North Sea are primarily foraging seals from the large populations in Great Britain and the German/Dutch Wadden Sea. Most grey seals in Danish waters are only visiting and migrate to other areas to breed. Two grey seals were tagged in Thyborøn in 2020, and one of these visited the pre-investigation area, so it could not be excluded that the area has some significance for the species in terms of foraging (Kyhn et al. 2021). Hence, the existing data were not considered sufficient and a tagging program of 20 grey seals was proposed by Aarhus University and NIRAS. Tagging conducted in the Netherlands indicated that although the grey seals from this area migrates far from shore covering large areas of the North Sea, grey seals tagged in the Netherlands do not enter the pre-investigation area (Brasseur pers. comm.). Grey seals from the Baltic area very rarely move into the North Sea region and hence this seal management unit is not likely to be affected by the planned wind farms (Dietz et al. 2015).

3.1.2.2 Vulnerable periods for grey seals in the North Sea

Grey seals are most vulnerable when they are about to give birth to their young, during mating and when they moult. The female seal gives birth to one pup in an undisturbed place not influenced by the tide and nurses the young for three weeks, during which the pup rarely enter the water as its fur (the lanugo fur) is not water repellent and will therefore cause potential lethal heat loss. If mother and pup are disturbed during this period, there is a risk that the mother will leave the pup or the pup suffer from hypothermia. The North Sea population gives birth in December-January (Abt and Koch 2000; Brasseur et al. 2015), the mating season takes place after the approx. three weeks nursing period (Hall and Russel 2018). Grey seals from the North Sea moult in March-April (Schop et al. 2017). Thus, grey seals are most vulnerable around their haul-out sites during the periods December-January and March-April. Grey seals are listed in appendix II and VI in the Habitats Directive. IUCN categorizes grey seals as Least Concern (Bowen 2016), however the Danish Red List considers grey seals as Vulnerable (Moeslund 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) Under water noise pollution, 4) Climate and habitat changes, 5) Recreational activities: physical disturbances and noise.

3.2 Cetaceans

There are several species of cetaceans living in the North Sea where impacts should be considered when planning construction of the energy island/platforms and several wind farms (se Kyhn et al. 2021). The most common species are harbour porpoise (*Phocoena phocoena*), white-beaked dolphin (*Lagenorhyncus albirostris*), minke whale (*Balaenoptera acutorostrata*) and killer whale (*Orcinus orca*). There are other species occurring regularly in the North Sea (Hammond, et al., 2013), but the listed species are the most common and therefore the focus of the tagging program and this report. Since all cetacean species are listed in Annex IV of the Habitats Directive these species are subject to an assessment of strictly protected species in relation to Article 12 (1) of the Directive 92/43/EEC of the Council on the protection of species. Article 12 (1) states that Member States shall take the requisite measures to establish a system of strict protection for the animal species listed in Annex IV in their natural range, prohibiting: (a) all forms of deliberate capture or killing of specimens of these species in the wild; and (b) deliberate disturbance of these species, particularly during the period of breeding, rearing, hibernation and migration. Therefore, knowledge on migrations and movements of cetaceans that occur in the pre-investigation area, especially harbour porpoise and white beaked dolphins, are needed in order for a future concessionaire and concrete project to fulfil the Habitats Directive.

3.2.1 Harbour porpoises (*Phocoena phocoena*)

Harbour porpoises are distributed in the north Atlantic from the southeastern USA to the Baffin Island, Disko bay in Western Greenland, Iceland, the Faroes, northern Norway and southwards into the North Sea. In continental Europe, they occur from the Baltic Sea and southwards Iberia, and further to West Africa and in the Black Sea, except the Mediterranean. Porpoises typically occur in coastal areas, but during winter, porpoises are found in large parts of the North Atlantic (Hammond et al. 2008a, Nielsen et al. 2018). Porpoises are found throughout Danish Waters, however rarely in the Limfjord and around Bornholm. Based on genetics, morphology and movement patterns, harbour porpoises around Denmark are divided into three populations: The North Sea-Skagerrak, the Belt Sea and the Baltic Proper (Galatius et al., 2012; Sveegaard et al., 2015; Wiemann et al., 2010(Celemín, Autenrieth et al.).

3.2.1.1 Harbour porpoises in the North Sea

The population size of harbour porpoises in the North Sea is estimated to be stable at just above 300,000 individuals in the period 1994-2022 (SCANS I-IV) (Hammond et al., 2017, Gilles et al. 2023). The best available knowledge on movements of harbour porpoises in this area is from animals incidentally caught in pound nets along the Inner Danish coastline and at Skagen (There are no pound nets on the west coast of Jutland). Once caught, the fishermen contact researchers at Aarhus University, who equip the porpoises with a satellite transmitter before being released again. This provides data on position and diving for up to 1.5 years. Some of these tagged porpoises regularly visit the pre-investigation area, but from these data, it does not appear to be a very important area for foraging. However, the nearest capture site is at Skagen, which is quite far from the pre-investigation area, and use of the pre-investigation area by these animals, may hence not be representative for how the area is used by porpoises in the North Sea in general.

3.2.1.2 Vulnerable periods for harbour porpoises in the North Sea

Harbour porpoise calves are entirely dependent on their mother for their first ten months of life, where they suckle and slowly learn to hunt 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). The vulnerable period is therefore all year in the North Sea, including birth and the 10 month lactation period.

Harbour porpoises are listed in Annex IV if the Habitats Directive and evaluated as Least Concern in the North Sea by IUCN (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.

3.2.2 White-beaked dolphins (*Lagenorhynchus albirostris*)

White-beaked dolphins live in temperate and subarctic areas in the North Atlantic. The distribution is from the White Sea/Barents Sea and around southern Greenland and Iceland in the North to the Waters around Portugal and Massachusetts (Hammond et al., 2013) in the South. White beaked dolphins in the North Sea and west of the British Islands are considered as a separate population (Galatius and Kinze 2016, Gose, Humble et al. 2024).

3.2.2.1 White-beaked dolphins in the North Sea

White-beaked dolphins are common in the more open waters of the North Sea (Hammond et al., 2017). The abundance of white-beaked dolphins in the North Sea has been estimated four times during SCANS' surveys in 1994, 2005, 2016 and 2022 (Hammond et al., 2017; Gilles et al. 2023). These surveys points to a stable population of around 20,000-40,000 individuals in the North Sea. It is not known whether this is the carrying capacity of the North Sea, since there are no counts or abundances estimates prior to 1994. White-beaked dolphins in the Danish part of the North Sea belong to the North Sea populations and there are no separate national management units. There are no distribution maps for white-beaked dolphins in the pre-investigation area, and there is generally very little knowledge on yearly pattern of presence and behaviour in Danish Waters. There are no movement data available for white-beaked dolphins in Danish Waters, and therefore no knowledge on their behaviour in or near the pre-investigation area.

3.2.2.2 Vulnerable periods for white-beaked dolphins in the North Sea

White-beaked dolphin calves are born in summer and mating takes place just after calving (Galatius et al., 2013). During calving and mating and in the months hereafter the dolphins are vulnerable to disturbances that may lead to mother-calf separation. In other, more well-studied dolphin species, the calves are dependent of their mother for several years. White-beaked dolphins are listed in Annex IV if the Habitats Directive and evaluated as Least Concern in the North Sea by IUCN (Sharpe and Bergman 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.

3.2.3 Minke whales (*Balaenoptera acutorostrata*)

Minke whales are widely distributed in the temperate to polar zones of all oceans of the northern and southern hemisphere, but are rare or absent at latitudes between 0-30 ° (Perrin et al., 2018). Minke whales live in open water but are sporadically also found in Inner Danish Waters (Hammond et al., 2017). Minke whales in the North Sea are likely part of a larger population in the northeastern Atlantic Ocean. The abundance of minke whales in North Sea has been estimated four times during the SCANS surveys in 1994, 2005, 2016 and 2022 (Hammond et al., 2002; Hammond et al., 2017; Hammond et al., 2013, Gilles et al. 2023). The results of the four SCANS surveys suggest an abundance of minke whales in the North Sea of around 10,000 individuals. Born et al. (2007) investigated population structure in a large part of the North Atlantic using a combination of heavy metals, organochlorines, genetics and fatty acids. The results indicated the following four subpopulations 1) West Greenland, 2) central Atlantic including Jan Mayen, 3) Northeast Atlantic including Svalbard, Barents Sea and northwestern Norway and 4) the North Sea.

3.2.3.1 Minke whales in the North Sea

Very little is known about minke whale distribution and abundance in Danish Waters. On two occasions, minke whales incidentally caught in a pound net at Skagen were tagged with a satellite transmitter and subsequently swam northwest of the British Isles during autumn and winter (Teilmann and Dietz, unpublished data). Minke whales in the Danish part of the North Sea are therefore unlikely to belong to a separate Danish population and there are no national management units established. There are no distribution maps for minke whales in the pre-investigation area, but there is overlap between the pre-investigation area and the area where minke whales have been observed during whale- or seabird surveys (Reid et al., 2003; Waggitt et al., 2019). Minke whales are often observed from Danish oil platforms in the North Sea from March to September (Delefosse et al., 2017). The weather is mostly unsuitable for observations during winter, and it is unclear whether minke whales are equally present at this time of the year. Generally, our knowledge on the abundance, distribution and behaviour of minke whales is sparse.

3.2.3.2 Vulnerable periods for minke whales in the North Sea

It is not known when minke whales are most vulnerable to disturbances. However, minke whales are observed regularly in the pre-investigation area. Despite a peak in observations in spring-summer (Risch, Wilson et al. 2019), there is not enough knowledge to point to specific periods where minke whales are more vulnerable than other periods, as the lack of observations during fall and winter could be due to bad weather.

Minke whales are listed in Annex IV if the Habitats Directive and evaluated as Least Concern in the North Sea by IUCN (Cooke 2018). 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.

3.2.4 Killer whales (*Orcinus orca*)

The killer whale is considered the most widespread of all cetacean species, inhabiting all the world's oceans from the Polar Regions to the Tropics. They are apex predators, feeding on a broad range of prey items, from small schooling fish and squids to pinnipeds, toothed or baleen whales, and are not limited in their distribution by abiotic factors such as water temperature or depth (Matkin and Leatherwood, 1986; Klinowska, 1991; Ford et al., 1998; Forney and Wade, 2006; Reeves et al., 2008). Although considered generalist as a species, across their range, dietary specializations have led to the evolution of killer whale ecotypes exploiting specific prey and ecological niches (Whitehead, 1998; Foote et al., 2009, 2012, 2016; Whitehead, 2017). Some of these ecotypes occupy a narrow spatial and ecological niche, whereas others are known to migrate and exhibit population genetic connectivity over large distances (e.g., Foote et al., 2009; Matthews et al., 2011; Durban and Pitman, 2011; Foote et al., 2012; Reisinger et al., 2015; Foote et al., 2016).

3.2.4.1 Killer whales in the North Sea

There is no estimate of abundance of killer whales in the North Sea as too few observations were made during SCANS surveys in 1994, 2005, 2016 and 2022 (Hammond et al., 2002; Hammond et al., 2017; Hammond et al., 2013; Gilles et al. 2023). Killer whales in Inner Danish Waters belong to the North Sea population. Killer whale sightings are likely to be shared immediately on Facebook via the platform Hvaler.dk.

3.2.4.2 Vulnerable periods for killer whales in the North sea

Very little is known about killer whale distribution and abundance, and temporal occurrence in Danish Waters. Killer whales are observed from Danish oil platforms in the North Sea (Delefosse et al. 2017) and Østrin (1994) mentions the killer whale as a seldom guest in the North Sea. So far killer whales have not been tagged in the North Sea. The closest tagging of killer whales has been conducted in northern Norway and the majority of these whale tagged during winter migrated southward along the Norwegian coast south to 64.2°N following herring to their spawning grounds, but none of them entered the North Sea (Dietz et al. 2020; Vogel et al. 2021). Killer whales are listed in Annex IV if the Habitats Directive and evaluated as Data Deficient by IUCN (Reeves, Pitman and Ford 2017). Threats according to the IUCN Red List categories are 1) Fishing & harvesting aquatic resources, 2) Pollution from industry and agriculture, 3) Noise pollution, 4) Climate and habitat changes.

4. Methods

In this chapter we go through the methodology for tagging the focal species. Methods enabling tagging of the species mentioned in chapter 3 was prepared: Harbour porpoise, white-beaked dolphin, killer whale and minke whale, as well as grey seal and harbour seal, which requires different methods.

The tagging program officially ran throughout 2022. Seals were captured in spring and fall 2022, however since we obtained extra tags (see further below) an extra capture was performed in spring 2023. Capture of harbour porpoises requires extremely calm weather and were attempted caught in summer 2022. The field part of the program was officially stopped at the end of 2022, however we were permitted tagging of white-beaked dolphins during service trips to the PAM stations in the North Sea Energy Island pre-investigation area in 2023.

Data from 33 grey seal pups was bought for this project from TIHO. The data has not previously been published. In tables and figures this data is called TIHO data, while data obtained in this project is called DEA data, as the data is owned by the Danish Energy Agency.

4.1 Capturing and tagging

Capturing and tagging different species of marine mammals requires optimal methods for the focal species. Seals haul-out on land and can be captured there, while cetaceans spent their entire lives at sea. In this chapter we explain the chosen methods.

4.1.1 Requirements for handling and tagging wild animals

Section for Marine Mammal Research, Aarhus University, possess all the required permits to capture/handle and/or tag wild harbour porpoises, white-beaked dolphins, killer whales and minke whales. The persons tagging the animals have the required Felasa B course, are experienced in tagging harbour porpoises, and have trained specifically for these procedures. The Section for Marine Mammal Research also have experience tagging killer whales in northern Norway (Dietz, Rikardsen et al. 2020) and white-beaked dolphins in Iceland (Nachtigall et al. 2008).

4.1.2 HSE requirements

In order for the tagging to be safe for both animals and humans some restrictions were placed on safety equipment, weather conditions, distance to shore and search area. An overview of the HSE requirements is given in the following, however the full HSE guidelines and risk assessment may be acquired if needed. Additionally, each vessel carried a number of other safety items, had an installed radio and all personnel wore survival suits and life wests.

4.2 Tags

In this study, tags from the manufacturer Wildlife Computers were used. The tags provide positions of the tagged animals via the Argos satellite system. The company's homepage explains thoroughly how the tags work by means of the Argos satellite system. Please see Wildlife Computers or Argos for further information on how satellite tags work.

The tags emit a signal whenever the tag is above water. This is possible via a saltwater switch. Saltwater is a good electrical conductor and therefore can act as a switch to connect/interrupt a circuit. In the tag, there is an inbuilt saltwater switch that enables transmission of a signal to a satellite via an antenna when the saltwater switch interrupts an internal circuit, i.e. interruption of this circuit is a signal to transmit the signal. This happens as the animal surfaces to breathe and the tag exits the water.

4.2.1 Seal tags

In this program a new generation of Wildlife Computer (WC) seal tags of the type SPLASH-AF-391A (160 g; 86 x 58 x 28 mm) were used with the capability of providing GPS and Argos positions as well as dive histogram data. In cooperation with Wildlife Computers, the tags were programmed to send dive information hourly accompanied by a GPS position. The tags collect position data whenever they are above water and contact to satellites can be obtained.

However, a programming failure from WC and electronic noise over Denmark prevented the expected high resolution of the position data from seals tagged in the spring 2022. Wildlife Computers provided a re-imbursement of 20 new tags, which were adjusted to a higher transmission output for the autumn tagging in September 2022. To enhance transmission of positions, a Mote was set up prior to the second autumn tagging when the Mote had terminated its duty for a different project at Sundsøre. The Mote is a stationary, unattended ground-based listening station which continually logs telemetry data from satellite tags nearby, providing 20-50% more positions than when just using Argos transmissions (https://wildlifecomputers.com/our-tags/extras/wildlife-computers-mote/). Online data were stored at Wildlife Computers' portal at: *https://my.wildlifecomputers.com/data/map/?id=6276f28d2c72b054ab72cb91* for the harbour seals and at *https://my.wildlifecomputers.com/data/map/?id=62728ba0e9b35157a7651e5a* for the grey seals. The tag is shown in Figure 4. 1 below.

