Final Report

FEHMARNBELT FIXED LINK
MARINE MAMMALS (FEMM)

Marine Mammal Studies - Baseline

Baseline Investigations and Evaluations

E5TR0014 / rev. 5.0

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Executive summary

As part of the EIA for the Fehmarnbelt Fixed Link, Femern A/S has commissioned the Fehmarnbelt Marine Mammals (FEMM) consortium to conduct baseline studies on marine mammals. This report presents results from baseline investigations providing information on the spatial and temporal use of the Fehmarnbelt area and adjacent waters by marine mammals. In the Fehmarnbelt area three species of marine mammals occur regularly: the harbour porpoise, *Phocoena phocoena*, a small cetacean which is widely distributed in the western Baltic Sea and the North Sea; the harbour seal, *Phoca vitulina,* with a haul-out site in the adjacent Rødsand lagoon which holds a substantial proportion of the small subpopulation in the western Baltic Sea, and the grey seal, *Halichoerus grypus,* which occurs in low but growing numbers in the Rødsand lagoon. In the area, three SACs have been declared and included into the Natura 2000 network to protect these animals.

In late 2008 FEMM started extensive and state-of-the-art baseline investigations on harbour porpoises, harbour seals and grey seals, lasting until January 2011. The studies include visual and acoustic surveys for mapping distribution and estimating abundance. Further studies on movements and behaviour were conducted using telemetry techniques. In this report, we present the analysis and assessments of the data covering both years of investigation.

i. Harbour porpoise general occurrence

Historical data indicate that the Fehmarnbelt area is regularly populated by porpoises with densities reaching up to 0.5 animals/km^2. Very preliminary investigations indicate a seasonal pattern with highest numbers during the summer months; however, there are uncertainties remaining about the seasonal occurrence of porpoises in the area (see for example Scheidat et al., 2008). Analysis of telemetry data suggest that the animals occurring in the Fehmarnbelt area belong to a population in the Inner Danish waters which is separate from the one in the Skagerrak. Recent genetic studies indicate that both groups represent different sub-populations, which are to some extent, also different from animals living in the Inner Baltic (Wiemann et al., 2010).

ii. Harbour porpoise visual surveys

Harbour porpoises have been counted from aerial transect surveys between November 2008 and November 2010 at monthly intervals in a 4,800 km^2 study area. Surveys were conducted at 600 ft altitude for mammals only, or at 250 ft altitude for combined mammal and bird surveys. Densities have been calculated applying Distance-Sampling methodology (Buckland et al., 2001). The results show a marked seasonal pattern with lowest numbers during the winter months and higher numbers from spring to autumn. Highest densities in 2009 were recorded in April with 0.59 porpoises/km^2, however, numbers in summer and autumn were lower. In 2010, highest densities reached 0.94 porpoises/km^2 in May with numbers in summer 2010 generally higher than compared to 2009.

For the surveys when calves were observed, calves made up 13.04% of all observed individuals (18 calves from 122 individuals) in 2009 but only 5.5% in 2010.

Aerial survey data were analysed and porpoise distributions were modelled in relation to several environmental parameters. In the modelling, the variables *position, water depth, sea temperature at depth and the strength of the east-west current component at depth* best described the dataset. The model-based estimates also compared well with the design-based results (for details on distance sampling methodology and design, see Buckland et al., 2001).

Model-based abundance estimates obtained the following pooled estimates for the months March – August and winter:

Table 2.1-1 Abundance estimates of harbour porpoise for the spatial and temporal ranges of interest, percentage CVs and 95% 'percentile' confidence interval (CI)

Year	Season	Abundance	%CV	95% CI
2009	Summer	1456	19.0	782 – 1631
	Winter	921	31.1	436 – 1467
2010	Summer	2078	17.8	1414 – 2709
	Winter	931	31.9	521 - 1800

The model-based abundance estimates presented for harbour porpoises during the winter in 2009 and 2010 in Fehmarnbelt were statistically the same, however, there was a greater difference between the summer estimates.

Monthly visual surveys from the ferries operating between Rødby, Denmark and Puttgarden, Germany provide evidence of year-round use of the alignment area by harbour porpoise. The seasonal pattern was less apparent as in the visual surveys and sighting rates remained at more or less constant levels until mid winter. The highest numbers were counted in spring / early summer and late autumn to winter. Some outliers with high sighting rates point towards a possible seasonal movement of porpoises through the Fehmarnbelt.

iii. Harbour porpoise passive acoustic monitoring

Porpoise activity was monitored using passive acoustic monitoring with autonomous porpoise click detectors (C-PODs). C-PODs were deployed at 27 locations in the wider Fehmarnbelt area in order to obtain maximum spatial resolution along with the very high temporal quality of the acoustic monitoring. We found an almost constant presence of harbour porpoises in the Fehmarnbelt area over the whole study period (Jan 2009 – January 2011). A general west-east gradient with more recordings in the northwest and fewest recordings in the southeast is in line with former studies on the distribution of harbour porpoises in the western Baltic Sea. Only in the eastern part and at some stations in the area around the planned link, a weak seasonal pattern with peaks in spring and late autumn/early winter could be seen. This pattern is very similar to the seasonal pattern of porpoise detections derived by PAM studies in the eastern part of the German Baltic. At most stations, in particular in the western part of the study area, no clear seasonal trend was recognisable in the POD data, at least at the daily scale being investigated in this study. Next to a high temporal oscillation in the POD data a pronounced spatial variation with high variability between single stations could also be detected. The high fluctuation of detected click activity at different times and stations might indicate more pronounced individual movements of porpoises across the study area. Several recent studies have shown that individual migration plays an important role in the annual life cycle of the harbour porpoise in the Fehmarnbelt area (Teilmann et al., 2008; Sveegard et al., 2011). From both, the high temporal and high spatial variability it can be assumed that localised movements in response to small scaled ecological drivers may play an important role in the annual life cycle of the harbour porpoise in the study region.

The modelling of C-POD data provided details on such effects as it could prove a weak to moderate effect of fine-scale hydrodynamic covariates, which are closely connected to inflow/outflow dynamics. Compared to static covariates describing the geo-location of the specific POD-station, the effects of hydrodynamic covariates were rather small, which in turn shows that they do not act as key factors governing the detection possibility of harbour porpoises in the Fehmarnbelt area. The strongest hydrographic variable was water temperature, which is not, or only weakly, affected by the flow regime in the belt area. Porpoise acoustic activity decreased abruptly when temperature dropped below 4°C. This can be interpreted as porpoises avoiding ice cover and are therefore likely to retreat from areas before ice coverage starts.

Further static variables, which were important in the final model, were latitude, longitude, and distance to main shipping lane, substrate and water depth. The power of these variables, which all describe station specific features, indicate that the distribution of harbour porpoises in the Fehmarnbelt is influenced, either primarily or secondarily, by the location specific environmental conditions.

iv. Harbour porpoise satellite telemetry

Movements of harbour porpoises in the study area have been investigated in the Baltic Sea by means of satellite telemetry for more than a decade (Sveegard, 2011). As part of the Fehmarnbelt Marine Mammal studies, available data from ongoing studies by the National Environmental Research Institute (NERI) were analysed, with additional porpoises equipped with transmitters as part of the FEMM baseline study. In total, data from 82 animals tagged between 1997 and 2010 could be analysed. The aim of the analysis was to describe the function of the Fehmarnbelt area and habitat choice in the annual cycle of harbour porpoises, especially in relation to large-scale movements of the animals which can only be detected by telemetry. In addition, possible responses of porpoises to existing bridges in the western Baltic Sea were investigated.

The analysis provides evidence that the harbour porpoises of the Fehmarnbelt area are part of the subpopulation of the Belt Sea which separated from the more northern Skagerrak subpopulation. A substantial number of the animals tagged in the Belt Sea, however, migrated to the Skagerrak in the winter months. Seasonal movements, as indicated by data from animals tagged for a longer period of at least three seasons, were very pronounced and indicated that a substantial part of the population seasonally migrates between the Skagerrak and the Belt Sea, including Fehmarnbelt and the areas to the east of Fehmarn. Daily movements of tagged animals were considerably larger in winter than compared to the rest of the year. The analysis further indicated – and is also supported by the results from previous investigations (See Sveegard et al., 2010) - that porpoises are not evenly distributed over the Baltic Sea but show preferences for certain areas. On a large scale, occurrence in straits, e.g. narrow waterways, is relatively high. It is likely, that hydrographic features such as increased currents and turbulence, which in turn could affect fish movements, are driving this higher occurrence in narrow straits. On the more local scale of the Fehmarnbelt, areas of strong current gradients and westward moving surface water current appeared to increase the probability of a harbour porpoise occurring. Eddy activity at depth (vorticity) was also a predictor of harbour porpoise locations. However, model predictions could only provide first indications on the behaviour of porpoises near bridges. Based on the analysis of tracks and the studies undertaken by others we conclude that although porpoises tend to cross areas with bridges less often than areas without bridges, no apparent avoidance behaviour was observed. Thus, it could be possible that the movement patterns of porpoises are not affected much by bridges. The results on the movements of porpoises in the vicinity of bridges will be discussed more comprehensively in the Great Belt study were the behaviour of porpoises at an existing bridge was investigated in more detail.

v. Harbour porpoise baseline pressure analysis

Analysis of the available literature identified a variety of anthropogenic pressures acting on harbour porpoises in the Baltic Sea and the Fehmarnbelt, for example fisheries, shipping and tourism. It can be assumed that porpoises in the Baltic Sea are affected by human activities and the overall Baltic population is probably well below carrying capacity. Harbour porpoises are exposed to underwater noise levels that are likely to affect their behaviour in the Fehmarnbelt area, but specific effects at population level are still unknown. Further analysis of potential pressures from underwater sound and relations to shipping intensity will be conducted as part of the Impact Assessment.

i. Harbour porpoise pressure from existing bridges and tunnel

The GBB represented an excellent opportunity to study the effects of a bridge on harbour porpoise behaviour and abundance and to then use these insights for the Environmental Impact Assessment of the planned Fehmarnbelt Fixed Link. A large amount of data was generated with the use of different approaches to study a potential barrier effect of the GBB on harbour porpoises. There was no indication from any of the results that harbour porpoises perceived the GBB as a barrier to movement. However, statistical power was limited for some of the analyses due to high spatial and temporal variability in porpoise relative abundance, behaviour and density.