Figure 4. 1. Picture of harbour seal tagged with a Wildlife Computer SPLASH-AF-391A tag. The seal has been set loose and is free to leave, but still recovering from the sedation.

4.2.2 Cetacean tags

For the tagging of whales, 15 tags of the type SPLASH10-F-333 produced by Wildlife Computers was ordered. The tags were to be fitted with two 5 mm diameter polyoxymethylene pins covered with silicone tubing (for more details on tagging procedure, transmitters and effects of tagging, see Eskesen et al., 2009; Geertsen et al., 2004; Teilmann et al., 2007; Sveegaard et al., 2011; Dietz et al., 2020; Vogel et al., 2021). For harbour porpoise tagging, three pins secured with iron nuts are used to allow tag release by corrosion. Antiseptic ointment (Betadine) is applied to the pins before deployment. The tag is lined with 3mm neoprene and on the opposite side of the fin shielded by a conveyor belt material lined with neoprene. The tag is shown in Figure 4. 2 below.

The SPLASH10-F-333 tags for killer whales, white-beaked whales and minke whales were to be fitted with stainless steel barbs with two 6 cm titanium darts (Andrews et al., 2008). The Wildlife Computer LIMPET "dart-tips" are shipped in packages consisting of a tube and 2 urethane end-caps. When holding the "dart tip" end-cap, the back end-cap and tubing can easily be removed, allowing the tagging personnel to screw the dart directly onto the tag without touching the "dart-tips". In addition, the tags were sterilized with 70 % ethanol in the minutes prior to the tagging attempts and antiseptic ointment (Betadine) was applied to "dart-tips" before deployment. For tag deployments an ARTS launcher with an approximate range of 20 m was bought from Restech Norway and delivery darts were built at Aarhus University and tested for the deployment of the limpet tags. The ARTS is connected to an air cylinder or a diving tank through an air filling hose with reduction valve, safety valve and quick coupling and a manometer/gauge showing chamber pressure, is mounted on the ARTS to regulate the air pressure during deployment. The tags collect position data whenever they are above water and contact to satellites can be obtained.

Figure 4. 2. The Wildlife Computers' SPLASH10-F-333 tag intended for cetaceans. Note the three different antennas.

4.3 Tagging methods

Methods varies between seals and cetaceans and are explained in the chapters below.

4.3.1 Seal tagging procedures

The original program agreed with Energinet was to tag 25 seals (divided between the two seal species). However, following the spring tagging, it was discovered that the deployed tags did not provide as many GPS positions as expected (although the tags provided useful Argos position data). As a compensation for the technical issues, 20 additional tags were provided from the manufacturer, Wildlife Computers, giving a total of 45 tags for this project. Only 42 of the deployed tags were used in the data handling as three of the tags had a too short lifetime to be included in the data analyses.

Haul-outs in Nissum Bredning was chosen for the tagging efforts as these are the nearest to the pre-investigation area (see Figure 4. 3). Tagging efforts were timed to provide the longest possible tag deployments before the moulting seasons and to have different seasons represented. Five tagging expeditions to Nissum Bredning near Thyborøn were conducted in 2022-2023; 1) one in Spring (2-5 May 2022), three in Autumn in 2) 5-7 September 2022, 3) 26-28 September 2022, and 4) 31 October to 1 November 2022, and finally 5) Spring 2023 (28 March). In spring 2022, five harbour seals and 13 grey seals were tagged. In September 2022, 12 harbour seal and three grey seals were tagged. In October/November no seals were tagged due to unfavourable weather conditions. On 28 March 2023, 11 harbour seals and one grey seal were tagged Table 4. 1.

The harbour and grey seals were caught and tagged along the sand banks in Nissum Bredning in the western part of the Limfjord east of Thyborøn in Northwest Jutland, Denmark (Figure 4. 3). The period of tagging was at low tide so that the sand banks were exposed and available for the seals to haul-out, and further restricted to weather conditions with limited rain and wind less than 10 m/s.

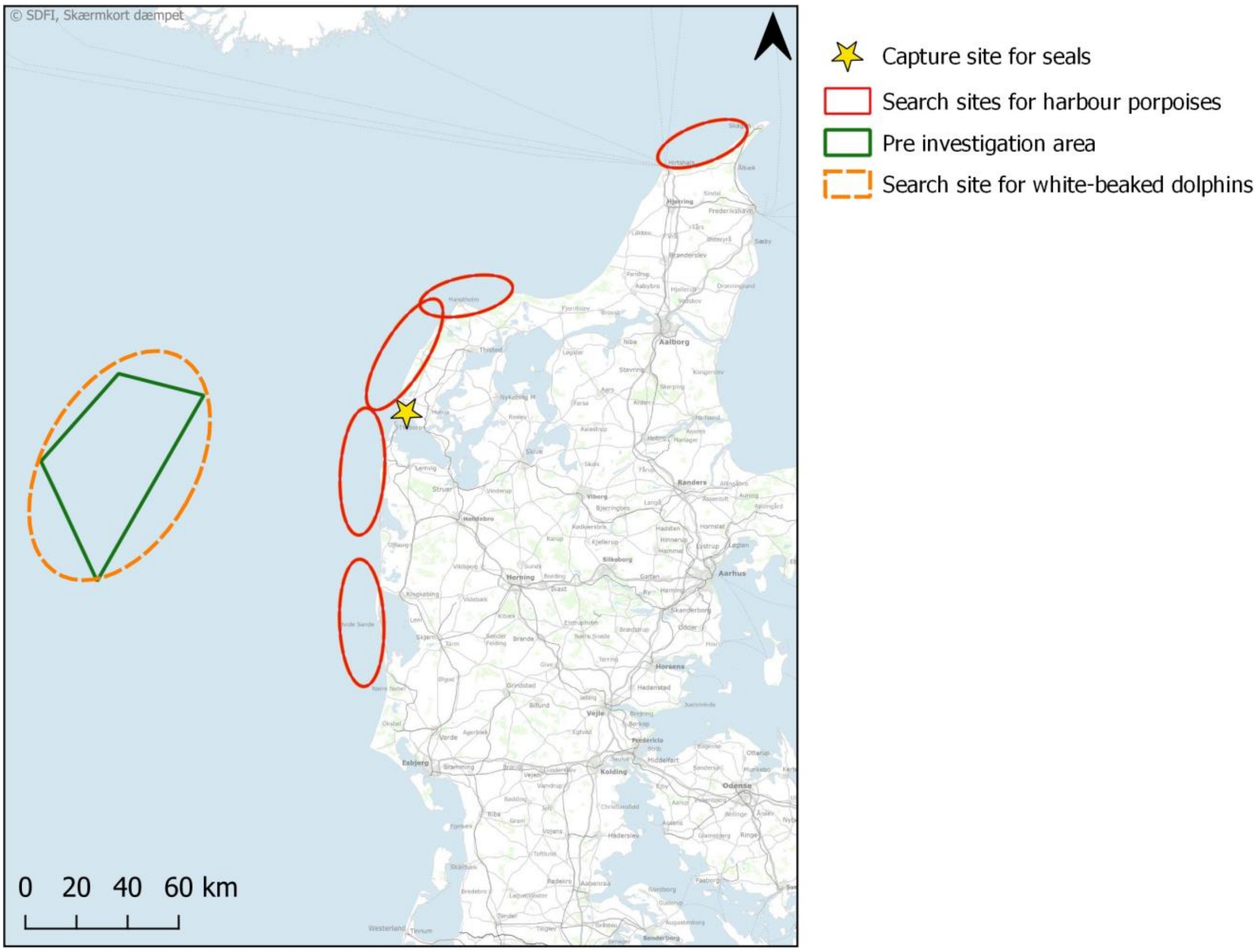

Figure 4. 3. Map of localities where search and capture was attempted for seals and cetaceans. For harbour porpoises large areas were searched over full days, but capture was not successful. HSE requirements to stay within 50 km from the shore. White-beaked dolphins were searched for during two PAM service trips in the pre-investigation area and east hereof.

Table 4. 1. Overview of field effort for tagging seals at Thyborøn in 2022 and 2023.

Date	Weather	Area	Seals	Seals tagged
03-05-2022	Perfect conditions, sunny 3 m/s	Nissum Bredning/ Thyborøn	>50 seals	13 grey seals
04-05-2022	Perfect conditions, sunny 3 m/s	Nissum Bredning/ Thyborøn	>50 seals	5 harbour seals
05-09-2022	Good conditions, 8-9 m/s	Nissum Bredning/ Thyborøn	>50 seals	3 grey seals & 3 harbour seals
27-09-2022	High tide, but workable	Nissum Bredning/ Thyborøn	<50 seals	2 harbour seals
28-09-2022	High tide, 7-8 m/s	Nissum Bredning/ Thyborøn	<50 seals	7 harbour seals
31-10-2022	Too high tide, 6 m/s. Wind from SE, which means that our smell reached the seals before we did. Seals nervous and quickly entered the water.	Nissum Bredning/ Thyborøn	<25 seals	0
01-11-2022	Too high tide, 12 m/s. Could not leave harbour.	Nissum Bredning/ Thyborøn	< 25 seals	Too bad weather, no effort
28-03-2023	Good conditions, 3 m/s	Nissum Bredning/ Thyborøn	>50 seals	11 harbour seals and 1 grey seals tagged

Three small out board boats were used in the tagging efforts. The first boat approaching the seals was the tourist boat from *Jyllands Akvariet*, which the seals were familiar with. Hiding behind the first boat followed the other vessels, first the Aarhus University boat *Hanne* which carried a surrounding net, with the rear end being handed over to the Aarhus University vessel *Onkel Bo*, when the seals started to enter the water at a distance of usually 50-100 m. The surrounding net was ca. 400 m long, and typically one boat would secure one end of the net to shore whereafter the other boat would encircle the seals and reach land with the other end. Meanwhile the boat from *Jyllands Akvariet* would try to prevent the seals from escaping by circling in front of the "open end" until the net was secured on land in both ends. The net was then hauled ashore with the entangled seals, typically by minimum 10 persons. The seals were secured with either pole nets, large butterfly nets or hoop nets and carried up on the sand banks to prevent escape before tagging. Prior to tagging, the seals were anesthetized using midazolam 5 mg/ml in 2-4 ml doses depending on the size of the seal. Midazolam will not give a full anaesthesia, but rather make the seals passive, much easier to work with and hence less stressed. When anaesthetized after 20-30 min, the sex of the seals was determined, morphometric measurements taken, and blubber thickness was measured with ultrasound. If needed, the seals were held by a person sitting on the back of the seals with the weight on his/her knees on the ground to hold the neck of the seal still while tagging. The tag was attached to the fur on the head, neck or the back of the seal using rapid setting Loctite 416 on the bottom of the tag and with an extra liner of epoxy resin (Loctite EA 3430) along the edge of the tag. Biological samples such as hair, hind flipper skin biopsies (where a cow ear tag was placed for long-term identification), and in a few cases also blood samples, urine or faecal samples were taken for additional investigations including genetics and disease-related studies conducted by University of Copenhagen beyond the scope of the tagging program.

4.3.2 Harbour porpoise tagging procedures

Harbour porpoises have not previously been tagged in the pre-investigation area. The harbour porpoises most likely to use the pre-investigation area, and hence the focal population for this project, was harbour porpoises on the West coast of Jutland. The area relevant for tagging was thus deemed the west coast of Jutland from Blåvandshuk to Skagen, as this is the area closest to the pre-investigation area. In Inner Danish waters, most tagged animals have been incidentally caught in pound nets, however pound nets are not used in the North Sea and hence are not an option for tagging the harbour porpoises, that potentially use the pre-investigation area. Harbour porpoises can however also be caught by active catch, which was intended for this program. An active catch consists of the following steps: 1) finding a group of harbour porpoises, 2) setting a range of nets and 3) herding the harbour porpoises into the nets. When the harbour porpoises are caught in the net, they are lifted from the net as fast as possible and moved onto the boat, where they are placed on a stretcher on soft matrasses. Here, they are measured and tagged. During the tagging procedure, a biopsy is taken from the dorsal fin where the tag is placed. Following tagging, the animal is lifted in the stretcher and lowered into the water, where it is released. The whole procedure usually does not take more than approximately 20 minutes.

Harbour porpoises are small animals with elusive behaviour. They spend most of their time under water, but briefly appear at the surface to breathe. Active catch and tagging of harbour porpoises therefore require ideal weather conditions with very low sea state (0-1), i.e.no waves or rain to be able to find and follow porpoises until capture. A team of six trained persons were constantly standby all through June, August and September 2022 to go to the field to catch harbour porpoises. The team went to the location with the best weather forecast on the given day. Four different areas were tried: Hvide Sande, Thyborøn, Hanstholm and Hirtshals (see Figure 4. 3). The team typically spent a few days in each location under appropriate weather conditions. There were restraints put on the suitable weather both in terms of being able to find and handle harbour porpoises, but also in terms of HSE requirements. Therefore, the weather forecast was followed closely with several prognoses analysed before the field crew went to sea.

Thyborøn is the closest point on the west coast of Jutland to the pre-investigation area and was therefore chosen as the most relevant location for tagging harbour porpoises. Thyborøn did also turn out to be a suitable location for finding porpoises. Many individuals were observed on days with flat water. Porpoise behaviour is individually, very variable, and context specific. Some groups were herdable, while others were impossible to herd towards the nets. There was also differences in behaviour with regards to water depths. Such differences in reactions are expected, but difficult to factor in when working with wild animals. In general, animals near Thyborøn appeared somewhat more skittish than in other places where we have worked.

Throughout the three months standby, the team were on the water for a total of 10 days, however the weather conditions were mostly less than ideal or there were only few hours with suitable weather (see Table 4. 2). Often the sea state was too high (>2) to be able to keep track of the porpoises' whereabouts, once they were observed. Catch was attempted on several occasions from Thyborøn, Hvidesande, Hanstholm and Hirtshals both with ideal and less than ideal weather conditions. However, no porpoises were caught. In conclusion, the tagging program for harbour porpoises was seriously hampered by too much wind in 2022, limiting the number of hours on the water and thereby catch trials. It would have benefitted from an extra years' activity. In comparison in another harbour porpoise tagging study conducted by Aarhus University, the tagging team had about fifty catch trials in and near the Wadden Sea in 2014 and 2016 before six porpoises were finally caught over a period of three days with ideal weather conditions. In that project, it came down to finding the ideal spot for the capture event. The study in the Wadden Sea shows that tagging of harbour porpoises using this method is possible, it is just highly weather and site dependent.

4.3.3 White-beaked dolphin capture and tagging procedures

White-beaked dolphins approach vessels to bow-ride. After finding a group of white-beaked dolphins that are willing to bow-ride, one person stands in the front of the boat on a custom-made pulpit in the stern (Nachtigall, Mooney et al. 2008, Rasmussen, Akamatsu et al. 2013). The person stands with a hoop net attached to a long pole. To the hoop is a net attached to a large metal ring with clamps. When a dolphin is close, the hoop will be lowered down in front of it, so the animal swims into it. As the dolphin swims into the hoop, the net detaches from the metal ring and the dolphin swims forward in the net. The net is attached to the boat, and the dolphin is dragged back to the boat and onto a stretcher placed between the two boats. The dolphin is then measured and tagged on the dorsal fin before it is released.

To obtain information on possible sightings and locations of white-beaked dolphins, killer whales or minke whales, we kept in contact with tour operators, working on a daily basis at Gule and Store Rev. We also kept updated on possible sightings at the Facebook platform 'Hvaler.dk', where cetacean sightings and especially killer whale sightings are likely to be shared immediately.