Measurements were carried out in the Øresund, Drodgen Tunnel, to investigate possible noise emissions. Directly above the tunnel, there are measurable vibration immissions during train passages, causing an increase in underwater sound pressure, i.e. noise immissions.

ii. Harbour seal and grey seal abundance

Sandbanks and rocks in the Rødsand lagoon provide haul-out sites for both seal species which occur in high numbers in this area. Close to 200 harbour seals and a small but increasing number of grey seals are regularly counted in the lagoon. The Fehmarnbelt area forms the southern-most haul-out site for harbour seals in the Baltic Sea. Rødsand lagoon harbours about one third of the small sub-population of harbour seals in the Baltic Sea.

iii. Harbour seal and grey seal visual surveys

Seals were counted between January 2009 and September 2010 on the haul-out sites in Rødsand lagoon by aerial surveys at monthly intervals. Numbers obtained during our surveys were lower for harbour seals than those obtained during national surveys, but provided new maximum numbers for grey seals. Surveys indicate a seasonal pattern with highest numbers of seals hauled-out in summer and lower counts either side in spring and autumn. There was very limited survey coverage during the winter months; however, in January 2009 exceptionally high numbers of 107 harbour seals were counted. Previous surveys conducted by NERI in winter resulted in very low numbers at that time of the year. Grey seal counts reached a maximum of 57 animals in June 2010. The seasonal increase in seal numbers at haul-outs during summer coincides with pupping and moulting activity.

iv. Harbour seal health status

In this study a number of different physiological parameters were measured in individual seals captured at Rødsand lagoon to indicate their current general health status. These included a standard set of haematology and clinical blood chemistry parameters, basic immunological measures to determine immune status and exposure to pathogens, and morphometric measurements. Parasite loads were investigated from faecal egg counts and examination of the animal for the presence of ectoparasites. The results indicate that the five harbour seals captured at Rødsand in October 2009 were in good nutritional and physiological health, with no signs of disease being detected, using the various blood parameters and morphological measures as indicators. The adult animals (3/4) had been exposed to a morbillivirus (probably PDV during the 2002 outbreak) and had protective levels of antibodies in their blood.

The two juvenile grey seals captured, sampled and released at the Rødsand haul-out were both in good general health with no signs of infection or other diseases.

From the small sample of animals captured at the Rødsand haul-out site it appears that both species were in good general health and body condition. Our data provides a set of baseline health and dietary parameters which can be used to compare results obtained from animals captured and faecal samples collected from the same haul-out during the construction phase of the Fehmarnbelt crossing.

v. Seal telemetry

In October 2009 five harbour seals were tagged at Rødsand – four adult males and a female juvenile. The four males were fitted with GPS/GSM tags. The juvenile female was fitted with an Argos tag. The tracks from all four adult male harbour seals showed that the tracked seals remained within 50 km of the two haul-out sites. The juvenile female harbour seal travelled much further. Overall the mean trip duration for the four adults was 66 hours (range 56 to 79 hours). Mean dive duration for the four GPS/GSM tagged harbour seals was 2.8 min (range 2.7 to 3.1 min). The overall mean maximum dive depth was 8.4 m (range 7.7 to 10.0 m). There was a strong association of feeding behaviour with substrate type. Almost all GPS locations that were associated with feeding (animals moving slowly and performing regular dives) were obtained from either ‘coarse sediment / boulders’ or ‘sand’. Finer substrates (those containing some quantity of mud) contained the remaining 4% of ‘slow travel rate’ locations which indicate feeding.

In October 2009 two juvenile grey seals were tagged with GPS/GSM tags at Rødsand – one male and one female. Both individuals travelled over large distances and commuted between other haul-out areas in Denmark and Sweden. The analysis of seal movements in relation to environmental variables pointed that distance to haul-out, bottom current strength and surface temperature determined the feeding locations of the tagged seals.

vi. Seal baseline pressure analysis

Analysis of available literature identified a variety of anthropogenic pressures acting on harbour seal and grey seal in the Baltic Sea and the Fehmarnbelt such as fisheries, pollution and underwater noise emissions. Seal abundance in the Baltic Sea is still under the influence of human activities and probably below carrying capacity. Historic data on seal hunting indicate that seal numbers in the area were considerably higher in former times, and it remains to be predicted at which state the current increase might level off.

vii. Evaluation of the status of harbour porpoise, harbour seal and grey seal

The current status of the three marine mammal species was evaluated using a four-scale matrix as developed for the Fehmarnbelt Environmental Impact Assessment. The evaluation ranks the overall abundance of harbour porpoises in the Fehmarnbelt area to be of medium importance with sub-areas likely to be of high to very-high importance due to uneven distribution. The function as a nursing area is ranked medium and similarly the function as a migration corridor is also ranked as medium. This evaluation is based on the present state of knowledge that no discrete population in the eastern part of the Baltic Sea is dependent on migration through the Fehmarnbelt.

The importance of the Rødsand lagoon and adjacent feeding areas for harbour seals is evaluated as very high, because a high proportion of Baltic seals occur in this area. Furthermore, the breeding and pupping ground at Rødsand is of importance for the whole Baltic population of harbour seals.

The importance of the Rødsand area for grey seals is evaluated as high, as it holds a substantial part of all Danish grey seals, but total numbers are low compared to the whole Baltic population.

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List of Abbreviations

Abbreviation	Meaning
3D	Three-dimensional
ADD	Acoustic Deterrent Devices
AHD	Acoustic Harassment Devices
AIC	Akaike's Information Criterion
AIS	Automatic Identification System
ALP	Alkaline phosphatase
ALT	Alanine aminotransferase
AR	Artificial reef
AR	Artificial reef
ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas
AST	Aspartate aminotransferase
BCPS	Bis-(4chlorophenyl) sulfone
BV	Brunt-Vaisala
CDV	Canine distemper virus
CITES	Convention on the International Trade in Endangered Species
CO_2	Carbon dioxide
CPE	Cytopathogenic effect
C-POD	Click – Porpoise Detector
CS	Current Speed
dB re 1µPa	Decibel referred to 1 Micropascal
DDT	Dichlorodiphenyltrichloroethane
Defra	Department for Environment, Food and Rural Affairs
Df	Degrees of freedom
DS	Distance sampling
DSM	Density surface model
EC	European Community
EcoQO	Ecological Quality Objective
EIA	Environmental Impact Assessment
ELISA	Enzyme linked immunosorbent assay
EU	European Union
FB-WF	Fehmarnbelt Water Forecast

FCM	Faecal cortisol metabolites
FEHY	Fehmarnbelt Hydrographic Services
FEMM	Fehmarnbelt Marine Mammal Studies
GAM	Generalised additive model
GB	Giga byte
GBB	Great Belt Bridge
GES	Good Environmental Status
h	Hour
HBV	Hydrologiska Byråns Vattenbalansavdelning
HCH	Hexachlorocyclohexane
HELCOM	Helsinki Commission: "Convention on the Protection of the Marine Environment of the Baltic Sea Area"
HPA	Hypothalamic pituitary axis
Hr	Hour
HRP	Horseradish peroxidase
Hz	Hertz
ICES	International Council for the Exploration of the Sea
ICI	Inter click interval
IFAW	International Fund for Animal Welfare
IgG	Immunoglobulin G
Ind	Individual
IRBP	Interphotoreceptor retinoid-binding protein
km	Kilometre
m	metre
mio	Million
mm	Millimetre
MOD	Ministry of Defence
MRDS	Mark-recapture distance sampling
ms	Millisecond
MS01	FEHY Main Station 01
MS02	FEHY Main Station 02
n	number
NERI	National Environment Research Institute
NOVANA	National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environments (in Denmark)

NOx	Nitrogen oxide
NS	Not significant
OP	Observation Point
OP	Observation Point
OSPAR	Oslo and Paris Conventions for the protection of the marine environment of the North-East Atlantic
PAH	Polyaromatic hydrocarbons
PAM	Passive Acoustic Monitoring
PC	Personal Computer
PCB	Polychlorinated biphenyl
PCR	polymerase chain reaction
PDV	Phocine distemper virus
pp10m	Porpoise positive 10 minutes
PPD	Porpoise positive days
PPH	Porpoise positive hour
PPM	Porpoise positive minutes
PSU	Practical Salinity Unit
PTS	Permanent threshold shift
PVC	Polyvinyl chloride
rms	Root mean square
RMSE	Root Mean Square Error
RP	Reference Point
s	second
SAC	Special Areas of Conservation
SCANS	Small Cetacean Abundance in the North Sea and Adjacent Waters
SCMM	Society for the Conservation of Marine Mammals
SCOS	Special Committee on Seals
SEL	Sound Exposure Level
Sight	Sighting
SMHI	Sveriges Meteorologiska och Hydrologiska Institut
SOx	Sulphur oxide
sqrt	square root
TBT	Tributyltin
TNT	Trinitrotoluene

T-POD	Timing Porpoise detector
TTS	Temporary threshold shift
TWBC	Total white blood cells
U	East velocity component
UBS	Under Bridge Sighting
V	Voltage
V	North velocity component
W	Vertical velocity component
WW II	World War II
ZFP	Zinc finger protein
µs	Microsecond

1. Introduction and scope of work

As part of the EIA for the Fehmarnbelt Fixed Link, Femern A/S has commissioned the FEMM consortium to conduct the baseline studies on marine mammals and to assess the impacts of the different Fehmarnbelt fixed link solutions on this group of marine life. In the Fehmarnbelt area three species of marine mammals occur regularly: the harbour porpoise *Phocoena phocoena*, a small cetacean which is widely distributed in the western Baltic Sea and the North Sea, the harbour seal *Phoca vitulina* with a haul-out site in the adjacent Rødsand lagoon which holds a substantial proportion of the small sub-population in the western Baltic Sea and the grey seal *Halichoerus grypus* which occurs in low but growing numbers in the Rødsand lagoon. In the area three SCAs have been declared and included into the Natura 2000 network to protect these animals.

The aim of the baseline study is to provide detailed information on the spatial and temporal use of the Fehmarnbelt area and adjacent waters by marine mammals. The objective was therefore to collect data on seasonal abundance, distribution and habitat use of harbour porpoises, harbour seals and grey seals in the project area and adjacent waters. The methods applied follow international standards – many of them developed under participation of FEMM team members - and comply with the German Standards for Environmental Impact Assessments for Offshore Wind Farms (StUK3) (Bundesamt für Seeschifffahrt und Hydrographie, BSH 2007).

The area of investigation stretches from a line between Kiel and Langeland in the west to a line between Gedser and Dahmeshöved in the east. The demarcation of the area of investigation ensures that all Natura 2000 sites designated for the protection of marine mammals in the Fehmarnbelt and adjacent areas are covered. The relatively large extent to the east and west allows for the registration of possible distribution gradients and focal points of the different mammal species. In addition, the area of investigation covers the maximum area potentially affected by sediment spillage as assessed in the feasibility studies. The baseline study includes the following approaches:

- For harbour porpoises, abundance and distribution have been investigated using monthly large-scale aerial surveys. These have been undertaken following the distance sampling approach (for details see Buckland et al., 2001)
- For seals, distribution and abundance data have been derived using regular counts at the existing haul-outs
- Habitat usage of harbour porpoises (occurrence in the Fehmarnbelt area) has been investigated using 27 passive acoustic monitoring devices deployed at different distances to the project corridor
- To determine the use and selection of habitat by both harbour porpoises and harbour seals, individuals of both species have been tagged in order to record their movements

via GPS technology and satellite telemetry. Furthermore, the relationship between occurrence of both seals and porpoises with environmental parameters such as temperature and currents has been analysed using established modelling approaches. For this purpose the results of the model calculations derived from the hydrological and other biological investigations were included as a basis for the investigation as much as possible. Aerial surveys and passive acoustic monitoring methods have been conducted since winter 2008

- To investigate interactions with present human activities, ambient noise profiles have been collected with autonomous acoustic recorders in a wider area, covering the project area and beyond. The analysis of the data is underway and results of these investigations will be presented at a later stage of the project.

This report describes the results of the investigations of the two year study period and thus has the status of a baseline report.

2. Harbour porpoise

2.1. Introduction and historical data

2.1.1. General biology of the harbour porpoise

The harbour porpoise (*Phocoena phocoena*: DK: Marsvin, D: Schweinswal) belongs to the order Cetacea (whales), the suborder Odondoceti (toothed whales) and within this to the family Phocoenidae. The harbour porpoise is a small odontocete inhabiting coastal areas of the northern hemisphere, and appears as the most abundant and resident cetacean species in the North Sea and the Baltic Sea. The harbour porpoise is a small phocoenid reaching an adult body length of 149 – 160 cm (Benke et al., 1998). According to a skeleton comparison undertaken by Galiatus (2005) on porpoises from inner Danish waters, females attain longer lengths and show an extended period of growth compared with males. The lifespan covers an average of 8 to 10 years; very few reach an age of 20 years (Benke et al., 1998). At an age of three to four years they become sexually mature. The mating season of harbour porpoises in the North Sea and the Baltic Sea is assumed to be June to August (Benke et al., 1998). Most adult females reproduce annually, gestation lasts for 11 months, giving birth to a single calf between May and August. Nursing lasts eight to ten months (Schulze, 1996). Both mating and reproduction periods can differ regionally and, as mating takes place between June and August, most adult females are pregnant and lactating at the same time, resulting in a high energetic need during this period (roughly from June and might last until the next gestation period).

2.1.2. Conservation of harbour porpoises in the Baltic Sea (legislation and management)

2.1.2.1. International frameworks

- **IUCN**

The harbour porpoise of the Baltic Sea has been catalogued as “critically endangered” in the red list of endangered species of the IUCN, based on the criterion C2a(ii), since the 2008 assessment.

- **Washington Convention –CITES**

CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora) is an international agreement between governments. Its aim is to ensure that international trade in specimens of wild animals and plants does not threaten their survival. The harbour porpoise is listed in Annex II which includes species that are not facing extinction, but strict controls on international trade are necessary in order to avoid these species becoming endangered.

- **Bonn Convention /CMS**

The Convention on the Conservation of Migratory Species of Wild Animals relates to the conservation of migratory species throughout their range. The Baltic harbour porpoise is listed in Annex II which supports international cooperation for conservation and management.

2.1.2.2. Regional frameworks

- **ASCOBANS**

The harbour porpoise is also covered by ASCOBANS, a regional Agreement on the Conservation of Small Cetaceans of the Baltic and North Sea resulting from the Bonn Convention. Since the harbour porpoise is the only cetacean resident to the Baltic Sea it has become the flagship species of this Agreement. In 2002 under the aegis of the ASCOBANS Secretariat, a special working group composed of representatives of international conventions, ministries, fishermen and environmental groups has developed a recovery plan for the Baltic harbour porpoise (Jastarnia Plan; see ASCOBANS, 2002), which recommends a programme for by-catch reduction, research and monitoring, marine protected area establishment and an increase of public awareness. The overall aim is to restore the Baltic population of harbour porpoises.

- **Helcom/ Helsinki Convention**

HELCOM known as "Convention on the Protection of the Marine Environment of the Baltic Sea Area” covers the whole Baltic Sea giving consideration to the specific needs of the Baltic. Helcom is concerned about the assumed decreasing population of the harbour porpoise in the Baltic Sea. It recommends an avoidance of by-catch, gaining data of threats and population data, to report these results every three years. Furthermore, based on the Baltic Sea

Protected Areas (BSPAs), marine protected areas might be established. The HELCOM Baltic Sea Action Plan focuses on the development of a good ecological status of the Baltic marine environment by 2021 and addresses all the major environmental problems affecting the Baltic marine environment.

2.1.2.3. EU frameworks

- **Habitats directive**

Within the framework of the European Union, the "Habitats Directive" (92/43/EEC) agreed on the conservation of the natural habitats of wild fauna and flora.

The harbour porpoise is listed in Annex IV where animal and plant species of community interest require strict protection. It is also listed in Annex II (all cetaceans are included here) in which all relevant member states are legally obliged to protect the harbour porpoise by designating MPAs, referred to as Special Areas of Conservation (SAC). The designation of marine SAC in the EU is scheduled to be completed by 2012 (European Commission, 2007).

According to Hoyt (2005) the Fehmarnbelt area is proposed as a Special Area of Conservation (SAC) under the EU Habitats and Species directive (DE 1332-301). For the proposed SAC it is estimated that a population of around 500 harbour porpoises use the area to swim regularly through the Fehmarnbelt. It is supposed that the Fehmarnbelt area is a reproductive area for the porpoise (Hoyt, 2005).

- **Bern Convention**

The Bern convention is the Convention on the Conservation of European Wildlife and Natural Habitats (1979 in Bern, Switzerland). The convention is aimed towards the conservation of wild flora and fauna and their natural habitats. The main focus is those species and habitats whose conservation requires the cooperation of several states and the further promotion of such cooperation. Particular emphasis is given to endangered and vulnerable species, including endangered and vulnerable migratory species. The harbour porpoise is listed in Annex II comprising "strictly protected fauna species".

2.1.3. Occurrence and status in the Baltic Sea

Since the presentation of the feasibility study for a fixed link across the Fehmarnbelt in 1999 by Riber et al., a number of additional investigations have been conducted on harbour porpoises in the Fehmarnbelt area as well as in the wider Baltic Sea. These studies have mainly been triggered by extensive plans to build offshore wind farms in the region and the accompanying need for baseline data to be able to carry out environmental impact assessments. Additionally, some studies have been funded by public programmes such as MINOS (Germany) and SCANS (EU). Since German parts of the Fehmarnbelt area are designated as "special area of conservation" (Krause et al., 2007) additional monitoring studies have been established. Studies have included the use of Passive Acoustic Monitoring

(PAM) devices such as PODs (Porpoise Detectors, e.g. Verfuß et al., 2007; Diederichs et al., 2008). Furthermore, large-scale surveys have been conducted from airplanes (e.g. Gilles et al., 2009), detailed studies on individual movements using satellite telemetry (e.g. Sveegaard et al., 2010) and genetic studies of population structure (e.g. Wiemann et al., 2010) in the Baltic Sea have also been carried out. The studies have offered new insights into different aspects such as seasonal occurrence of harbour porpoises.