On all porpoise trips (from respectively Thyborøn, Hvidesande, Hanstholm and Hirtshals – see Table 4. 2), equipment for catching and tagging white-beaked dolphins was also brought. However, no dolphins were observed. When talking to local fishermen going to the Yellow Reef every single day with tourist anglers, they said that no dolphins, killer whales or minke whales were observed in summer 2022, contrary to other years, and no killer whales were reported on Hvaler.dk in summer 2022.

Table 4. 2. Overview of field effort for porpoise/dolphin tagging.

Date	Weather	Area	Porpoises/dolphins	Porpoises tagged
09-08-2022	Too high sea state	Thyborøn	One individual observed	0
10-08-2022	Too high sea state	Thyborøn	Several individuals observed, but couldn't be followed in the waves	0
11-08-2022	Perfect conditions at first, but deteriorated over the day	Hvide Sande	Two sightings and one capture event	0
12-08-2022	First good conditions, then wind picked up and white caps appeared	Thyborøn	Six groups of porpoises observed. All very shy and difficult to follow	0
13-08-2022	Perfect conditions at first, then wind picked up	Thyborøn	A group of four porpoises was followed and catch was tried for 2 ½ hours, but the animals kept diving under the boat and was very difficult to herd	0
15-08-2022	To high sea state	Thyborøn	No observations	0
16-08-2022	Ok weather	Hanstholm	Few observations and two catch trails	0
30-08-2022	Weather good to begin with	Hirtshals	Few observations	0
31-08-2022	Weather good to begin with	Hirtshals	Few observations	0
01-09-2022	Perfect weather	Hirtshals	Several observations and several catch trials. Very close to catching three porpoises.	0

In 2022 the SCANS IV survey was carried out with aerial surveys all around Jutland and no dolphins were observed within 50 km from the Danish shore (Gilles et al. 2023), where we were allowed by HSE requirements to search for cetaceans. White-beaked dolphins were, however, observed inside, and west and north of the Energy Island pre-investigation area. These data are shown in the main report for the monitoring in the phase 1 area of the proposed plan for the program North Sea Energy Island.

4.3.4 Other cetacean tagging procedures

Minke whales and orcas are too large to be handled in a small-scale setup as this program. Therefore, the aim was to shoot a tag into the dorsal fin or blubber of these species with an ARTS airgun. The tags are the same as those for harbour porpoises and white-beaked dolphins and can also be used for darting after mounting of the Wildlife Computers LIMPET Titanium Tag Darts.

The tag is shot into the skin/blubber of the animal with a dart. The dart falls off when the dorsal fin or dorsal ridge is hit. If a shot misses, the dart floats, allowing retrieval and reuse. In addition, to the ARTS launcher, a Daninject airgun, was equipped to obtain biopsies from the tagged whales for information on sex and genetic relatedness and potentially information on fatty acids, stable isotopes and POP exposure.

On every porpoise trip (see Table 4. 2), equipment for shooting tags into minke whales and killer whales was brought, however, none of these species were observed. As explained above, none of these species were observed close to shore during the summer of 2022 from aerial surveys or by anglers at the Yellow Reef, and was presumably further offshore. There is no data on the yearly pattern of presence of these species in Danish Waters.

4.3.5 Additional attempts to tag white-beaked dolphins, minke whales and killer whales

On almost all service cruises to the Energy Island PAM stations in 2019-2022, white-beaked dolphins were observed by the bird spotter stationed at the roof of the service vessel Skoven. Therefore, in 2023, a trained airgun shooter (see method description above) and a trained marine mammal observer joined the PAM service cruises on two occasions to search for and tag white-beaked dolphins and potentially other cetacean species found in the area. A RIB (Rigid Inflatable Boat) approved by Energinet was rented and brought along for the purpose. On both cruises white-beaked dolphins were observed and tagging was attempted. It appeared as if the dolphins reacted to the sudden onset of engine noise from the RIB. They disappeared as soon as the RIB was started, as witnessed by the observer at the roof of the Skoven.

4.4 Analysis methods

4.4.1 Seal data extractions

Data from the Wildlife Computers (WC) web page (https://my.wildlifecomputers.com/) were extracted for each tag after they had ceased to transmit. For the tags still transmitting, data were downloaded from the Mote on 20th October 2023 and uploaded to the Wildlife Computers portal on 21st October 2023. The merged Mote and satellite relayed GPS and Argos data were downloaded from the WC Portal during the night between 21st and 22nd October 2023. In addition, to increase the sample size and coverage of the phase 1 area of the proposed plan for the program North Sea Island, data from 33 juvenile grey seals tagged with Argos satellite transmitters (Wildlife Computer SPOT6-287 and Sirtrack KiwiSat 202 K2G 276A) at Helgoland by TIHO in 2018-2022 were included in the analysis. This data is directly comparable to the DEA data obtained in this project. TIHO holds all necessary permits to capture and tag seals in German waters.

4.4.2 Filtering of seal movement data

The satellite tags simultaneously collected Argos positions and Fastloc GPS positions (see above). Both types of data contained extended periods where no data were collected due to unknown reasons, which had to be accounted for before analysing the data statistically. First duplicate positions, i.e., where both time and position were identical, were removed. Then data were split into 'bursts' of positions whenever there was a gap between consecutive positions of more than three days. Only bursts containing data for at least 20 days were retained. Positions with missing time stamp were removed, as were Argos positions with missing location class. Positions with latitude <51 or >61 or with longitude <–8 or >15 were removed as these were deemed unrealistic. Finally, positions were filtered using the Argosfilter package for R to remove positions yielding unrealistically high speeds (>10 m sec-1) (Freitas 2022) and positions >2 km inland were omitted.

4.4.3 Fitting state-space models (SSM)

The number of collected positions varied considerably among individuals and time periods, and there were in most tracks long periods without any positions received. The raw data therefore did not provide an unbiased estimate of how much time animals spent in the phase 1 area of the proposed plan for the program North Sea Energy Island. Instead, we fitted state-space models (SSMs) that allowed us to predict hourly positions along the movement tracks to fill in the empty parts of the tracks; one model per burst (defined as a sequence at least 20 days with positions). This was done using the R package AniMotum, which makes it possible to fit SSMs that account for variability in Argos position accuracy (Argos location class) and to fit models using Argos and GPS positions jointly (Jonsen et al. 2023). SSMs fitted using a correlated random walk model yielded unbiased estimates of the next position in the movement track (based on one-step-ahead residuals), so this was used throughout rather than a random walk model. One model was fitted for each burst, based on both Argos and GPS data, and it was recorded whether the hourly positions were on land, in the phase 1 area of the proposed plan for the program North Sea Energy Island, or at sea, but outside the Phase 1 area.

4.4.4 Characterizing environmental conditions

The seals' choice of where to forage is likely to be influenced by a range of environmental parameters that are of importance for the distribution of the fish that seals prey on. Data on all such parameters are neither known, nor obtainable. We could however include data on surface temperature, surface salinity, surface current strength, sea surface height, and mixed layer thickness (MLD) that were obtained from the Copernicus Marine database (https://data.marine.copernicus.eu; https://doi.org/10.48670/moi-00054; https://doi.org/10.48670/moi-00054) as a proxy for prey occurrence and distribution.). Data were available with a spatial resolution of 1.5 km and a temporal resolution of one hour for the entire North Sea, but not for waters east of Skagen. Data on substrate type and water depth were obtained from EMODnet (https://emodnet.ec.europa.eu). Substrate type was re-grouped into mixed coarse sediment, mud/sandy mud, rock/reef or sand to reduce the risk of rank deficiency in subsequent statistical models.

4.4.5 Calculating track tortuosity

The tortuosity of a movement track is an important characteristic of animal behaviour, as animals generally use more convoluted movements when foraging than when traveling to their foraging sites. One of the most used measures of track tortuosity is the 'residence time', which measures how long an animal spends up to a certain distance from each position in the track (Barraquand & Benhamou 2008). After some experimentation, we decided to calculate this measure for the SSM positions using a distance of 5 km from each position. The analysis was done using the R-package adehabitatLT.

4.4.6 Habitat suitability modelling

To assess whether the seal locations were associated with particular environmental conditions, we compared the locations where the tagged seals had been observed with random positions that they could have used, but were they were not observed. This complies with the use-availability approach used in other studies of seal habitat selection (Aarts et al. 2008; Carter et al. 2022). The comparison was done using generalized additive models (GAMs) with seal presence as binary dependent variable and with temperature, salinity, current strength, sea surface height, MLD, substrate, distance to tagging site, water depth and substrate type as predictors. Only substrate type was discrete. In addition to these main terms, we included the interaction between water depth and distance to tagging site in the model, as we expected the seals' propensity to use shallow waters to depend on how far they were from their main haul-out site. Models were fitted based on hourly positions obtained from the SSM models after merging these with matching environmental data. The positions where seals had not been observed were distributed at random up to a certain distance to the tagging site (480.4 km for harbour seal and 869.8 km for grey seal). These distances corresponded to the maximum distances the tagged seals moved away from the tagging sites. The number of random positions was equal to the number of hourly SSM positions. Before fitting the models, we tested that none of the predictors were strongly correlated (see Figure 4. 4 and Figure 4. 5), positions where one or more of the predictor variables were missing were removed, and all continuous variables were scaled and cantered in order to avoid that results were influenced by the units in which they were measured. Models were fitted in R using a special type of cubic regression splines with shrinkage (bs="cs", k=5). One model including all predictor variables (full model) was fitted for each species.

To determine which environmental variables that best predicted presence of seals, we calculated the corrected Akaike Information Criterion (AICc) for all possible models including one or more of the predictor variables from the full model. The models with the lowest AICc values, and those with AICc up to 10 higher, were considered good (following Burnham & Anderson 2002). This analysis was done using the MuMIn package for R (Bartoń 2019).

The mapping of how suitable different parts of the North Sea were for seals was based on the models that best predicted presence of seals (i.e., those with lowest AICc; one model per species). Whereas the models were fitted based on distance to tagging site, the predictions were based on distance to the different places where seals had been observed to haul-out along the West Coast of Jutland and northern Germany. The aerial surveys used in this analysis were conducted in August 2021 for harbour seals and in the period March–April for grey seals, which is the period where seals are moulting and where they spend most time on land (Hansen and Høgslund 2021). Environmental variables used in these predictions were from 15 Aug 2021 at 12:00 for harbour seal and from 1 April 2021 at 12:00 for grey seal. One prediction was generated for each of the haul-out sites. Afterwards the different predictions were weighted by the number of seals observed at each haul-out site and combined into one map per species.

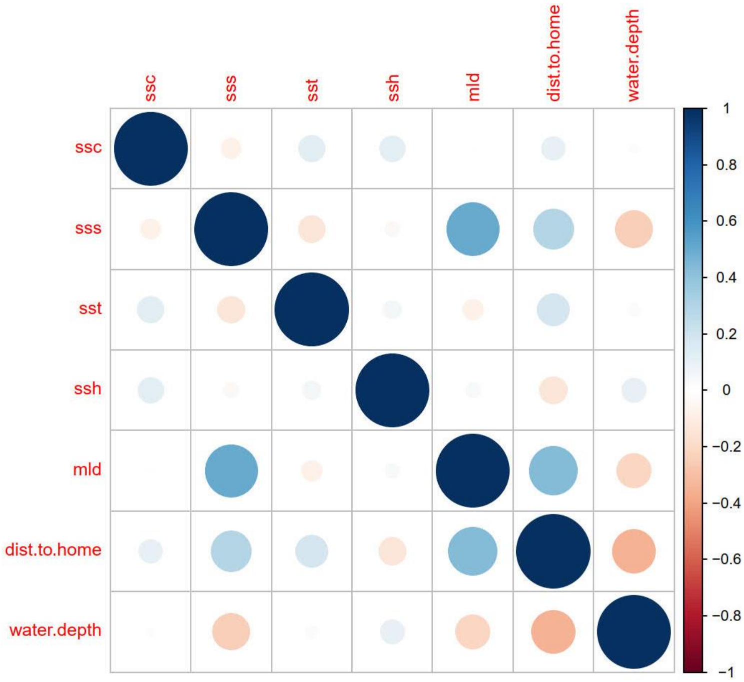

Figure 4. 4. Correlation plot for the variables included in the habitat suitability model for harbour seals. It is the same variables as is shown in Figure 5. 9 to Figure 5. 10. ssc is sea surface current. sss is sea surface salinity. sst is sea surface temperature. ssh is sea surface height. mld is mixed layer thickness. dist.to.home is distance to haul-out.

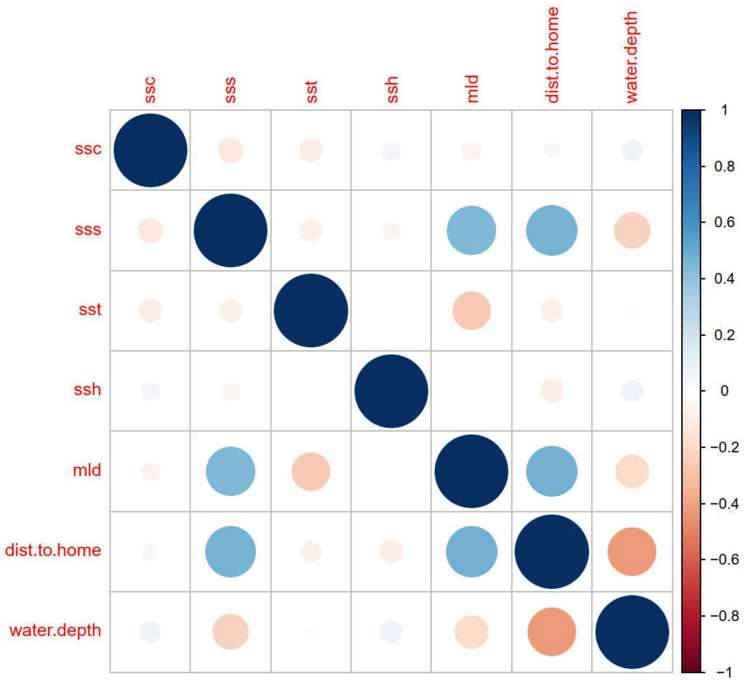

Figure 4. 5. Correlation plot for the variables included in the habitat suitability model for grey seals. It is the same variables as is shown in Figure 5. 9 to Figure 5. 10. ssc is sea surface current. sss is sea surface salinity. sst is sea surface temperature. ssh is sea surface height. mld is mixed layer thickness. dist.to.home is distance to haul-out.

5. Results

As explained above, only seals were caught (Table 5. 1) and tagged in this project, and the results is shown in the following chapters. There is little available tag data from harbour porpoises, white-beaked dolphin, minke whale and killer whale in general. Existing tag data from these species is shown in the main technical report for marine mammals, where results from the tagging program is also shown.

Table 5. 1. Overview of tagged animals per species.

Species	Attempted tagged?	Succes?
Grey seal	Yes	15 animals tagged
Harbour seal	Yes	27 animals tagged
Harbour porpoise	Yes	0
White-beaked dolphin	Yes	0
Minke whale	No (not observed)	0

5.1 Tagged animals

The results of the four seal capture events near Thyborøn at Nissum Bredning included in this report are from May 3-4th, September 5th, September 28th 2022 and March 28th 2023. Out of the 45 tagged seals, sufficient data were generated from 42 seals including 27 harbour seals and 15 grey seals used in the present report. In addition, data from 36 grey seal pups tagged at Helgoland were obtained from TIHO (Table 5. 2), but three had to be excluded from analysis bringing the sample size to a total of 48 grey seals tagged either in Thyborøn/Nissum Bredning or Helgoland. Animals were excluded due to missing metadata or too short duration of the data collection period. The average lifetime of the harbour seal tags was 105 days. The corresponding average lifetime for the grey seal tags was 132 days for grey seals tagged at Thyborøn and 141 days for grey seal pups tagged at Helgoland. The difference in duration is due to deployment date relative to the moulting period. For example, the majority of the harbour seals tagged in spring already lost their tags during start of the moulting period in July or earlier (See Table 5. 2).

Table 5. 2. Tagging and biological information as well as performance of the included tagged harbour and grey seals.

Tag ID	Number	Tagging location	Tagging date	Last transmission date	Tag lifetime, days	Species	Sex	Age group	Length (cm)	Weight (kg)
233502	1	Thyborøn	04-05-2022	09-07-2022	66	Harbour seal	M	Adult	154	110
233503	2	Thyborøn	04-05-2022	13-07-2022	70	Harbour seal	M	Adult	144	100+
233504	3	Thyborøn	04-05-2022	03-06-2022	30	Harbour seal	M	Adult	143	101
233505	4	Thyborøn	04-05-2022	27-07-2022	84	Harbour seal	M	Adult	137	100+
233506	5	Thyborøn	04-05-2022	12-07-2022	69	Harbour seal	M	Adult	148	100+
237343	6	Thyborøn	05-09-2022	13-01-2023	130	Harbour seal	M	Adult	144	71
237344	7	Thyborøn	05-09-2022	10-01-2023	127	Harbour seal	F	Yearling	89	21
237345	8	Thyborøn	05-09-2022	26-01-2023	143	Harbour seal	M	Adult	144	75
237346	9	Thyborøn	28-09-2022	30-01-2023	124	Harbour seal	M	Adult	152	92.5
237347	10	Thyborøn	27-09-2022	17-03-2023	171	Harbour seal	M	Adult	138	75.5
237348	11	Thyborøn	27-09-2022	25-03-2023	179	Harbour seal	M	Adult	144	68
237349	12	Thyborøn	28-09-2022	15-02-2023	140	Harbour seal	M	Adult	165	94
237350	13	Thyborøn	28-09-2022	30-01-2023	124	Harbour seal	M	Adult	156	87
237351	14	Thyborøn	28-09-2022	09-02-2023	134	Harbour seal	M	Adult	147	74.5
237352	15	Thyborøn	28-09-2022	19-12-2022	82	Harbour seal	M	Adult	142	78.5
237353	16	Thyborøn	28-09-2022	05-02-2023	130	Harbour seal	F	Adult	137	57
237354	17	Thyborøn	28-09-2022	11-02-2023	136	Harbour seal	F	Yearling	106	32.5
233507	18	Thyborøn	28-03-2023	03-07-2023	97	Harbour seal	M	Adult	145	90
233508	19	Thyborøn	28-03-2023	31-05-2023	64	Harbour seal	M	Adult	151	95
233509	20	Thyborøn	28-03-2023	01-05-2023	34	Harbour seal	M	Adult	153	102
233510	21	Thyborøn	28-03-2023	13-07-2023	107	Harbour seal	F	Adult	141	101
233516	22	Thyborøn	28-03-2023	02-07-2023	96	Harbour seal	M	Adult	147	91
237355	23	Thyborøn	28-03-2023	12-08-2023	137	Harbour seal	M	Adult	147	91
237356	24	Thyborøn	28-03-2023	08-08-2023	133	Harbour seal	M	Adult	128	99
237357	25	Thyborøn	28-03-2023	02-08-2023	127	Harbour seal	M	Adult	155	82
237361	26	Thyborøn	28-03-2023	10-05-2023	43	Harbour seal	M	Adult	142	68,5
237362	27	Thyborøn	28-03-2023	05-06-2023	69	Harbour seal	M	Adult	146	80
Average					105					
233492	1	Thyborøn	03-05-2022	24-08-2022	113	Grey seal	F	Juvenile	172	95
233493	2	Thyborøn	03-05-2022	01-10-2022	151	Grey seal	M	Juvenile	100	34
233494	3	Thyborøn	03-05-2022	28-07-2022	86	Grey seal	M	Adult	165	100+
233495	4	Thyborøn	03-05-2022	07-09-2022	127	Grey seal	M	Juvenile	159	74
233497	5	Thyborøn	03-05-2022	26-08-2022	115	Grey seal	M	Adult	157	100+
233498	6	Thyborøn	03-05-2022	24-08-2022	113	Grey seal	M	Juvenile	141	64
233499	7	Thyborøn	03-05-2022	25-09-2022	145	Grey seal	M	Juvenile	138	??
233500	8	Thyborøn	03-05-2022	31-08-2022	120	Grey seal	M	Juvenile	136	56
233501	9	Thyborøn	03-05-2022	01-08-2022	90	Grey seal	M	Adult	150	100+
233511	10	Thyborøn	03-05-2022	13-08-2022	102	Grey seal	F	Juvenile	142	88
233512	11	Thyborøn	03-05-2022	10-10-2022	160	Grey seal	M	Juvenile	139	65
233513	12	Thyborøn	03-05-2022	07-02-2023	280	Grey seal	M	Adult	163	100+
237358	13	Thyborøn	05-09-2022	19-01-2023	136	Grey seal	F	Yearling	108	32.5
237359	14	Thyborøn	05-09-2022	04-01-2023	121	Grey seal	M	Adult	194	200+
237360	15	Thyborøn	05-09-2022	05-01-2023	122	Grey seal	M	Juvenile	128	47
Average					132					
43643	1	Helgoland	04-02-2018	06-05-2018	91	Grey seal	M	Juvenile	111	31.7
43644	2	Helgoland	04-02-2018	18-06-2018	134	Grey seal	F	Juvenile	110	29.1
43648	3	Helgoland	04-02-2018	22-08-2018	199	Grey seal	M	Juvenile	110	36.4
43652	4	Helgoland	04-02-2018	17-08-2018	194	Grey seal	M	Juvenile	121	37.3
43655	5	Helgoland	04-02-2018	30-09-2018	238	Grey seal	M	Juvenile	129	33.1
65935	6	Helgoland	07-01-2020	19-08-2020	225	Grey seal	F	Juvenile	120	46.6
65937	7	Helgoland	10-01-2019	05-03-2019	54	Grey seal	F	Juvenile	127	51.1
65938	8	Helgoland	07-01-2020	04-07-2020	179	Grey seal	M	Juvenile	120	45
65940	9	Helgoland	10-01-2019	05-03-2019	54	Grey seal	F	Juvenile	107	32.9
65942	10	Helgoland	07-01-2020	06-05-2020	120	Grey seal	M	Juvenile	116	38.6
65946	11	Helgoland	10-01-2019	16-09-2019	249	Grey seal	F	Juvenile	129	47.1
65955	12	Helgoland	10-01-2019	20-05-2019	130	Grey seal	F	Juvenile		58.6
65962	13	Helgoland	10-01-2019	30-06-2019	171	Grey seal	M	Juvenile	125	44.3
208807	14	Helgoland	09-01-2021	12-06-2021	154	Grey seal	F	Juvenile	118	44.1
208808	15	Helgoland	09-01-2021	27-06-2021	169	Grey seal	F	Juvenile	121	29.5
208809	16	Helgoland	09-01-2021	31-05-2021	142	Grey seal	F	Juvenile	121	39.2
208810	17	Helgoland	09-01-2021	29-06-2021	171	Grey seal	F	Juvenile	120	36.9
208811	18	Helgoland	09-01-2021	27-05-2021	138	Grey seal	M	Juvenile	128	48.4
208812	19	Helgoland	09-01-2021	09-07-2021	181	Grey seal	M	Juvenile	112	34.4
208813	20	Helgoland	09-01-2021	02-03-2021	52	Grey seal	M	Juvenile	110	27.2
208815	21	Helgoland	09-01-2021	17-07-2021	189	Grey seal	M	Juvenile	117	33.8
208816	22	Helgoland	09-01-2021	17-05-2021	128	Grey seal	F	Juvenile	126	40.3
227525	23	Helgoland	11-01-2022	04-04-2022	83	Grey seal	M	Juvenile	131	38
227526	24	Helgoland	11-01-2022	28-02-2022	48	Grey seal	M	Juvenile	126	44.6
227527	25	Helgoland	11-01-2022	23-05-2022	132	Grey seal	M	Juvenile	135	39.8
227528	26	Helgoland	11-01-2022	01-03-2022	49	Grey seal	M	Juvenile	120	27.6
227529	27	Helgoland	11-01-2022	05-03-2022	53	Grey seal	F	Juvenile	129	50.2
227531	28	Helgoland	11-01-2022	01-03-2022	49	Grey seal	F	Juvenile	116	41.6
227532	29	Helgoland	11-01-2022	17-03-2022	65	Grey seal	F	Juvenile	116	40.7
227533	30	Helgoland	11-01-2022	13-06-2022	153	Grey seal	F	Juvenile	115	37.9
227534	31	Helgoland	11-01-2022	16-05-2022	125	Grey seal	M	Juvenile	105	35.1
43644b	32	Helgoland	07-01-2020	07-04-2021	456	Grey seal	F	Juvenile	124	40.1
65936b	33	Helgoland	09-01-2021	25-03-2021	75	Grey seal	M	Juvenile	129	51
Average					141					

5.2 Results from seal movement data

For the filtered data (GPS and ARGOS data), the cleaned dataset consisted of 187,784 high quality positions with data from 27 harbour seals (n = 75,732) and 48 grey seals (n = 112,052) (Table 5. 3). The movement tracks covered a period of 2–4 months for most seals. The distribution of all filtered positions from the harbour seals is shown on Figure 5. 1. Likewise, the distribution of positions from grey seals are shown in Figure 5. 2, of which 15 animals were tagged at Thyborøn (n = 27,191) and 33 were tagged at Helgoland (n = 84,861) (Table 5. 3).

5.2.1 Filtering positions

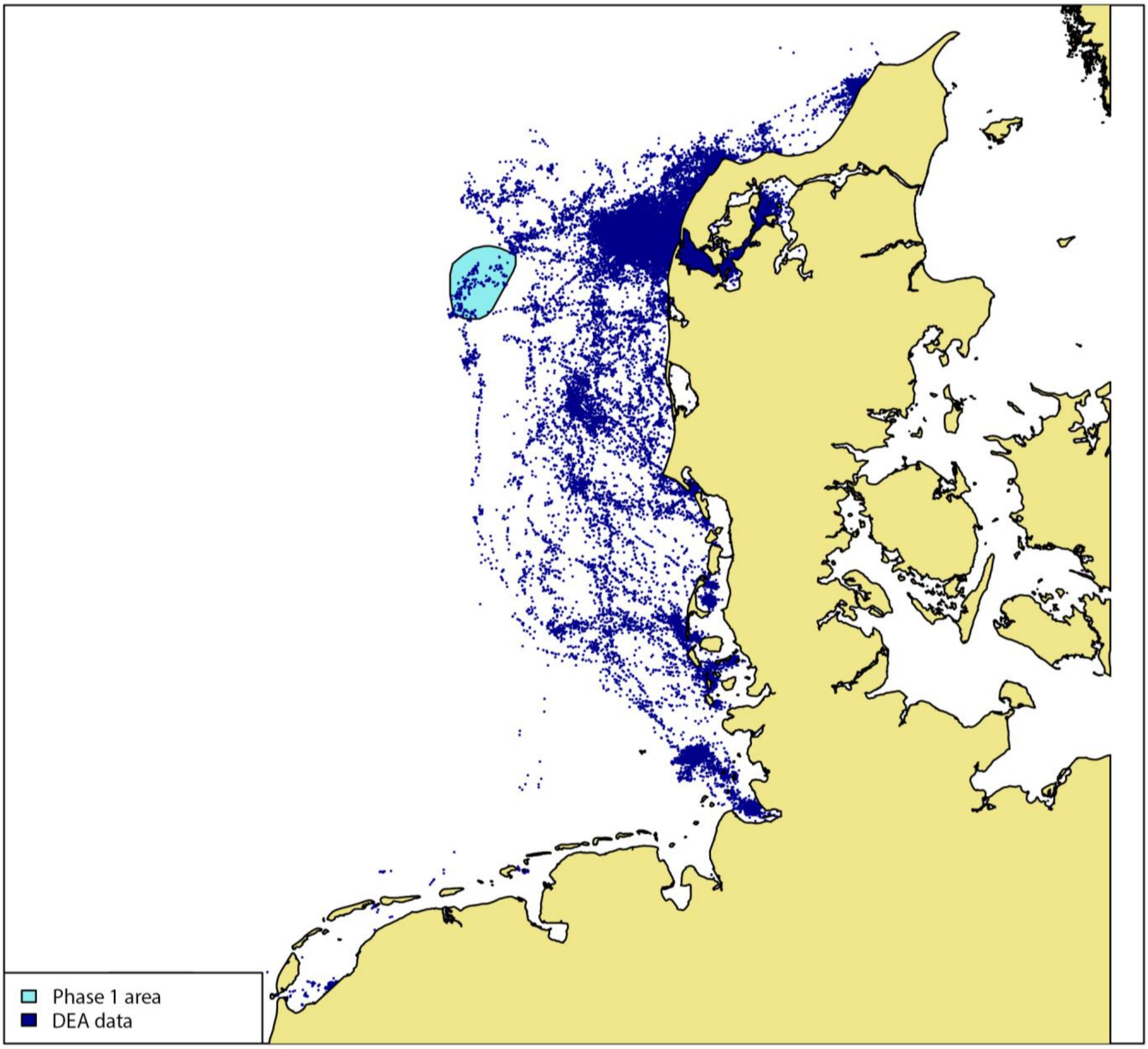

Figure 5. 1. All filtered positions from included harbour seals. Data includes ARGOS and GPS data. Maps are based on the UTM zone 32N projection. DEA = Danish Energy Agency and is data obtained in this project.

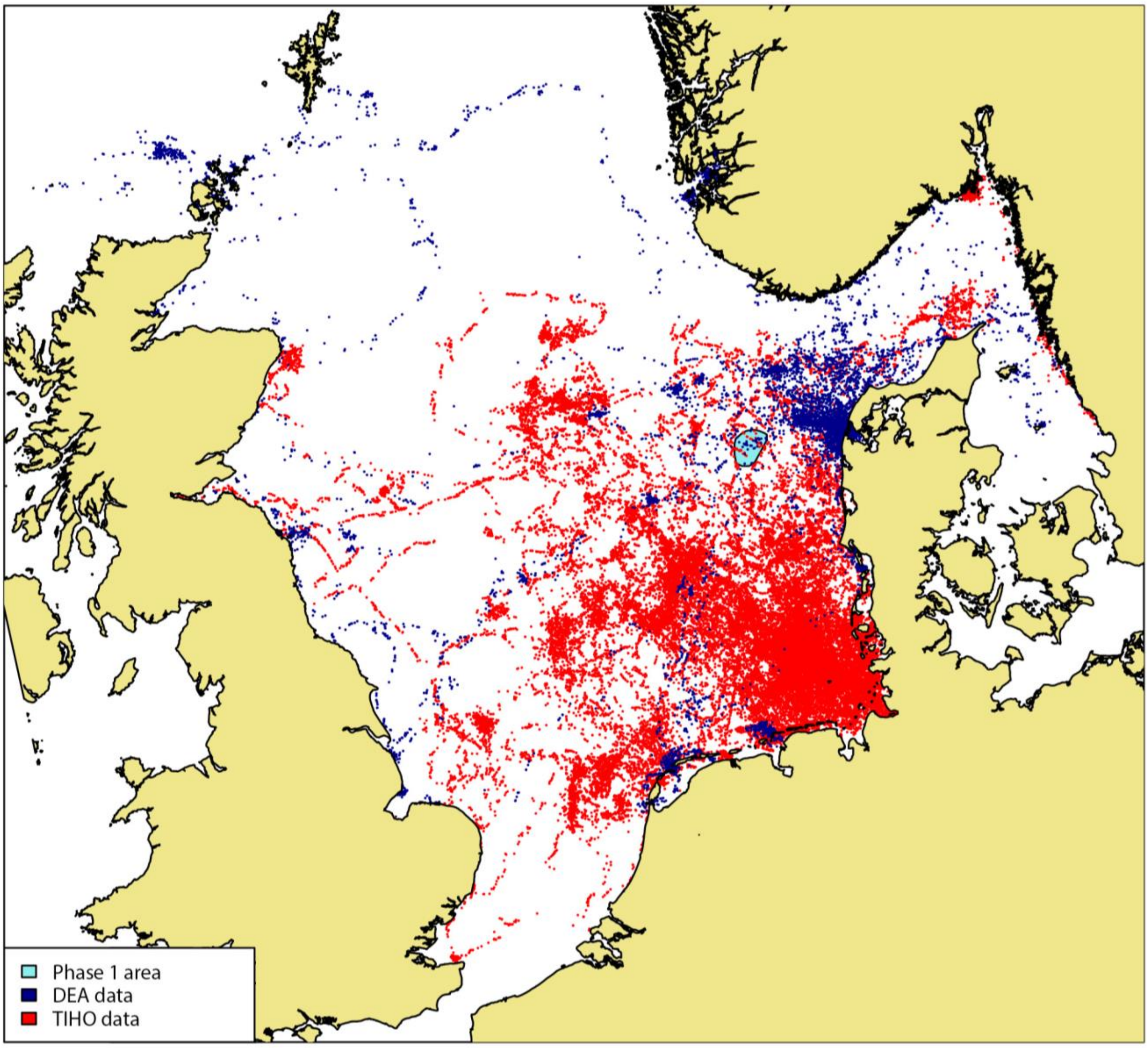

Figure 5. 2. All filtered positions from included grey seals based on both DEA (Danish Energy Agency) and TIHO (Stiftung Tierärztliche Hochschule Hannover) data from Thyborøn and Helgoland, respectively. TIHO data is from grey seal pups and was bought for this project. Data includes ARGOS and GPS data. Maps are based on the UTM zone 32N projection.