2.1.3.1. Abundance and distribution in the Baltic

SCANS I and SCANS-II: In order to assess the abundance of harbour porpoises in the North Sea and adjacent waters, the SCANS I project (Small Cetacean Abundance in the North Sea and adjacent waters) was undertaken in 1994. The study area included all parts of the Danish Waters. This project was repeated in 2005 with the SCANS II project. Line transect sampling from shipboard surveys was used as the basic survey method to estimate abundance during both projects. The absolute abundance, gained by design-based estimates for harbour porpoises in the entire SCANS I area, was 341,366 porpoises (CV=0.14; 95% CI= 260,000 - 449,000) in 1994 and for almost the same area surveyed 335,000 (CV=0.21) in 2005 (Hammond 2006). Furthermore, for comparison, density surface modelling was also applied and yielded 345,132 (CV=0.16; 95%CI=272,904 – 479,222) harbour porpoises in 1994 and 367,260 animals (CV=0.14; 95%CI= 246,271 – 429,018) in 2005.

Whereas the overall density of porpoises did not change significantly between the two surveys, large distributional shifts could be observed. In the northern North Sea the abundance estimate decreased by about 119,000 animals from 1994 to 2005, while in the southern North Sea the estimate increased by about 113,000 (Figure 2.1-1)

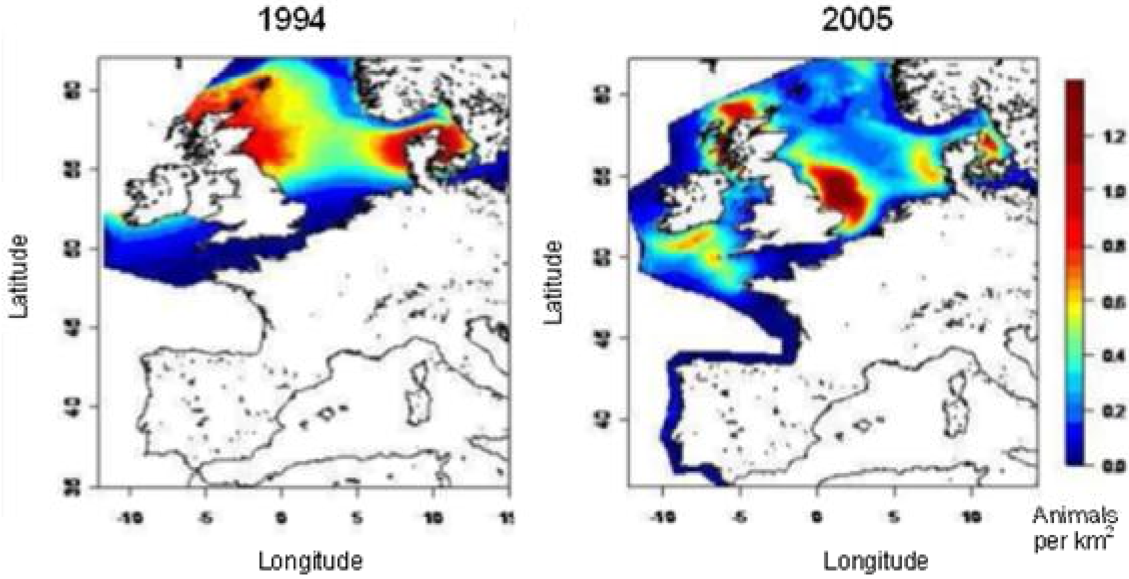


Figure 2.1-1 **Density surface modelling of the SCANS I and II data collected during July 1994 and 2005, respectively. The maps are based on visual sightings. The colours indicate the absolute density in animals/km² (from Hammond, 2006).**

For the Danish Waters the Scans I project calculated 36,046 (CV = 0.34) porpoises in the Kattegat, 5,262 (CV = 0.25) porpoises in the Belt Seas and 588 (CV = 0.48) porpoises in the Western Baltic Sea. The SCANS II project in 2005 came out with a decreased abundance estimate of 23.227 (CV = 0.36) harbour porpoises in the whole area mentioned above. Using Density Surface Modelling based on SCANS data Teilmann et al. 2011 (unpublished paper in phd of Signe Sveegaard 2011) recalculated the population size for this area to be 27,767 (CV=0.45, 95% CI=11,946-64,549) in 1994 and 10,865 (CV=0.32, 95% CI=5,840-20,214) in 2005. The estimates had large confidence intervals and the difference between the two abundance estimates was not statistically significant.
In 2005 no observations of harbour porpoises could be made east of the island of Fehmarn (Hammond pers. com.).

As porpoises are not believed to be evenly distributed throughout their range, their distribution is presumed to be linked to the dispersal of their prey, which in turn is linked to parameters such as hydrography and bathymetry (Raum-Suryan and Harvey, 1998; Skov and Thomsen 2008; Embling et al., 2010). However, little is known about the relationship between porpoises and their prey. In order to identify and monitor important areas, according to the EU habitat directive, several studies on numbers and distribution of harbour porpoises have been carried out both by German and Danish institutions covering entire German and Danish waters including the Fehmarnbelt area.

During the MINOS and MINOS+ project, aerial surveys were undertaken in order to reveal absolute densities of harbour porpoises within the German part of the Baltic Sea (Scheidat et al., 2004; Gilles et al., 2007; Scheidat et al., 2008). Results from the 46 aerial surveys between 2002 and 2006 showed a clear west-east gradient with highest densities observed within the Kieler Bight and Mecklenburg Bight. These data also show high densities within the Pomeranian Bight which is based on an aggregation of harbour porpoises in the first study year, however, there were no more sightings in the following three years (see Figure 2.1-2). Results also showed a seasonal pattern with highest numbers during late summer and lowest numbers during late winter and early spring. The summer results correspond very well with observations made during summer in both SCANS surveys.

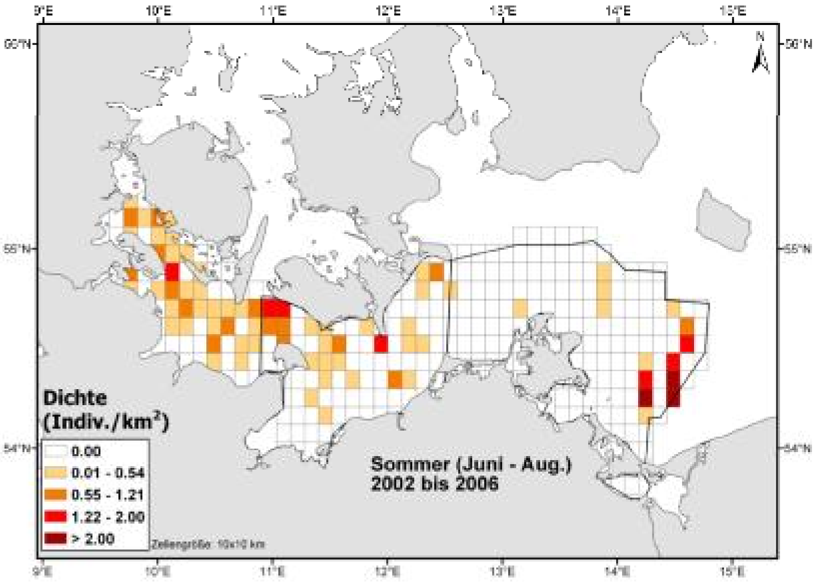


Figure 2.1-2 **Seasonal distribution of harbour porpoises in the south-western Baltic Sea 2002 – 2006. The mean density of harbour porpoises is shown per grid cell (10 x 10 km) for the time period June to August. Results from the MINOS+ Project (from Gilles et al., 2007).**

On behalf of the German Federal Agency for Nature Conservation (BfN), monitoring of harbour porpoises in German offshore waters was established in 2008. First results of this monitoring are documented in an unpublished report by Gilles and Siebert (2009) and Dähne et al. (2009). From aerial surveys conducted in June 2008 an estimation of 5,183 animals was made. Beside the west-east gradient they found a declining gradient in abundance from north to south. Although the distribution was more scattered around the Fehmarnbelt area, there were some areas of high density and all the mother-calf pairs were detected in this area. (Figure 2.1-3)

Scheidat et al. (2008) published MINOS data in conjunction with a discussion on the possible effect of by-catch rates. The MINOS area of the south western Baltic was divided into three different strata. The surveys of the three strata were covered within 25 consecutive days and the abundance for the whole area was estimated. For the entire area the number of calculated animals varied between 457 (March 2003) and 4610 (May 2005).