5.2.2 State-space models (SSM)

State-space models (SSM) showed the best fit using a correlated random walk model, as it yielded unbiased estimates of the next position in the movement track (based on one-step-ahead residuals), so this was used throughout rather than a random walk model. One example of a fitted SSM is shown in Figure 5. 3. All fitted SSMs are shown in appendix 1. The SSMs were then used to calculate how much time individual seals spent in the phase 1 area, on land or at the haul-out (see Table 5. 3). Time in the phase 1 area is based on one position per hour as predicted in the SSM.

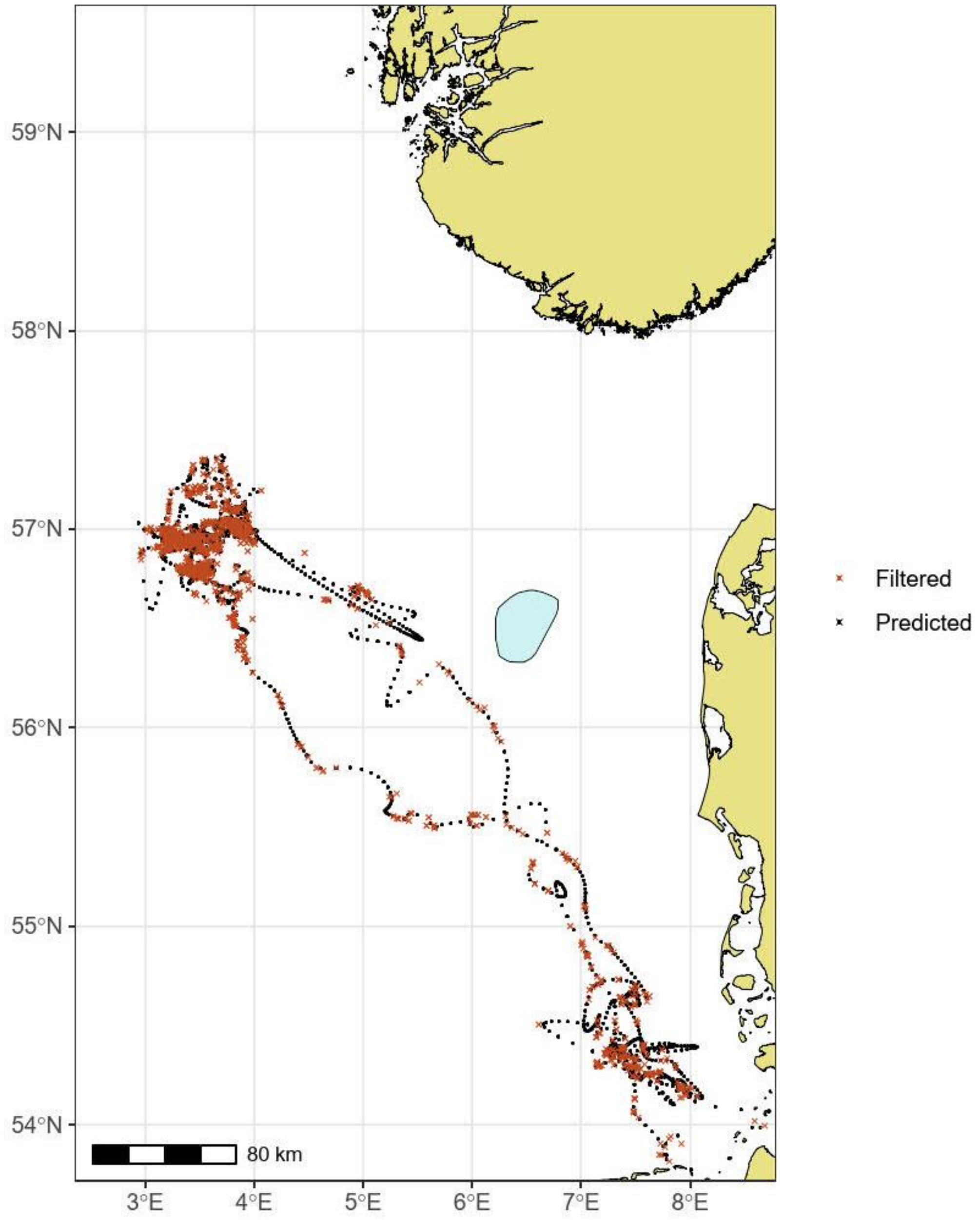

Figure 5. 3. Example of a fitted state-space model (SSMs) that allows prediction of hourly positions along the movement tracks of individual seals. Here grey seal 43643 tagged by TIHO at Helgoland is shown. All fitted tracks are shown in Appendix 1. The black circle is the phase 1 area of the proposed plan for the program North Sea Energy Island.

Table 5. 3. Number and positions and time spent on land, in water and in water in the phase 1 area of the proposed plan for the program North Sea Energy Island. Hours used in the phase 1 area was calculated based on hourly positions predicted using the state-space model. TIHO is Stiftung Tierärztliche Hochschule Hannover. DEA is Danish Energy Agency.

Meta data						Water		Land		Phase 1 area		Water		Land		Phase 1 area	
ID	Data provider	Species	Start time	End time	Positions in track	Positions	%	Positions	%	Positions	%	Hours	%	Hours	%	Hours	%
233496	DEA	Harbour seal	28-03-2023 17:00	17-04-2023 11:16	214	211	99	3	1	0	0	452	94,958	24	5,04	0	0
233502	DEA	Harbour seal	04-05-2022 21:24	09-07-2022 11:04	1998	1998	100	0	0	0	0	1575	100	0	0	0	0
233503	DEA	Harbour seal	11-05-2022 12:57	13-07-2022 15:24	1355	1340	99	15	1	0	0	1444	95,251	72	4,75	0	0
233504	DEA	Harbour seal	04-05-2022 18:19	22-06-2022 10:11	1249	1243	100	6	0	0	0	1139	97,434	30	2,57	0	0
233505	DEA	Harbour seal	05-05-2022 20:50	30-06-2022 11:44	1136	1131	100	5	0	0	0	1316	98,503	20	1,5	0	0
233506	DEA	Harbour seal	04-05-2022 18:09	11-07-2022 17:56	860	777	90	83	10	0	0	1410	86,344	223	13,7	0	0
233507	DEA	Harbour seal	28-03-2023 20:02	03-07-2023 22:18	3667	3621	99	46	1	0	0	2229	95,583	103	4,42	0	0
233508	DEA	Harbour seal	27-03-2023 20:00	31-05-2023 20:31	2191	2184	100	7	0	0	0	1489	95,327	73	4,67	0	0
233509	DEA	Harbour seal	27-03-2023 20:00	01-05-2023 09:51	1198	1158	97	40	3	0	0	768	92,419	63	7,58	0	0
233516	DEA	Harbour seal	27-03-2023 21:42	02-07-2023 12:42	3809	3690	97	119	3	0	0	2200	94,828	120	5,17	0	0
237343	DEA	Harbour seal	06-11-2022 05:36	13-01-2023 18:25	1151	1134	99	17	1	0	0	1429	91,838	127	8,16	0	0
237344	DEA	Harbour seal	05-09-2022 18:27	10-01-2023 06:21	1791	1784	100	7	0	0	0	2849	93,81	188	6,19	0	0
237345	DEA	Harbour seal	21-09-2022 06:38	26-01-2023 08:02	2314	2146	93	168	7	0	0	2596	85,087	455	14,9	0	0
237346	DEA	Harbour seal	27-09-2022 10:41	30-01-2023 19:02	5040	4896	97	59	1	0	0	2859	94,983	113	3,75	38	1,262
237347	DEA	Harbour seal	27-09-2022 11:00	17-03-2023 21:05	4533	3706	82	698	15	0	0	3217	78,158	812	19,7	87	2,114
237348	DEA	Harbour seal	27-09-2022 11:00	25-03-2023 12:36	4402	4373	99	29	1	0	0	3689	89,582	429	10,4	0	0
237349	DEA	Harbour seal	28-09-2022 13:00	15-02-2023 21:13	4153	4067	98	86	2	0	0	2997	88,932	373	11,1	0	0
237350	DEA	Harbour seal	28-09-2022 13:00	30-01-2023 12:03	4835	4692	97	143	3	0	0	2796	93,92	181	6,08	0	0
237351	DEA	Harbour seal	28-09-2022 13:00	09-02-2023 10:27	4703	4553	97	150	3	0	0	2881	89,611	334	10,4	0	0
237352	DEA	Harbour seal	04-10-2022 19:54	19-12-2022 04:57	2393	2361	99	32	1	0	0	1670	92,214	141	7,79	0	0
237353	DEA	Harbour seal	29-09-2022 03:22	05-02-2023 12:05	4345	4297	99	48	1	0	0	2794	89,955	312	10	0	0
237354	DEA	Harbour seal	29-09-2022 06:01	08-02-2023 21:00	4761	4652	98	109	2	0	0	3032	95,226	152	4,77	0	0
237355	DEA	Harbour seal	27-03-2023 17:26	12-08-2023 03:18	3161	3075	97	86	3	0	0	3023	93,766	201	6,23	0	0
237356	DEA	Harbour seal	27-03-2023 17:12	08-08-2023 18:45	3183	3171	100	12	0	0	0	3075	95,527	144	4,47	0	0
237357	DEA	Harbour seal	28-03-2023 17:39	02-08-2023 06:10	4721	4493	95	228	5	0	0	2885	94,964	153	5,04	0	0
237361	DEA	Harbour seal	27-03-2023 17:00	06-05-2023 09:00	256	249	97	7	3	0	0	742	77,859	211	22,1	0	0
237362	DEA	Harbour seal	28-03-2023 22:39	05-06-2023 07:41	2313	2260	98	53	2	0	0	1515	92,209	128	7,79	0	0
Average					**2.804,9**	**2.713,4**	**97,1**	**83,6**	**2,7**	**0,0**	**0,0**	**2.150,8**	**92,2**	**191,9**	**7,7**	**4,6**	**0,1**
Sum					**75.732**	**73.262**		**2.256**		**0**		**58.071**		**5.182**		**125**	
233492	DEA	Grey seal	05-05-2022 07:20	28-08-2022 09:34	1566	1513	97	45	3	0	0	2587	93,596	159	5,75	18	0,651
233493	DEA	Grey seal	03-05-2022 19:23	01-10-2022 18:09	1415	1374	97	41	3	0	0	3262	92,408	268	7,59	0	0
233494	DEA	Grey seal	03-05-2022 19:22	28-07-2022 11:04	1206	1165	97	41	3	0	0	1929	93,777	128	6,22	0	0
233495	DEA	Grey seal	04-05-2022 09:10	06-09-2022 21:00	1612	1510	94	102	6	0	0	2697	89,512	316	10,5	0	0
233497	DEA	Grey seal	04-05-2022 10:55	26-08-2022 20:06	1492	1438	96	38	3	0	0	2467	89,807	267	9,72	13	0,473
233498	DEA	Grey seal	04-05-2022 20:14	24-08-2022 18:17	1377	1211	88	166	12	0	0	2190	84,621	398	15,4	0	0
233499	DEA	Grey seal	03-05-2022 18:25	25-09-2022 10:49	2183	2122	97	61	3	0	0	3117	89,724	357	10,3	0	0
233500	DEA	Grey seal	04-05-2022 09:18	21-08-2022 16:02	660	623	94	33	5	0	0	1946	90,428	192	8,92	14	0,651
233501	DEA	Grey seal	03-05-2022 16:01	31-07-2022 20:48	1660	1543	93	117	7	0	0	1871	87,348	271	12,7	0	0
233511	DEA	Grey seal	03-05-2022 20:39	13-08-2022 19:43	1168	1101	94	67	6	0	0	2171	88,648	278	11,4	0	0
233512	DEA	Grey seal	06-05-2022 15:00	10-10-2022 07:03	1997	1597	80	400	20	0	0	3145	83,599	617	16,4	0	0
233513	DEA	Grey seal	04-05-2022 17:04	06-02-2023 21:58	3821	3496	91	325	9	0	0	5800	86,852	878	13,1	0	0
237358	DEA	Grey seal	26-09-2022 19:04	02-01-2023 22:22	642	610	95	32	5	0	0	2088	88,587	269	11,4	0	0
237359	DEA	Grey seal	05-09-2022 21:30	04-01-2023 10:09	1671	1638	98	25	1	0	0	2813	97,201	58	2	23	0,795
237360	DEA	Grey seal	06-09-2022 05:50	06-01-2023 11:12	1316	1253	95	62	5	0	0	2797	95,298	135	4,6	3	0,102
Average					**1.585,7**	**1.479,6**	**93,8**	**103,7**	**6,0**	**0,0**	**0,0**	**2.725,3**	**90,1**	**306,1**	**9,7**	**4,7**	**0,2**
Sum					**23.786**	**22.194**		**1.555**		**0**		**40.880**		**4.591**		**71**	
208807	TIHO	Grey seal	18-01-2021 08:15	12-06-2021 07:55	3405	3398	100	7	0	0	0	3409	97,932	72	2,07	0	0
208808	TIHO	Grey seal	09-01-2021 15:59	27-06-2021 06:23	2321	2310	100	11	0	0	0	3407	98,639	47	1,36	0	0
208809	TIHO	Grey seal	24-01-2021 09:55	31-05-2021 09:34	3006	3002	100	4	0	0	0	2991	98,098	58	1,9	0	0
208810	TIHO	Grey seal	09-01-2021 10:05	28-06-2021 14:46	2553	2541	100	12	0	0	0	4027	98,556	59	1,44	0	0
208811	TIHO	Grey seal	09-01-2021 10:59	27-05-2021 12:02	2716	2685	99	31	1	0	0	3136	94,6	179	5,4	0	0
208812	TIHO	Grey seal	09-01-2021 11:49	09-07-2021 09:29	4557	4524	99	33	1	0	0	4231	97,421	112	2,58	0	0
208813	TIHO	Grey seal	09-01-2021 16:00	02-03-2021 12:19	1207	1204	100	3	0	0	0	1217	97,673	29	2,33	0	0
208815	TIHO	Grey seal	09-01-2021 17:41	17-07-2021 02:23	2446	2432	99	14	1	0	0	4258	98,633	59	1,37	0	0
208816	TIHO	Grey seal	09-01-2021 17:52	16-05-2021 21:54	2708	2705	100	3	0	0	0	2932	98,754	37	1,25	0	0
227525	TIHO	Grey seal	11-01-2022 11:54	03-04-2022 20:25	2071	2043	99	2	0	0	0	1941	98,129	11	0,56	26	1,314
227526	TIHO	Grey seal	11-01-2022 09:29	28-02-2022 11:14	1345	1341	100	4	0	0	0	1152	99,74	3	0,26	0	0
227527	TIHO	Grey seal	11-01-2022 10:16	16-05-2022 19:26	2323	2317	100	6	0	0	0	2963	98,406	48	1,59	0	0
227528	TIHO	Grey seal	16-01-2022 07:05	01-03-2022 21:04	894	891	100	3	0	0	0	972	90,756	99	9,24	0	0
227529	TIHO	Grey seal	11-01-2022 10:58	05-03-2022 17:42	1384	1368	99	16	1	0	0	1257	98,203	23	1,8	0	0
227531	TIHO	Grey seal	17-01-2022 11:33	28-02-2022 21:00	683	680	100	3	0	0	0	998	97,939	21	2,06	0	0
227532	TIHO	Grey seal	11-01-2022 16:36	17-03-2022 07:00	1485	1479	100	6	0	0	0	1521	98,003	31	2	0	0
227533	TIHO	Grey seal	11-01-2022 18:15	13-06-2022 21:13	3420	3413	100	7	0	0	0	3542	98,883	40	1,12	0	0
227534	TIHO	Grey seal	17-01-2022 03:13	16-05-2022 04:09	3228	3223	100	5	0	0	0	2832	99,09	26	0,91	0	0
43643	TIHO	Grey seal	04-02-2018 15:29	06-05-2018 05:15	1956	1949	100	7	0	0	0	2156	99,126	19	0,87	0	0
43644	TIHO	Grey seal	08-01-2020 04:54	05-04-2021 11:12	3690	3278	89	412	11	0	0	9001	84,019	1712	16	0	0
43644a	TIHO	Grey seal	04-02-2018 08:59	18-06-2018 08:11	3197	3196	100	1	0	0	0	3203	99,565	14	0,44	0	0
43648	TIHO	Grey seal	04-02-2018 18:50	11-08-2018 04:19	3341	3321	99	20	1	0	0	4333	98,165	81	1,84	0	0
43652	TIHO	Grey seal	04-02-2018 18:42	17-08-2018 11:59	2432	2379	98	53	2	0	0	4505	98,47	70	1,53	0	0
43655	TIHO	Grey seal	04-02-2018 17:34	30-09-2018 08:29	3471	3455	100	16	0	0	0	5407	96,039	223	3,96	0	0
65935	TIHO	Grey seal	07-01-2020 11:12	19-08-2020 10:34	7917	7553	95	364	5	0	0	5155	95,445	246	4,55	0	0
65936	TIHO	Grey seal	09-01-2021 17:37	26-02-2021 15:51	628	611	97	17	3	0	0	1140	98,958	12	1,04	0	0
65937	TIHO	Grey seal	10-01-2019 17:26	04-03-2019 11:12	774	717	93	57	7	0	0	1210	95,501	57	4,5	0	0
65938	TIHO	Grey seal	07-01-2020 09:59	03-07-2020 10:45	3635	3347	92	273	8	0	0	4042	94,572	221	5,17	11	0,257
65940	TIHO	Grey seal	11-01-2019 11:10	05-03-2019 02:17	693	676	98	17	2	0	0	1241	98,103	24	1,9	0	0
65942	TIHO	Grey seal	07-01-2020 15:21	06-05-2020 20:08	1501	1436	96	65	4	0	0	2724	96,836	89	3,16	0	0
65946	TIHO	Grey seal	11-01-2019 16:51	16-09-2019 12:52	5959	5696	96	263	4	0	0	5743	96,521	207	3,48	0	0
65955	TIHO	Grey seal	10-01-2019 14:05	14-05-2019 10:19	1982	1909	96	73	4	0	0	2870	96,503	104	3,5	0	0
65962	TIHO	Grey seal	10-01-2019 20:39	30-06-2019 07:11	4232	4227	100	5	0	0	0	4066	99,365	26	0,64	0	0
Average					**2.641,2**	**2.585,0**	**98,1**	**54,9**	**1,8**	**0,0**	**0,0**	**3.138,8**	**97,2**	**123,0**	**2,8**	**1,1**	**0,05**
Sum					**87.160**	**85.306**		**1.813**		**0**		**103.582**		**4.059**		**37**	

5.2.3 Animal behaviour

The tortuosity of the seal tracks is a measure of how convoluted the tracks are and is frequently used as a measure of how seals use different regions. The more convoluted the tracks, the more likely it was that the seals were foraging at the time. Analyses suggest that the seals' foraging grounds are scattered all over the general area where the tagged seals were observed, and that grey seals occasionally travelled to foraging grounds located very far from where they were tagged (Figure 5. 4).

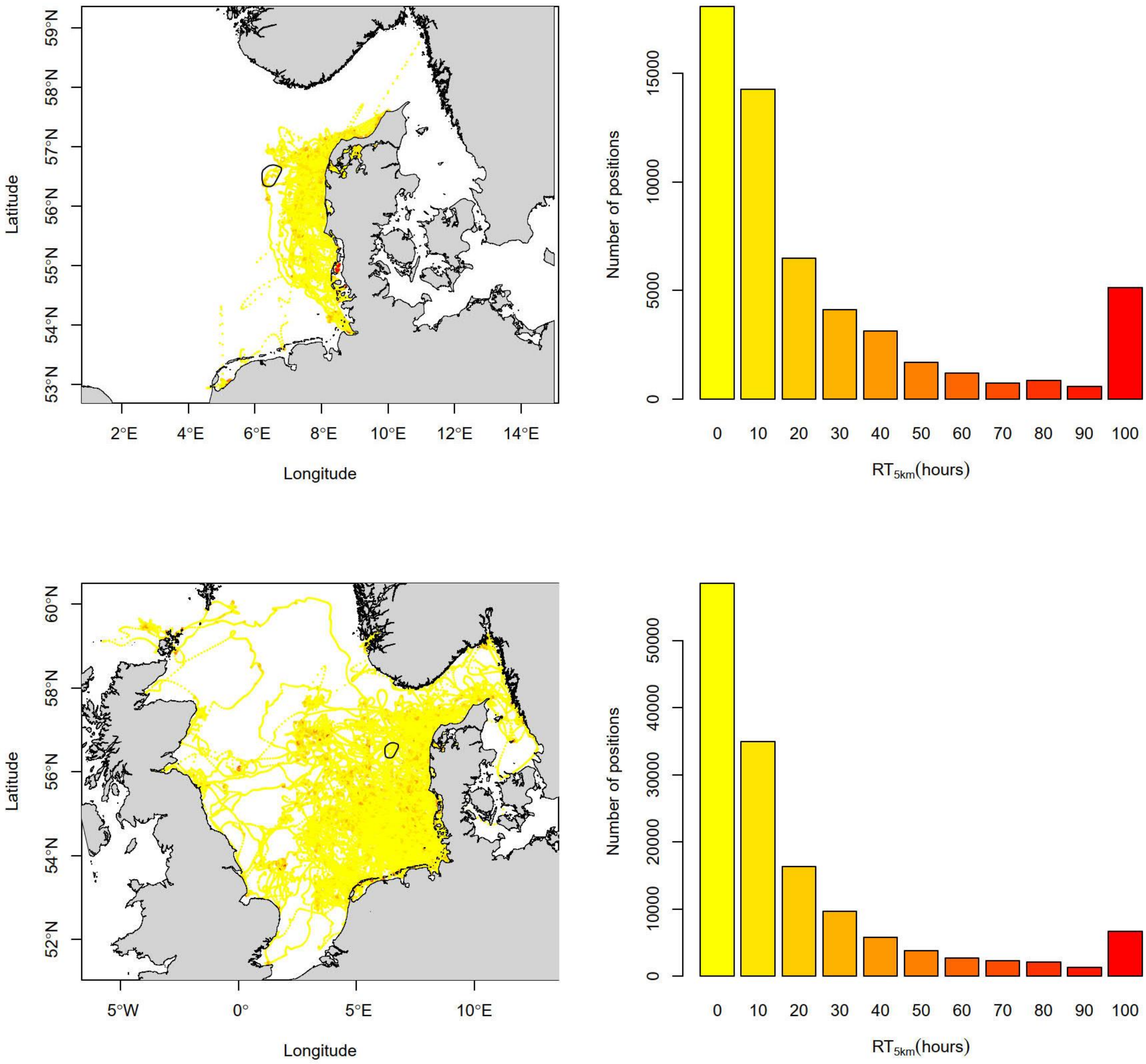

Figure 5. 4. Tortuosity analysis of harbour seal residence time (RT) for harbour seal (top) and grey seal (bottom). The colour scale represents time in hours spent in each part of the track and within 5 km off the track. The phase 1 area of the proposed plan for the program North Sea Energy Island is shown as a black circle in the North Sea. Notice that the scale of the y-axis differs between harbour and grey seals.

The time spent in the phase 1 area of the proposed plan for the program North Sea Energy Island was calculated. For the harbour seals tagged at Nissum Bredning/Thyborøn only two of the 27 seals passed through the phase 1 area of the proposed plan for the program North Sea Energy Island, and only 125 hours of the 63,378 predicted hourly positions were from this area (0.1%). This equalled five hours on average for the 27 seals (Table 4.2). For the grey seals tagged at Nissum Bredning/Thyborøn, five of the 16 seals passed through the phase 1 area, and 71 of the 49,023 hourly positions were from this area (0.2%). This was equivalent to four hours on average for the 16 grey seals (Table 4.2). Of the grey seals tagged at Helgoland, only two of the 33 seals spent time in the phase 1 area (37 of the 105,754 hourly positions; 0.04%). This is less than the percentual time used for the Nissum Bredning/Thyborøn seals with only one hour on average for the 33 grey seals from Helgoland (Table 4.2). Likewise, accumulated time per individual and time spent in the phase 1 area was also calculated (Figure 5. 5) and per month (Figure 5. 6). Winter months are under-represented for grey seals tagged at Nissum Bredning/Thyborøn, as most seals were captured in spring and summer. For grey seal pups captured at Helgoland in January-February, late fall is under-represented. It is evident from these figures that the phase 1 area was used little by the tagged seals.

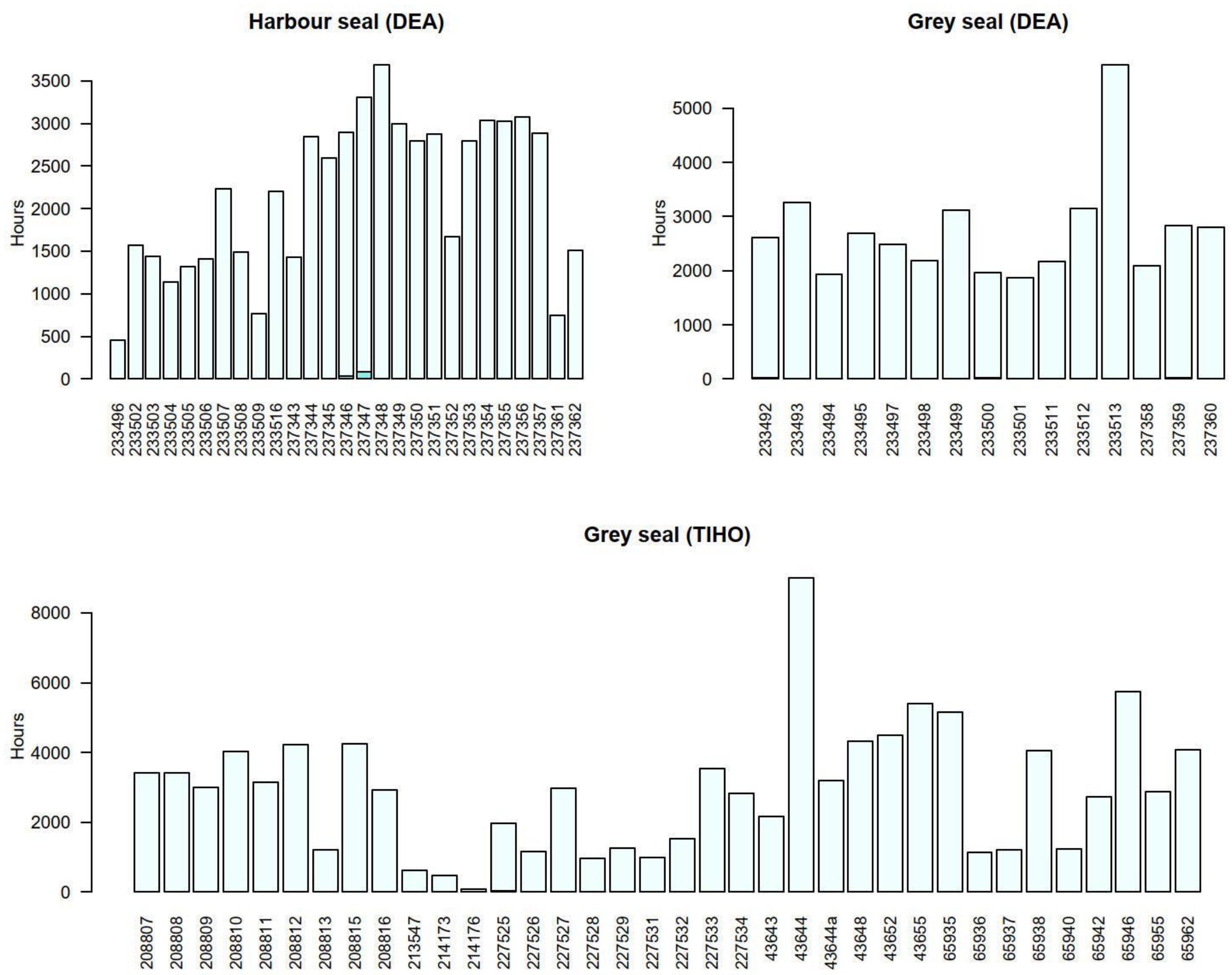

Figure 5. 5. Accumulated time with data per individual. Time spent in the phase 1 area of the proposed plan for the program North Sea Energy Island is shown in turquoise. DEA is data from this project owned by Danish Energy Agency and TIHO is data bought from Stiftung Tierärztliche Hochschule Hannover, for this project. Notice that the scale of the Y-axis differs.