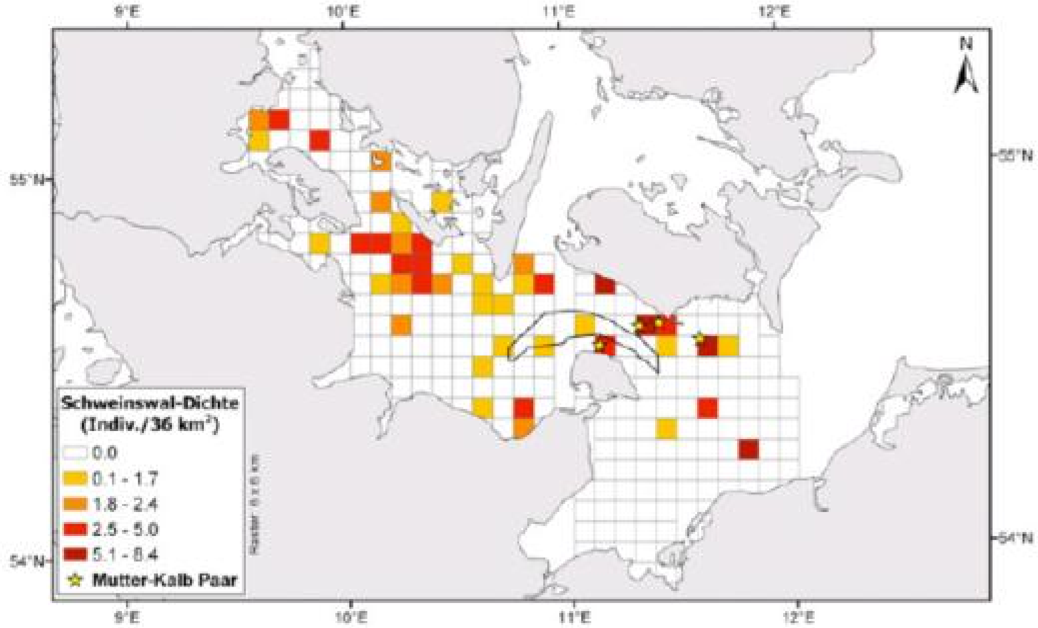


Figure 2.1-3 **Gridmap with mean density of harbour porpoise per cell (6x6km) in June 2008. The star indicates mother-calf-pairs (from Gilles and Siebert 2009).**

Results from Scheidat et al. (2008) as well as other investigations confirmed the west-east gradient in numbers of sightings with a drop in the number of sightings east of the Darss and Limhamn Ridge (Herr et al., 2009). Koschinski (2002) reported considerable differences in absolute density values in the Baltic proper (<0.01 individuals/km²) compared to the Kattegat and Belt Seas (0.73 – 0.99 individuals/km²), while Scheidat et al. (2008) also recorded very low densities of porpoises east of the ridge, ranging from 0 to 0.008 individuals/km² in all but two surveys, with 62 % of the surveys recording no porpoises at all. A survey in 1995, covering the German and Swedish waters of the Baltic proper, did pick up an estimation of porpoise abundance around the island of Bornholm, of 599 animals (CV = 0.57), which corresponds to a density of 0.009 individuals/km² (Scheidat et al., 2008). However, it can be seen that porpoises are not very common east of the Darss and Limhamn Ridge, and migration between western and eastern parts of the Baltic remains to be fully determined, although some studies suggest limited migration. (Berggren et al., 2002; Siebert et al., 2006). The different studies show that abundance estimates vary within the different areas of the Baltic Sea. The studies show a gradient in porpoise abundance with a decreasing density from west to east. The density of porpoises in the Eastern Baltic is lower compared to the Western Baltic.

A further MINOS/MINOS+ project dealt with the distribution of harbour porpoises within the German Baltic Sea using passive acoustic monitoring (PODs; Verfuß et al., 2004; Verfuß et al., 2007). More than 40 measuring positions were distributed over the German Baltic Sea for a period of at least three years. At each position T-PODs continuously recorded harbour porpoise echolocation signals. Results further confirmed the west-east gradient found in the visual investigations. Relative abundance decreased from the area west of Fehmarn towards the Pomeranian Bight (Figure 2.1-4). In the western part of the German Baltic a north-south gradient, with fewer recordings close to the coastline of Mecklenburger Bight and more recordings close to the Danish border, was found. Also, a distinct seasonal pattern could be shown on a much finer temporal scale than revealed by aerial surveys. For the area around Fehmarnbelt most recordings occurred during the third and fourth quarter of the year, whereas during the first quarter the lowest numbers of porpoise recordings were made.

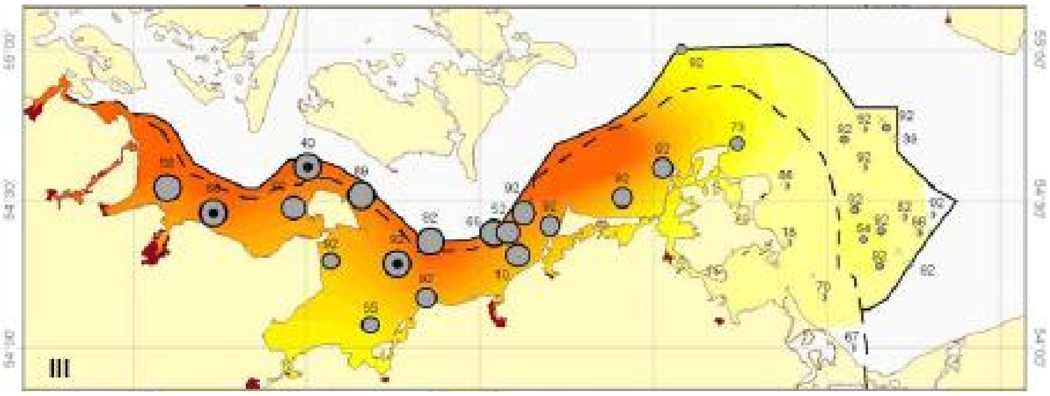


Figure 2.1-4 **General additive model applied on the results of the static acoustic monitoring program during MINOS+ project. Shown is the relative abundance of harbour porpoises in the third quarter of the year 2006 by percentages of porpoise positive days (PPD)/quarter. Size of circles and colour represents the number of PPD/quarter: The bigger the circle and the deeper red the colours, the more PPD were recorded. The grey circles with the black centre represent 100% of these (from Verfuß et al., 2007).**

Gillespie et al. (2005) found similar results with acoustic and visual surveys from a boat. The highest densities were detected in the Kiel Bight and Little Belt, the lowest in the eastern Polish part of the Baltic, resulting in a gradient falling from west to east (for a review of German data see Siebert et al., 2006). Loos et al. (2010) analysed 5605 opportunistic sightings of harbour porpoises in the Western Baltic (Figure 2.1-5). The sightings were made by sailors from the Society for the Conservation of Marine Mammals – a German NGO-processed the observations further. The results confirmed yet again the above trend. Caution should be taken in the interpretation of this rather opportunistic data set which could also be biased by sailing season. For the Flensburg Fjord they found a low density of harbour porpoises, but sightings of juveniles were greatest here.

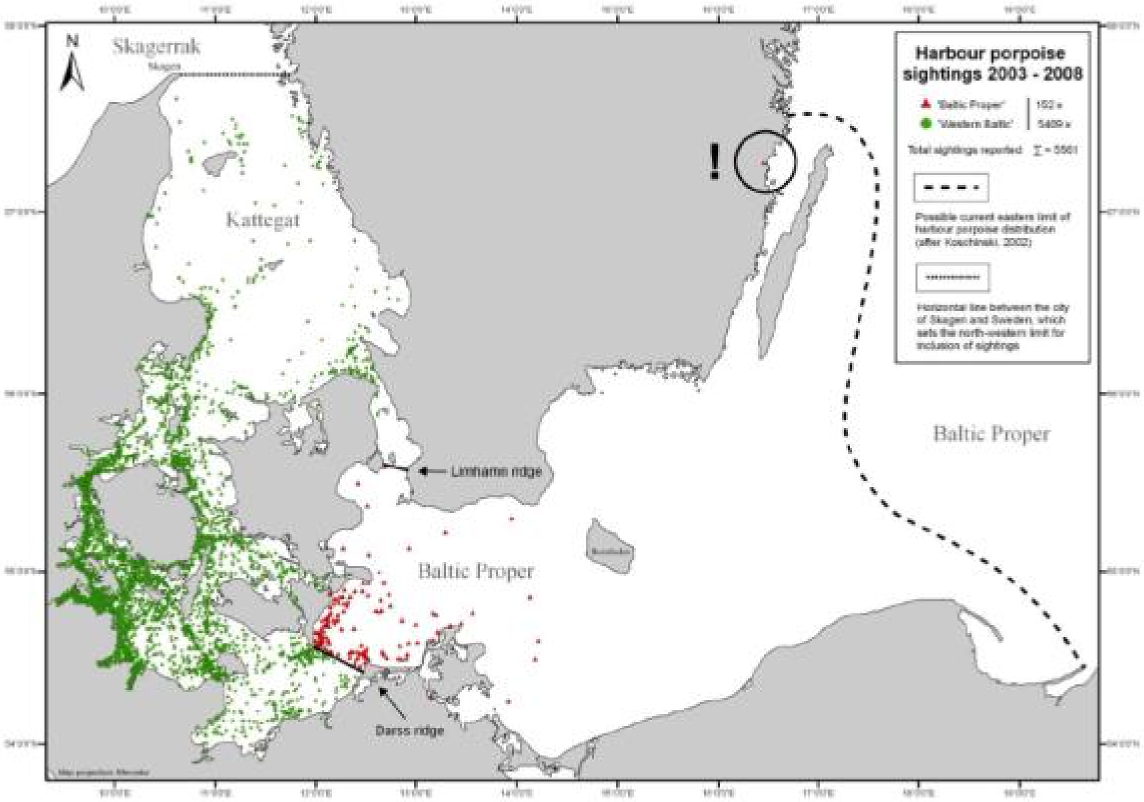


Figure 2.1-5 Harbour porpoise sightings (2003-2008) which were included in the analysis of opportunistic sightings by sailors (see Loos et al., 2010).

Comprehensive data from satellite tracking, aerial and shipboard surveys as well as acoustic surveys collected from 1991 to 2007 in Danish waters were analysed by Teilmann et al. (2008) and Sveegaard et al. (2010). Sixteen areas were found to have a high density of porpoises and were ranked either as being of high, medium or lower importance based on the current knowledge of population structure, density, seasonal variation in distribution and other relevant information (detailed description in Teilmann et al., 2008).