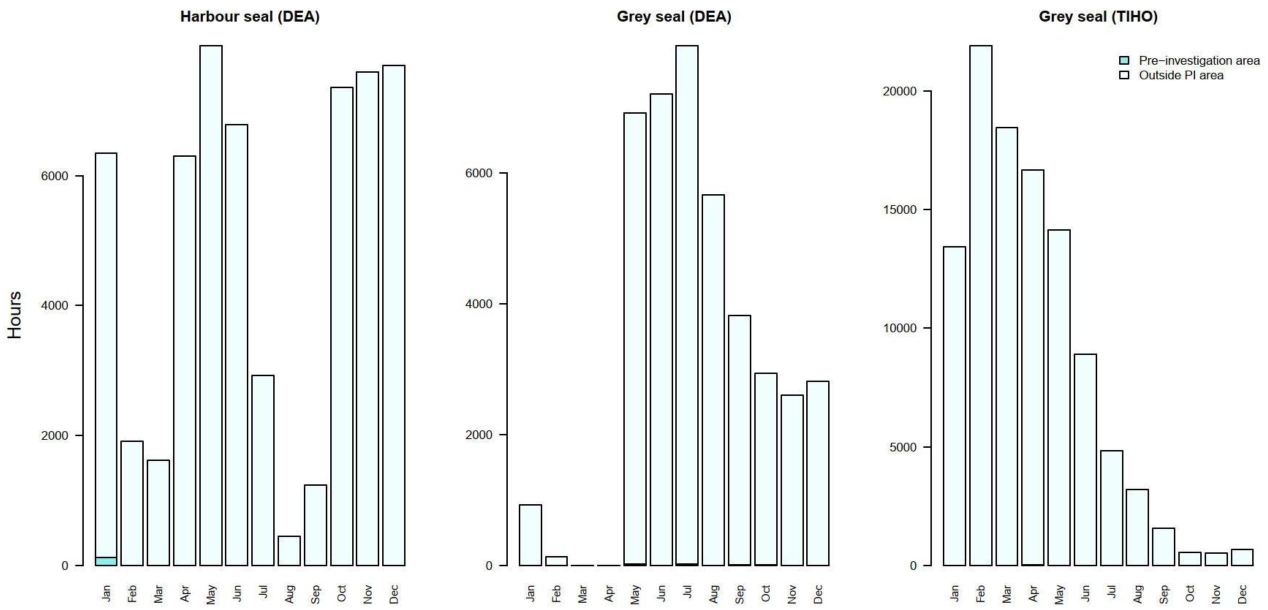

Figure 5. 6. Accumulated time per month for all tagged individuals. Time spent in the phase 1 area of the proposed plan for the program North Sea Energy Island per month is shown in turquoise. Be aware that some months are under-represented as most animals were captured and tagged in spring, summer and autumn, whereas animals from Helgoland (TIHO) were all tagged in winter (January and February). Data from TIHO was bought for this project. DEA is data from this project owned by Danish Energy Agency.

5.2.4 Habitat suitability modelling

We only tagged a tiny fraction of the entire population. Thus, to model how other, non-tagged animals might use the North Sea, a habitat suitability model was built based on the tag data for harbour seals and grey seals, including multiple environmental variables. The models were based on hourly predictions from the state-space models, using distance to the tagging site (Thyborøn or Helgoland) as covariate. Subsequently one habitat suitability map was produced per species, assuming that animals were as likely to stay in the vicinity of known haul-out sites as the tagged seals were to stay in the vicinity of the tagging sites (Figure 5. 7 and Figure 5. 8). One prediction was generated for each haul-out site, and subsequently the predictions were weighted by the number of seals observed on each of these. The number of seals on the different haul-out sites was obtained from aerial surveys during the moulting season of 2021, i.e. in August for harbour seal and in the period March–April for grey seal. However, grey seals were not counted regularly in the moulting season at the time, so there were no grey seals to include in 2021. Therefore, the habitat suitability map was not based on a prediction for this site (i.e. the weight for this haul-out site) was zero, which is a known underestimate as we return to in the discussion.

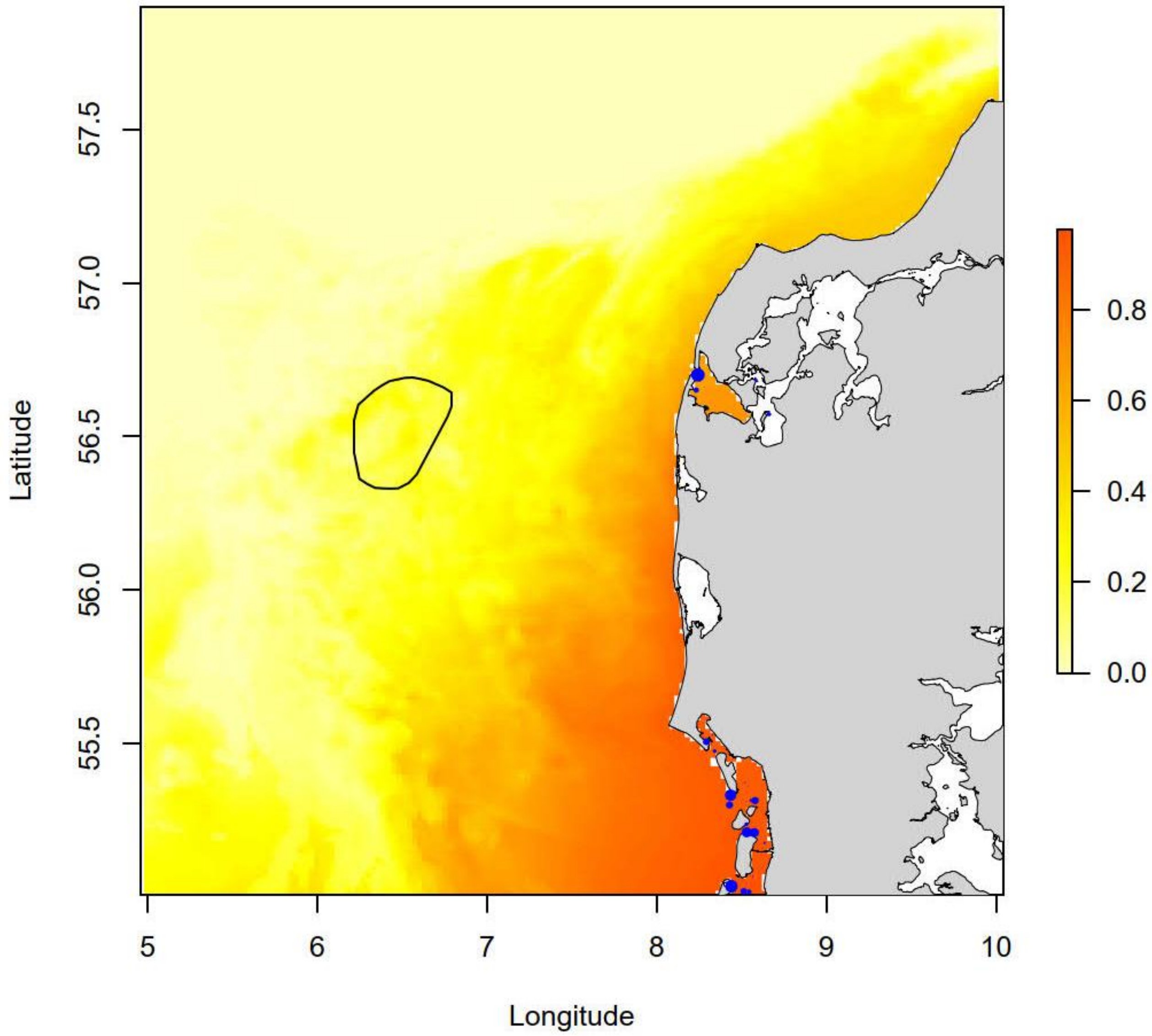

Figure 5. 7. Habitat suitability model for harbour seals. Blue dots are haul-out areas with seals counted in the moulting season – August 2021; the size of the dots is proportional to the number of seals. The colour scale signifies the relative probability that an area is used by seals with red-orange being high and white/yellow being low. Note that the colour scales for the two seal species cannot be compared directly. The black circle signifies the phase 1 area of the proposed plan for the program North Sea Energy Island. The colour scale is different between the two maps.

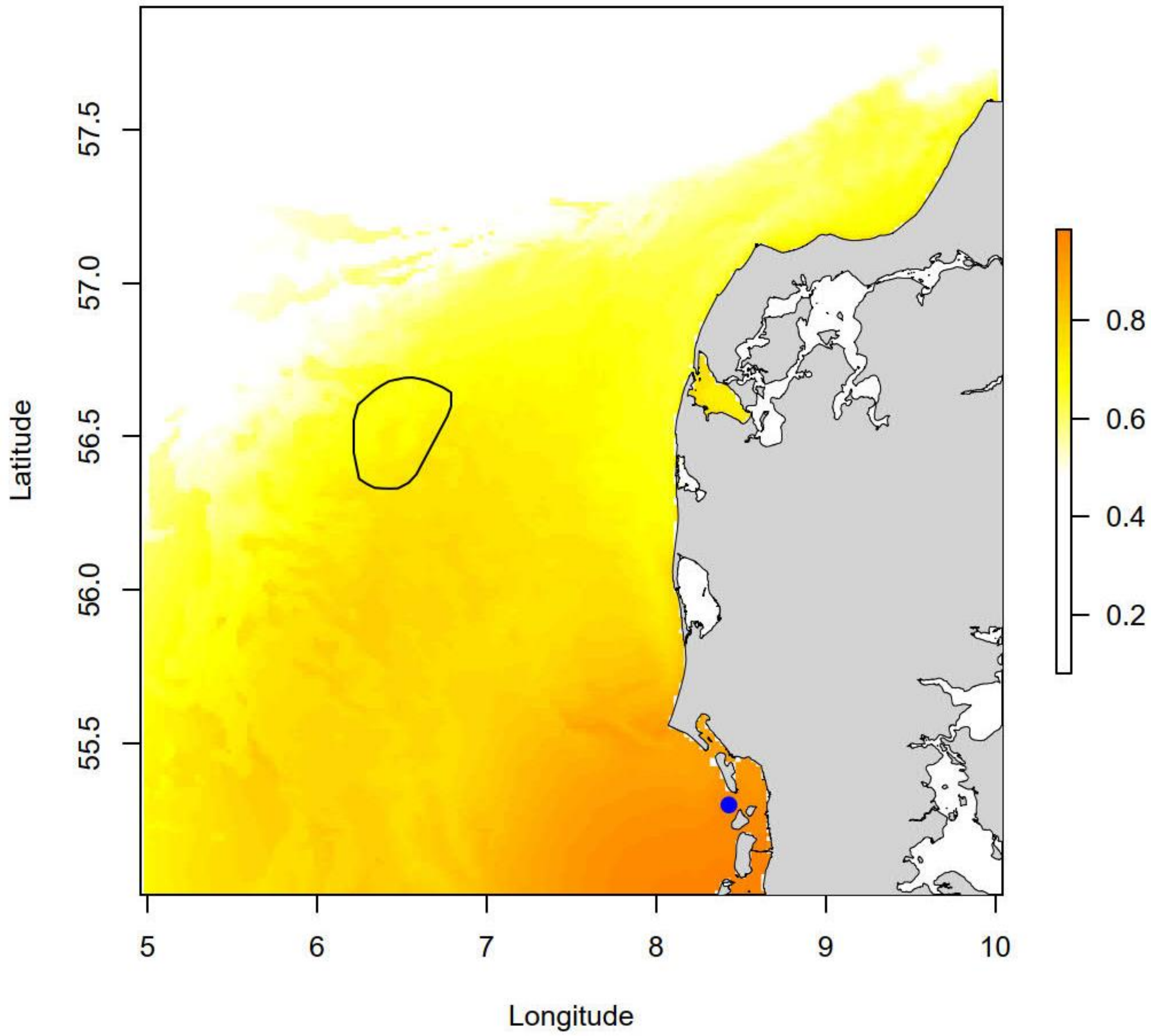

Figure 5. 8. Habitat suitability model for grey seals. The blue dot is the haul-out area (there are additional haul-out sites south of the shown area) with grey seals counted in the moulting season of 2021, i.e., March–April. No seals were counted at Thyborøn that year. The colour scale signifies the relative probability that an area is used by seals with red-orange being high and white/yellow being low. Note that the colour scales for the two seal species cannot be compared directly. The black circle signifies the Phase 1 area of the proposed plan for the program North Sea Energy Island.

The habitat suitability modelling indicated that a model including all covariates was superior to models were one or more predictors were omitted (ΔAICc=38 for grey seal; see Table 5. 5). Both species were predominately found on shallow water close to the tagging sites (Figure 5. 9 and Figure 5. 10). Distance to haul-out and water depth are naturally correlated as the haul-out are on sandbanks in Denmark. The correlation among all variables are shown in Table 5. 5 and Figure 5. 9. The average residence times for the two seal species in the phase 1 area of the proposed plan for the program North Sea Energy Island is shown in Table 5. 4. Harbour seals spent a mean of 5.7 or 41.0 hours in the phase 1 area if a radius of respectively 1 km or 5 km from the track line was used. Grey seals spent a mean of 4.2 or 26.1 hours in the phase 1 area if a radius of respectively 1 km or 5 km from the track line was used. It is evident from the graphs that areas as distant as the phase 1 area of the proposed plan for the program North Sea Energy Island is used less by both harbour and grey seals than the more shallow areas closer to land and the haul-out sites.

Table 5. 4. Statistical measures for seals that spent time in the phase 1 area of the proposed plan for the program North Sea Energy Island. Based on analysis of convolution, where a radius of 5 km from the tracks where used.

Species	Radius from track, m.	median	mean	Std
Grey seal	5000	13.0	26.1	39.6
Harbour seal	5000	16.4	41.0	78.8

Table 5. 5. Predictive values used to find the model with the lowest AICc, here, model 1. Top grey seals and bottom harbour seals.

Species	Model #	Dist. home	Dist. home x depth	Mixed layer	Current	Sea surf. hgt.	Salinity	Temperature	Depth	Substrate	df	logLik	AICc	delta AIC	weight	R^2	delta R^2
Grey seal	1	+	+	+	+	+	+	+	+	+	56	-62085	124284	0	1.00	0.48	-
	2	+	+	+	+	NA	+	+	+	+	52	-62108	124322	38	0.00	0.48	0.00
	3	+	+	+	NA	+	+	+	+	+	52	-62159	124422	138	0.00	0.48	0.00
	4	+	+	+	+	+	+	+	NA	+	53	-62169	124446	162	0.00	0.48	0.00
	6	+	+	+	+	+	NA	+	+	+	52	-62181	124468	184	0.00	0.48	0.00
	9	NA	+	+	+	+	+	+	+	+	50	-62210	124522	238	0.00	0.48	0.00
	15	+	+	+	+	+	+	+	+	NA	53	-62238	124583	299	0.00	0.48	0.00
	65	+	+	+	+	+	+	NA	+	+	52	-62634	125374	1090	0.00	0.48	0.00
	68	+	+	NA	+	+	+	+	+	+	53	-62693	125494	1210	0.00	0.48	0.00
	230	+	NA	+	+	+	+	+	+	+	30	-63862	127786	3502	0.00	0.47	0.01
Harbour seal	1	+	+	+	+	+	+	+	NA	+	51	-13761	27625	0		0.66	
	2	+	+	+	+	+	+	+	+	+	48	-13772	27640	14	0.00	0.66	0.00
	4	+	+	+	+	NA	+	+	+	+	44	-13785	27659	33	0.00	0.66	0.00
	6	+	+	+	NA	+	+	+	+	+	46	-13793	27679	54	0.00	0.66	0.00
	11	NA	+	+	+	+	+	+	+	+	47	-13803	27702	77	0.00	0.66	0.00
	16	+	+	+	+	+	+	+	+	NA	45	-13820	27730	104	0.00	0.66	0.00
	34	+	+	+	+	+	NA	+	+	+	46	-13943	27979	354	0.00	0.66	0.00
	38	+	+	NA	+	+	+	+	+	+	41	-13967	28016	391	0.00	0.66	0.00
	129	+	NA	+	+	+	+	+	+	+	29	-14340	28738	1113	0.00	0.66	0.00
	141	+	+	+	+	+	+	NA	+	+	39	-14479	29039	1413	0.00	0.66	0.00

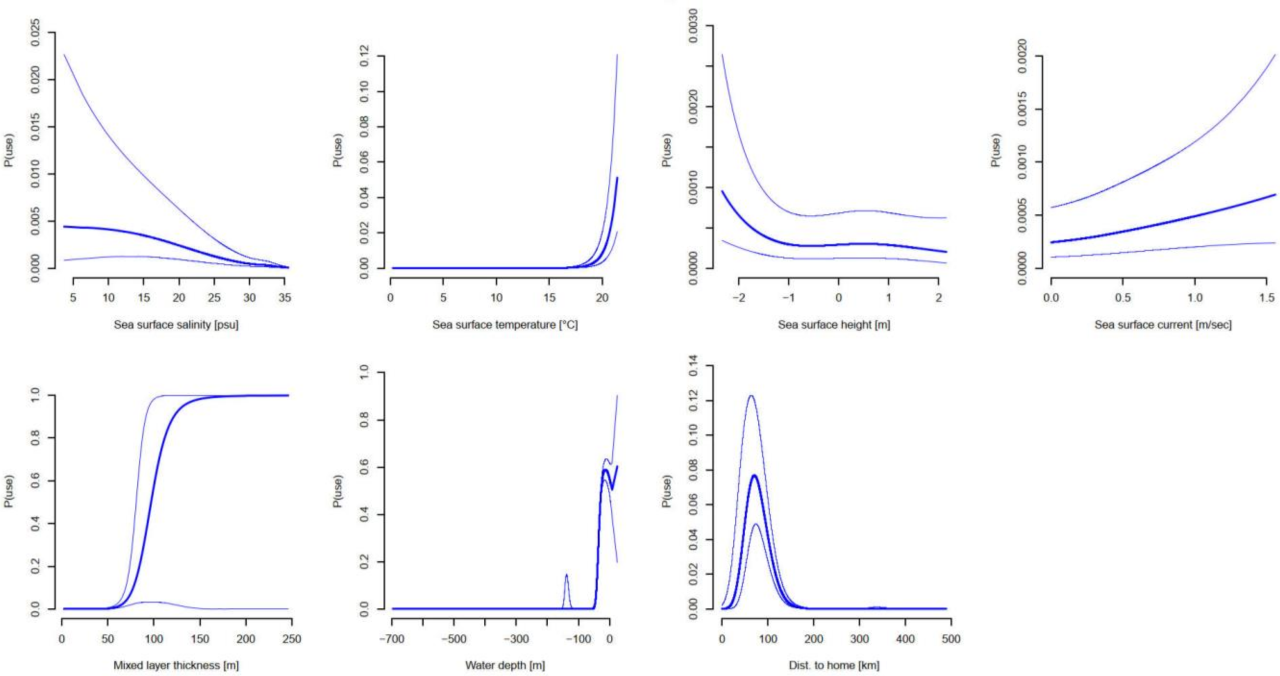

Figure 5. 9. Relative probability of occurrence in the habitat suitability model for harbour seals tagged at Thyborøn.

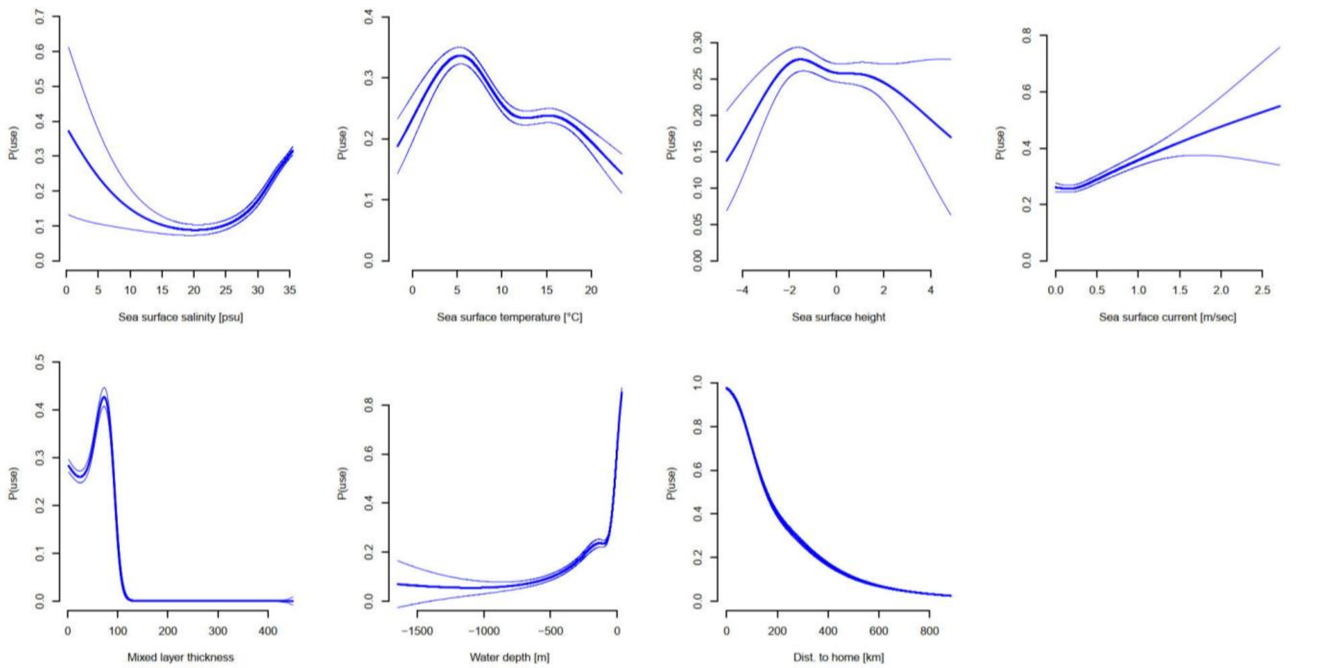

Figure 5. 10. Relative probability of occurrence in the habitat suitability model for grey seals tagged at Thyborøn.

6. Discussion

The study is based on tracks from 75 tagged harbour and grey seals, analysed using a combination of different methods to understand the use of the phase 1 area of the proposed plan for the program North Sea Energy Island for harbour and grey seals. The data were also used to build habitat suitability models that could be extended to cover most of the Danish North Sea. The different analyses were carried out to answer three different questions: 1) How much time did the animals spend in the phase 1 area? 2) What did they do in the area? And 3) Is the phase 1 area used more by these species than other parts of the eastern North Sea? The discussion is structured to reflect answers to these questions.

6.1 Time spent in the area

Technical issues resulted in many of the tagged seals having periods without any positions received. Hence, we used a method called a state-space model to model the empty periods. This was done to be able to calculate time use in the phase 1 area of the proposed plan for the program North Sea Energy Island. The modelled tracks looked convincing for the purpose of calculating time use in the area. Judged by the state-space model tracks, the seals spent overall little time in the phase 1 area. On average harbour seals spent 0,1 % of their time in the phase 1 area (up to 87 hours for one individual) and grey seals spent 0,2 % of their time (up to 23 hours) (tagged at Thyborøn) and 0,05% of their time (up 26 hours) (tagged at Helgoland). However, if this little time inside the area is spent foraging, it may still be of use to the seals, thus we also conducted behavioural analyses.

The analysis of tortuosity of the seal tracks provides indications on the behavioural state of the animals when at sea. Animals generally use more convoluted movements and spend longer time at a specific site when foraging than when traveling. The convolution of the tracks indicates that some seals did forage in the phase 1 area of the proposed plan for the program North Sea Energy Island. This is also visible in Figure 5. 4, where some of the tagged harbour seals – based on the convolution – foraged in the phase 1 area. However, the harbour seals generally spent more time closer to shore which is also an apparent output of the habitat suitability model (see Figure 5. 7). The Thyborøn/Nissum Bredning site, where many of the grey seals were tagged, did not have any grey seals during the counts at the haul-outs in the moulting season of 2021, which was the year included in the model. Therefore, this resulted in a slightly lower predicted suitability of the northern part of the mapped region than would have been the case if seals had been counted on haul-out sites near Thyborøn (see Figure 5. 7).

Monitoring data show that there is very little harbour seal breeding activity in the western Limfjord, most likely due to the sand banks being flooded during high tide, and in this context, harbour seals here may be seen as 'visitors', having their key life cycle events in other areas, such as the inner Limfjord and the Wadden Sea. In addition, aerial surveys reveal that there are more harbour seals in the Wadden Sea as well as in the Inner Limfjord. For grey seals, both animals tagged at Helgoland and animals tagged at Thyborøn used the phase 1 area of the proposed plan for the program North Sea Energy Island, but the area appeared less used for foraging than it did for harbour seals (see Figure 5. 4). The habitat suitability model for grey seals showed that depth seemed to be the primary driver of where they spent time. The Norwegian trench seemed to mark a barrier for most of the grey seals, which appeared rather different for harbour seals in the habitat suitability model. Overall, the habitat suitability modelling showed that the phase 1 area is suitable habitat for both harbour and grey seals.

6.2 Area use

Our analyses of seal tracks indicated that most seals spent a large part of their time in areas close to the haul-out sites where they were tagged or other haul-out sites they visited, and that some of them occasionally passed through the phase 1 area of the proposed plan for the program North Sea Energy Island. The phase 1 area is used by at least some harbour seals for foraging, but the area does not appear to stand out as a highly used area as compared to the rest of the map (see Figure 5. 7), neither when viewing the individual tracks, their convolution as a measure of foraging activity, nor the final habitat suitability model predictions. The habitat suitability model for grey seals predicted the phase 1 area to be of medium to high use as compared to the rest of the map and for harbour seals to be of low to medium use. The habitat suitability models provide a possible picture of how it could have looked, had the entire Danish population been tagged, not just our sample of 45 animals. However, if for example grey seals from Norway had been included, the habitat suitability model, the results would likely have looked different, as the environmental parameters near Norwegian haul-outs are very different from the Danish haul-out sites. It is possible that grey seals from Norway and UK use the North Sea Energy Island pre-investigation area.

6.3 Assumptions

Habitat suitability modelling builds on the assumption that if animals are observed occurring under particular environmental conditions, they are likely found under similar environmental conditions in parts of the seascape where no animals have been tagged. The models developed here are based on all the environmental variables that other studies have demonstrated to influence the distribution of seals (see references in appendix of Carter et al. 2022, if needed), yet they are in reality only proxies for the environmental conditions that drive foraging choices in seals in nature. In reality seals have access to fine-scale information about the distribution of ocean frontal systems, changes in local currents etc. that are directly linked to the distribution of their prey. This clearly limits the accuracy of the prediction maps, and can potentially be important when using the model to make predictions for areas far from any place where seals are observed.

The models are also limited in their predictive capacity by the availability of haul-out data. If no seals are observed on particular haul-out sites, this can lead to an under-estimation of the seal densities in the areas surrounding those haul-out sites. This is potentially the case for grey seals in the neighbourhood of Thyborøn (Figure 4.8). Further, the predictions may underestimate the true habitat suitability of the regions closest to the Netherlands and United Kingdom, as data on haul-out sites could not be obtained.

The sex ratio of the tagged seals is skewed with only 3 female grey seals and 4 female harbour seals tagged in Thyborøn, compared to 12 grey and 23 harbour seal males. TIHO tagged an equal number of males and females because they have tagged weaned pups where it is possible to specifically select an equal sex distribution for tagging. The tracks of seals from the tagging program in this project may therefore by skewed by sex and the results therefore pertain mainly to males. TIHO only tagged juvenile grey seals less than a month of age, and their results therefore pertain to naïve juvenile grey seal pups, adapting to the marine environment and developing their foraging skills. We tagged primarily adult harbour seals and an equal distribution of adult and juvenile grey seals. TIHO tagged juvenile grey seals in January-February, whereas we tagged adult harbour seals and mixed age grey seals in March, May and September. This means that we have data from across the year, however, not equally for the different age classes. Although this study does not represent an equal sex and age ratio, the number of tagged seals is high compared to other studies and we feel confident that the results represent the general behavioural patterns for both species.

We used haul-out counts from the western Limfjord and the Wadden Sea to estimate the use of these waters to seals of both species and include this information in the habitat suitability. The counts we used were obtained during the respective moulting season of harbour seals and grey seals in 2021. For the western Limfjord haul-outs at Thyborøn, there are no regular surveys during the grey seal moulting season. As a consequence, there was no data points to include in the prediction. This is an underestimate, as we encounter more grey seals during surveys at other times of the year (up to 61) as well as during our tagging expeditions. This means that we have likely underestimated the suitability of the area in the vicinity of the Thyborøn haul-outs with respect to grey seals.

6.4 Tagging attempts of cetaceans

Capturing elusive animals such as cetaceans that are very briefly at the surface is highly weather dependant and requires very calm winds and flat water. Summer 2022 was especially windy and despite having ten experienced and specifically trained persons standby and ready to go in the field, as well as dedicated people watching the weather forecasts intensively, we only had very few days in the course of the three months stand-by period where search and capture attempts were possible. In fact only three days had optimal conditions. The tagging program would have benefitted from several seasons, which is normal with this type field work. Additionally, the HSE requirements for how far offshore we were allowed to go, prevented search for white-beaked dolphins in the offshore areas that they were observed during service trips to the North Sea Energy Island pre-investigation area. This was wise HSE requirements, but not optimal in terms of finding white-beaked dolphins. A better approach would be to have a large vessel offshore for several weeks with the required tagging staff onboard, but that was not feasible in this set-up.

7. Conclusions on use of the area

7.1 Harbour and grey seals

Overall, the movement data of the tagged harbour seals (n=27) and grey seals (n=15) from Nissum Bredning/Thyborøn, as well as the grey seals from Helgoland (n=33), showed that the phase 1 area of the proposed plan for the program North Sea Energy Island was used little by the tagged seals, making up an average of 0.1% of the time use for harbour seals and an average of 0.2% and 0.05% for grey seals from Nissum Bredning/Thyborøn and Helgoland, respectively. The habitat suitability model predicted the area to be of medium to high suitability for grey seals and low to medium suitability for harbour seals. The analyses of track convolutedness did not indicate that seals foraged more in the phase 1 area than elsewhere.

7.2 Cetaceans

The cetacean program consisted of three work packages; active catch of harbour porpoises, active catch of white-beaked dolphins and darting satellite transmitters into killer whales and minke whales.

The summer 2022 was very windy and therefore limited the time at sea with suitable weather conditions for tagging. There were only three ideal days and seven less than ideal days on the water out of the three entire months for which we had a full field crew on standby and working on-off in the field.

We did not observe other relevant cetacean species during the porpoise catch trials. We spoke with tour operators, working on a daily basis at Gule and Store Rev, and they had not seen any cetaceans, except porpoises, throughout the summer of 2022. Killer whale sightings are likely to be shared immediately on Facebook via the platform Hvaler.dk, but none were observed in the summer of 2022 near the Westcoast of Jutland.

During this tagging program, we did not succeed in tagging harbour porpoise in the relevant area close to the North Sea Energy Island pre-investigation area. The nearest tagging site to the North Sea Energy Island pre-investigation area is at Skagen, and data from Skagen are relatively old. Few of these animals have moved into the North Sea Energy Island pre-investigation area, but as the tagging site is far away, harbour porpoises tagged at Skagen is not likely to represent the actual use of the pre-investigation area, and it is therefore not possible to evaluate on the use of the area in terms of whether the area is used as a migration corridor or not. The North Sea Energy Island passive acoustic monitoring program from November 2021 – November 2023 showed that the pre-investigation area is used on a daily basis by harbour porpoises year round and at high levels, particularly in summer. Aerial surveys conducted in July 2022 and 2023 also found a high density of harbour porpoises in the North Sea Energy Island pre-investigation area with a high percentage of calves. In 2023, the entire Danish part of the North Sea was monitored by aerial surveys and the results indicated that the North Sea Energy Island pre-investigation area is part of a larger area with a high density of harbour porpoises during summer. There is a high level of harbour porpoises in summer with a high percentage of mother-calf pairs, as observed during aerial surveys in the pre-investigation area during the breeding period in 2022 and 2023 (please see the North Sea Energy Island technical report for marine mammals). Since harbour porpoises has a high metabolic rate and must forage continuously, especially when they are nursing calves, it means that the pre-investigation area must hold adequate amount of prey (please see the technical report WP-I Fish and Fish Populations), and that the area hence must be used for foraging.

Similarly, during this tagging program, we did not succeed in tagging white-beaked dolphins in/near the North Sea Energy Island pre-investigation area, and we can therefore not conclude on the use of the area as a migration corridor. The North Sea Energy Island passive acoustic monitoring program showed that white-beaked dolphins were present in the pre-investigation area 5-50% of the days year round. White-beaked dolphins with calves were observed during the aerial surveys in the pre-investigation area, and white-beaked dolphins were observed on almost all service trips to the PAM stations in the pre-investigation area.

8. Acknowledgements

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