2.1.3.2. Satellite tracking studies

In Danish waters 64 porpoises were tagged between 1997 and 2007 (Teilmann et al., 2004; Sveegard et al., 2010). All animals were unintentionally trapped in pound nets in the Danish waters from Skagen to Gedser. Twenty-six porpoises were tagged on the border between Skagerrak and Kattegat on the northern tip of Denmark (Skagen, Jylland) and 38 were tagged in the Inner Danish Waters. Based on the satellite-tracked porpoises, a Kernel distribution was chosen to identify areas of high importance. In order to illustrate how the porpoises used the 30 % kernel areas (high density areas), additional data on the number of animals visiting the area and the number of days they stayed within these areas were analysed. In the study by Teilmann et al. (2004) an area was defined as "corridor" if animals stayed for a period of less than two days. Subsequently, areas were defined as "foraging areas" if the animals stayed longer than two days. The results show several areas with higher density of recordings of tagged animals than other areas throughout the year, while some areas were only important during summer or winter: among others, the Fehmarnbelt area could be identified as an area of high importance all year round. Around Fehmarnbelt, tagged animals showed peak densities during April, June and December, yet most of them were using the area as a corridor rather than a foraging area (see above) (Teilmann et al., 2004). Sveegard et al. (2010) analysed the same dataset as Teilmann et al. (2004) and found nine high-density areas over the entire year in the Inner Danish Waters (Figure 2.1-6). The Fehmarnbelt area is one of these areas. Furthermore Sveegaard et al. (2010) showed seasonality in the distribution of harbour porpoises: in spring and summer animals in Inner Danish Waters spread out into the whole region. In autumn and winter these animals avoided the Kattegat area and stayed south.

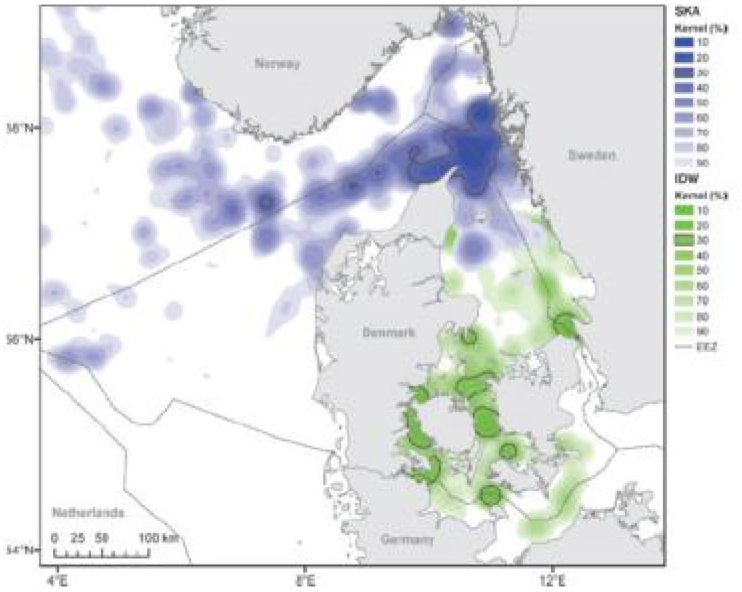


Figure 2.1-6 **All year distribution of harbour porpoises (*Phocoena phocoena*) tagged between 1997 and 2007 displayed by fixed kernel density based on one location every four days. The Inner Danish Waters (IDW) group is shown in green (N = 38 porpoises, n = 950 locations) and the Skagerrak group (SKA) is shown in blue (N = 26 porpoises, n = 665 locations). Black line indicates high-density areas defined as the 30 % kernel contour. Dashed line indicates international Exclusive Economic Zones (EEZ). Kernel layers are placed below the land layer (from Sveegaard et al., 2010).**

Edren et al. (2010) modelled the occurrence of harbour porpoises in the western Baltic. Data from 39 satellite tagged harbour porpoises were used for a MAXENT-(maximum entropy)-analysis. The advantages of this method are on the one hand that no absence data are needed and on the other hand that it is robust in application for small datasets. This study focused on identifying environmental variables in order to predict the distribution of harbour porpoises. The most powerful explanatory environmental variables were “distance to coast” and “bottom salinity” through all modelled seasons. Based on the results spatial predictions about areas with high probability of porpoise occurrence in the Baltic were made. The results show that the Kiel Bight, southern Kattegat and the Belt Sea are highly suitable for harbour porpoises all year round.

2.1.3.3. Population genetics and subpopulations

Results of genetic studies with focus on population structure in porpoises are as yet highly equivocal. Walton (1997) looked at 291 stranded, and 36 incidentally caught porpoises in waters surrounding the UK. Mitochondrial DNA (mtDNA) was extracted from skin samples and analysed. Results revealed that there were several different populations of porpoises in these waters. Significant differences were found between female porpoises in samples from the northern North Sea and those found in the southern North Sea (Walton, 1997). Walton (1997) suggested that male porpoises are more likely to migrate, whereas females were more likely to stay within an area and therefore form genetically distinct units. Furthermore, the author proposed that porpoises from Baltic Sea populations may migrate to the North Sea during winter months allowing genetic exchange (see also Børjesson and Berggren, 1997 below).

Wang and Berggren (1997) carried out a study on skeletal tissue of 65 incidentally caught harbour porpoises from the Baltic, Kattegat-Skagerrak Seas and of the west coast of Norway. Mitochondrial DNA (mtDNA) was extracted from skeletal tissue samples and was analysed using nine restriction enzymes. The analysis revealed significant differences in mtDNA haplotypes from samples that were collected from the Baltic, the Kattegat-Skagerrak Seas and of the west coast of Norway. Analysis on nucleotide divergence revealed that samples collected from the Baltic showed the smallest amount of genetic variation. The study presents therefore some evidence of separate harbour porpoise subpopulations in Baltic Kattegat-Skagerrak Seas and off the west coast of Norway (Wang and Berggren, 1997).

A study that undertook morphometric comparisons of porpoise skulls from the Baltic and Kattegat-Skagerrak Seas found morphological differences between females between the regions, thus supporting the hypothesis that two subpopulations are present in that region. Samples collected during winter showed fewer differences across the two sites than those collected during the summer. This could suggest a migration of porpoises during the winter from the Baltic to the Kattegat-Skagerrak Sea (Børjesson and Berggren, 1997).

Huggenberger et al. (2002) measured 242 harbour porpoise skulls from the North and the Baltic Sea and subdivided them into three geographical areas: the German Bight, the outer part or transition area of the Baltic Sea (Skagerrak, Kattegat, Belt Seas, Øresund, Kiel Bight, Lübeck Bight, and Fehmarnbelt Sea), and the central Baltic Sea (Arkona Sea and waters off the eastern Swedish coast). The results revealed significant differences between samples across areas. The study also indicated the existence of separated populations in the Baltic. Furthermore, differences between animals from the transition area and the central Baltic Sea respectively were found, indicating that porpoises inhabiting the waters east of the Darss Sill do not migrate over longer distances to the west in ice-free winters. The authors hypothesised the existence of a separate sub-population of harbour porpoises in the Baltic proper, i.e. east of Darss Sill. These data are in line with genetic investigations (Tiedemann and Boysen, 2000).

However, other authors believe that the scientific support for an isolated Baltic population is weak (e.g. Palme et al., 2008). One of the major critiques is the use of mtDNA, rather than nuclear DNA, in several studies. Although mtDNA is useful for investigating mutations and inherited diseases, it only contains maternally inherited information whereas nuclear DNA encodes the complete genome and therefore gives a better distinction of genetic information (Palme et al., 2008). Another critique has been the comparably small sample size and the data collection methodology as several studies have used stranded porpoises for their genetic studies. The problem with using stranded animals is that there are uncertainties with regards to the origin of the porpoise. A porpoise carcass could drift for many kilometres and once stranded the place of origin is very difficult to determine (Moreno et al., 2003). For this reason it may be more useful to use by-caught porpoises to determine the geographical range. Due to the difficulties in gaining samples from harbour porpoises, sample size has been rather limited in several genetic studies.

Genetic studies by Tiedemann et al. (1996) have also demonstrated that porpoises sampled in the Baltic have a much lower genetic variation than in surrounding seas. This may be due to a founder effect in the population which may lead to limited genetic variation. Although some studies have discussed the possibility of migration from the Baltic region to the Kattegat-Skagerrak and North Sea, it has also been implied that the population in the Baltic may not migrate at all (Koschinski, 2002). Due to limited genetic exchange through gene flow of isolated Baltic populations, porpoises may be susceptible to inbreeding and consequently lower population genetic diversity. Inbreeding may also have negative effects on populations such as reduced reproductive success and genetic disorders, which may cause a further bottleneck in an already vulnerable population. Due to very low densities of porpoises in the Eastern Baltic this argument would lead to a much lower acceptable threshold for by-catch in the Baltic proper (Inner Baltic management unit) than for one merged population (management unit) for the whole Baltic. By-catch is assumed to be the greatest threat for harbour porpoises in the Baltic region (Kock and Benke, 1996; Vinther, 1999; ASCOBANS, 2002; Berggren et al., 2002; Koschinski, 2002; Larsen et al., 2002; Vinther and Larsen, 2004; Siebert et al., 2006; ASCOBANS, 2009)

The most actual study on population genetics was published by Wiemann et al. (2010). They analysed mtDNA and microsatellite data with a sample size of 497 harbour porpoises arranged by stranding/by-catch, sex and finding season. They found at least two populations with significant differences: one in the Skagerrak and another in the Belt Sea with overlaps in the Kattegat. Although some differences between the Belt Sea and the Inner Baltic samples were found, this trend was not statistically strong enough to separate genetically a third population in the Inner Baltic. However, from a conservational point of view, the authors would argue that the harbour porpoises present in the Inner Baltic should be handled as an own management unit with a probably limited gene-flow.

General consensus from the genetic and morphological studies conducted so far is that there may be some genetic differences between Baltic and North Sea porpoises. However, confirming discrete or isolated sub-populations and the genetic exchange between them has proven to be very difficult. Lack of scientific data such as abundance, migration patterns and defining geographical boundaries has led to a poorly understood genetic diversity of the harbour porpoise. Comparative studies have shown some consistencies in results, however it remains difficult to investigate comparisons due to the different geographical range of sampling areas and different methods used.

2.1.3.4. Diet of harbour porpoises in the Baltic

A review from Santos and Pierce, (2003) shows that harbour porpoises forage on pelagic schooling fish as well as on benthic fish. Often herring (*Clupea harengus*) and whiting (*Merlangius merlangus*) were found in harbour porpoise craws. All studies from the German and Polish Baltic Sea present cod (*Gadus morhua*), gobies and herring as the main feeding sources (Lick, 1991; Benke and Siebert; 1996; Malinga and Kuklik, 1996). Börjesson et al. (2003) found, in porpoise stomachs from the Kattegat and Skagerrak between 1988 and 1996, Atlantic herring (*Clupea harengus*) and Atlantic hagfish (*Myxine glutinosa*) as the dominating species. All study results show that porpoises are opportunistic feeders, preying on a number of different species which are very common in the region they were caught or found.

In a review done by Nabe-Nielsen (2010) for Fehmarnbelt A/S the most frequent species fed on by harbour porpoises were herring, goby and cod (Figure 2.1-7).

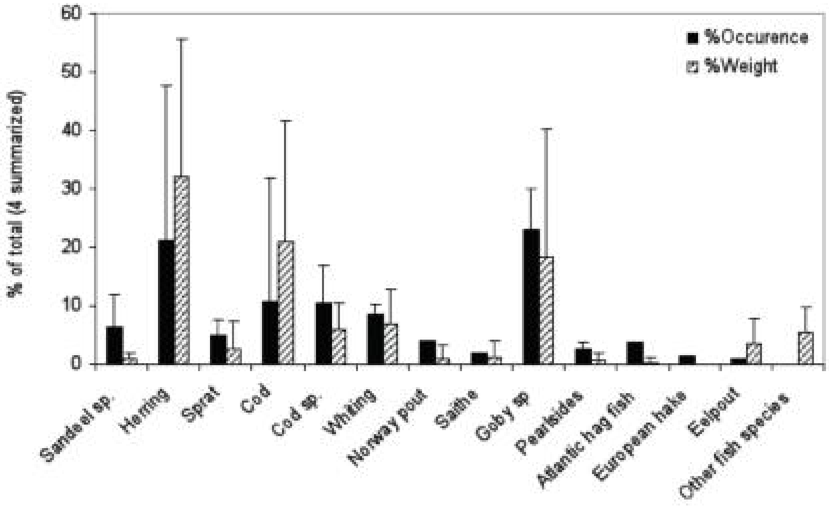


Figure 2.1-7 **Percentage by occurrence and weight of fish species found in the stomachs of harbour porpoises (from Nabe-Nielsen, 2010).**

2.2. Telemetry

2.2.1. Introduction

2.2.1.1. Porpoises in the Baltic

There are good data on the overall abundance of harbour porpoise in different parts of the Baltic during summer. In particular, dedicated aerial surveys of the Skagerrak, Kattegat and Belt Sea carried out as part of the Small Cetacean Abundance in the North Sea (SCANS) project in 1994 and 2005 (Hammond et al., 2002; SCANS-II, 2008) and national programmes have provided relatively good estimates of the abundance of porpoises in these areas during summer. However, sightings rates for porpoises in the Baltic Sea proper are so low that it is not possible to obtain reliable estimates of density.

Much less was known about the population structure of these animals. However, Wiemann et al. (2010) analysed data on mitochondrial DNA and microsatellite polymorphism from 497 harbour porpoises collected in the North Sea, Skagerrak, Kattegat, Belt Sea and Inner Baltic Sea to see if they could identify what Dizon (2002) refers to as “demographically significant” population units. They concluded that there was strong evidence for two population units, one in the Skagerrak and North Sea (which we henceforth refer to as SKAG), and the other in the Belt Sea (referred to as BELT), with a transition zone in the Kattegat (Figure 2.2-1). There was also some evidence (i.e. statistical significance was only achieved in some tests and not all) of genetic separation between animals from the Inner Baltic Sea and the Belt Sea. Separation between the Inner Baltic and Belt Seas has been proposed by other studies based on genetic and morphological differences (Huggenberger et al. 2002; Tiedemann et al. 1996). Wiemann et al. (2010) concluded that there was sufficient evidence to support the existence of three geographical population units: 1) the Skagerrak/Northern Kattegat (SKAG); 2) Southern Kattegat/Belt Sea (BELT) and 3) Inner Baltic sea.

The genetic structure of Baltic harbour porpoise populations only provides information on how animals segregate during the breeding season. At other times of the year, any geographical location, and particularly the Kattegat, may contain a mixture of animals from the different population units. Additional insight into which population units are likely to be affected by anthropogenic activity in a particular location can be obtained from knowledge of the animals' seasonal movements. Satellite telemetry is a proven technology that can be used to obtain information about the large scale movements of a small number of individuals of these species and to investigate the factors that may affect these movements.

In the last 15 years, satellite telemetry has been widely used to investigate harbour porpoise movement, behaviour, and distribution in relation to environmental factors (Johnston et al., 2005, Teilmann et al., 2007, Edren et al., 2010; Sveegaard et al., 2010). Recently, Sveegaard et al. (2010) analysed data from 64 harbour porpoises that were captured in the Baltic and fitted with satellite transmitters. They divided these animals into two groups: individuals from one group spent the majority of their time in the southern Kattegat, Belt Sea, and Inner Baltic Sea, which Sveegaard et al. (2010) refer to as Inner Danish Waters (IDW), and the other group spent the majority of its time in the northern Kattegat, the Skagerrak, and the northeast North Sea. They refer to these animals as the Skagerrak group. Their analysis demonstrated a marked seasonal difference in the average distribution of these two groups (Figure 2.2-2). In this report we have reanalysed the data from the 64 animals used by Sveegard et al. (2010), together with data from a further 18 satellite tagged animals, to provide information on the way in which Baltic harbour porpoises use the waters around the Fehmarnbelt.

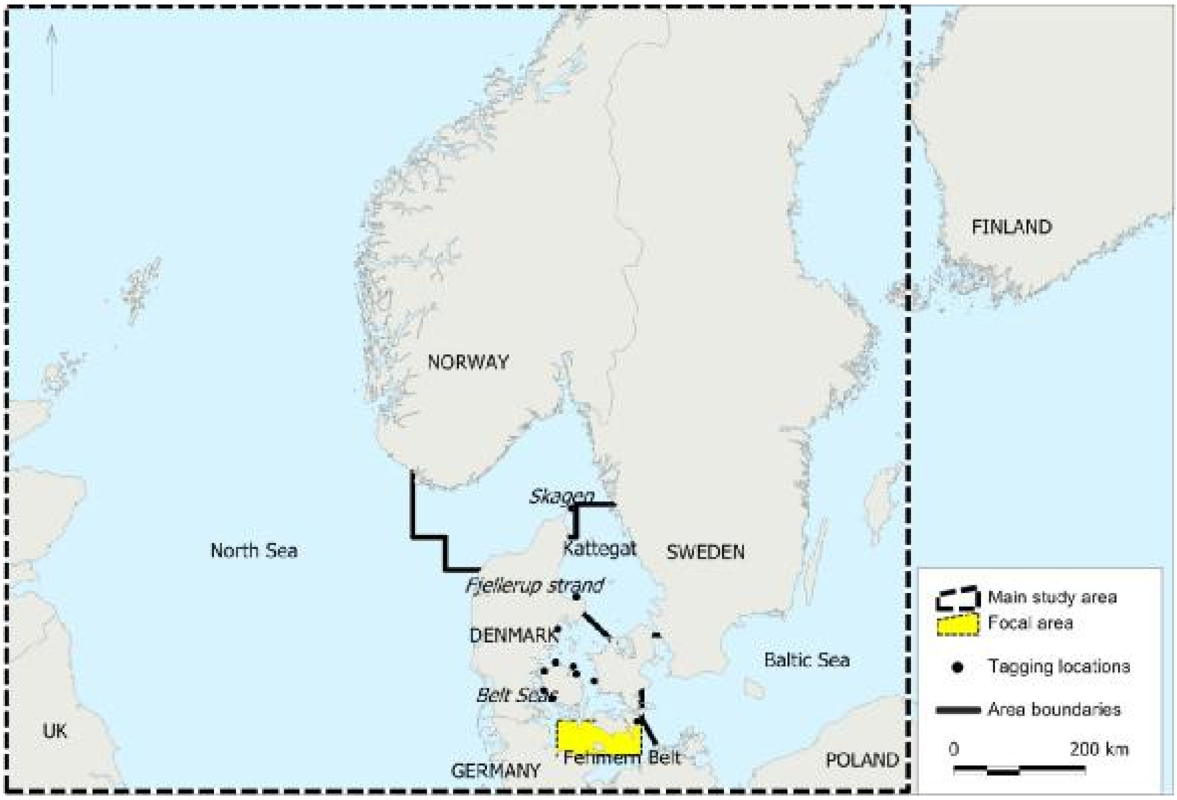


Figure 2.2-1 **Fehmarnbelt focal study area (yellow), showing boundaries between the population units for harbour porpoise in the Baltic identified by Wiemann et al. (2010), and locations where the satellite transmitters used in this study were attached (location indicated by a black dot, with the location name in italics).**

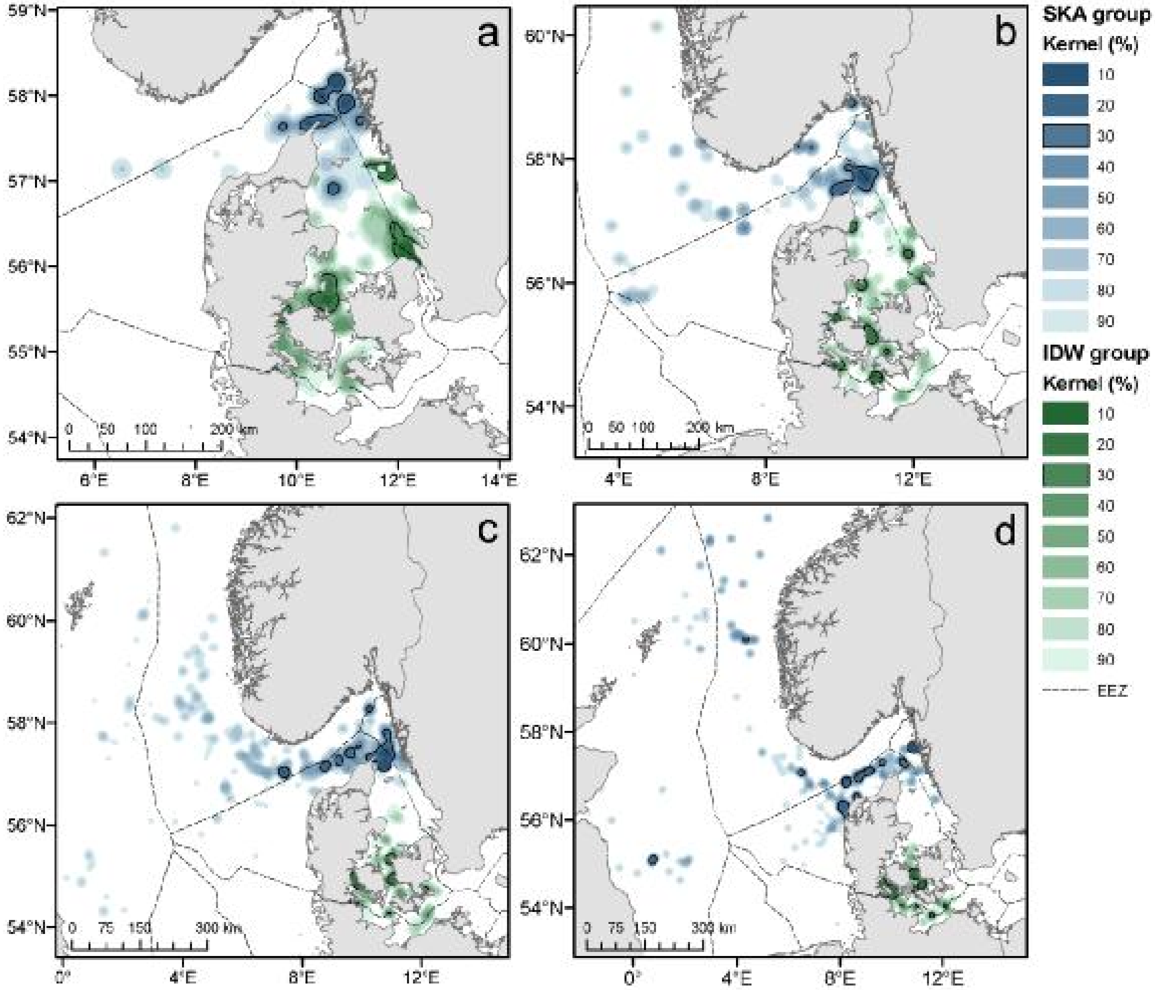


Figure 2.2-2 **Figure 5 from Sveegard et al. (2010) showing the seasonal distribution for satellite tagged harbour porpoises *Phocoena phocoena* in the Inner Danish Waters (IDW) group (green) and the Skagerrak group (blue) displayed by fixed kernel density estimations based on one location every four days. Black line indicates high-density areas defined as the 30% kernel contour. (A) spring (IDW: N = 29, n = 268; Skagerrak: N = 12, n = 103), (B) summer (IDW: N = 27, n = 353; Skagerrak: N = 18, n = 155), (C) autumn (IDW: N = 17, n = 210; Skagerrak: N = 19, n = 250) and (D) winter (IDW: N = 8, n = 119; Skagerrak: N = 12, n = 157). Dashed line indicates international Exclusive Economic Zones (EEZ). Kernel layers are placed below the land layer.**

2.2.1.2. Objectives

The objective of the study was to investigate the movements and habitat use of harbour porpoises in the Fehmarnbelt and adjacent waters using satellite telemetry. In order to do so we address six questions:

1. How much time do porpoises spend within the Fehmarnbelt focal study area (FEHM) compared to the rest of their home range, and what factors (such as time of the year) affect this?

2. How do the home ranges of porpoises tagged in the Belt Sea compare to home ranges of individuals tagged elsewhere in central/northern Danish waters?

3. How can a ‘local population’ be defined?

4. Does FEHM have a specific function in the annual cycle of harbour porpoises?

5. What is the habitat choice of porpoises in FEHM?

6. What proportion of tagged porpoises has been tracked swimming under the Little Belt, Great Belt and Øresund bridges? Given that the proposed alignment across Fehmarnbelt could be a bridge, it was decided to assess movements of porpoises near existing bridges to investigate whether bridges pose a barrier to porpoises utilising the area.

2.2.2. Methods

2.2.2.1. Data sets

We analysed data from 82 harbour porpoises tagged between 1997 and 2010 in the Skagerrak and IDW as part of a number of projects. Details of these animals are provided in Appendix 1. Fifty one were tagged between 1997-2002 as part of a joint project between the NERI, Danish Institute for Fisheries Research, the Fjord and Belt Centre and University of Southern Denmark (Teilmann et al., 2004). Another 13 were tagged from 2003-2007 by NERI and the University of Kiel, FTZ. From 2007-2010 nine porpoises were tagged by NERI for the Fehmarnbelt project. In the period 2007-2010 NERI tagged another nine porpoises as part of another project. Based on tagging location, the sample represented 45 animals in the Belt Sea, 13 in the Kattegat (Fjellerup Strand, and 24 in the Skagerrak (Skagen).

A variety of tags were deployed but all used the Argos satellite system for transmission. The key information transmitted allowed swimming depth and location data to be collected. Harbour porpoises were incidentally caught in pound nets and generally tagged within 24 hours of being discovered. The tag was bolted onto the animals’ anaesthetized dorsal fin. The tag is secured onto a backing plate with iron nuts, which eventually rust off after approximately one year for tag detachment. The tag transmissions to the Argos satellites are relayed to the Argos ground systems and are used to calculate the location of the tag. Locations are then classified according to their accuracy (km).

We used a pre-processed dataset received from NERI. The location data had been filtered using algorithms (based on distance between successive locations, turning angles and maximum swim speed) designed to detect unlikely, low accuracy locations and these were removed from the dataset. The remaining dataset consisted of a maximum of one location per day for each animal, together with data on the water depth and the distance to the coast for each location. Additionally, locations recorded on the first four days of tag activity were removed from the dataset (Sveegard et al. 2010) to allow time for porpoises to resume normal behaviour should there have been any affect from the tagging process.

Table 2.2-1 shows the total number of locations and the number of locations per animals for individuals from each of the three tagging locations shown in Figure 2.2-1, in each quarter of the year.

Table 2.2-1 Number of tags from each tagging location that were operating in each season (Spring = March, April, May; Summer = June, July, August; Fall = September, October, November; Winter = December, January, February), and the number of daily locations that were obtained from these tags

Tagging location	Season	Number of tags operating	Total number of locations	Mean (and SD) number of locations per tag
Belt Sea	Spring	31	1106	35.68 (16.10)
	Summer	27	1067	39.52 (23.74)
	Fall	25	809	32.36 (24.18)
	Winter	14	502	35.86 (18.93)
Fjellerup strand	Spring	10	233	23.30 (25.77)
	Summer	11	365	33.18 (26.31)
	Fall	5	211	42.20 (5.22)
	Winter	3	98	32.67 (11.24)
Skagen	Spring	10	191	19.10 (10.96)
	Summer	17	366	21.53 (15.33)
	Fall	18	576	32.00 (26.60)
	Winter	12	331	27.58 (21.94)

2.2.2.2. Study area

We defined a study area bounded by 2°30’W and 21°40’E, and by 53°19’N and 64°50’N, (Figure 2.2-1), which we divided into 10 km x 10 km grid cells. Within this study area we defined a Fehmarnbelt focal study area, with boundaries of 10°09’E and 12°10’E, and 54°19’N and 54°50’N.

2.2.2.3. Data analysis

A preliminary analysis of the available data indicated that there was considerable variation in the use of space among the animals tagged at any particular location. We, therefore, concluded that it would be inappropriate to pool results from all of the individuals tagged at a particular location and constructed our analyses so that we could take account of this among-individual variation (see below).

A similar approach was used to address questions 1 and 2 (how much time do porpoises spend within the FEHM and how do the home ranges of porpoises tagged in the Belt Sea compare with those of animals tagged elsewhere?). The estimated probability of animal presence for each grid cell in the area, across years, seasons and populations (tagging locations) was obtained using intercept only Generalized Linear Models (GLMs) with Binomial errors and a logit link function.

Separate models that included covariates for year, season and population were fitted to each grid cell to obtain, where possible, estimated probabilities for combinations of year, season and tagging population. 1246 grid cells contained at least one daily porpoise location, necessitating the estimation of 1246 individual GLMs for this and the subsequent analyses.

Animal locations, and therefore presence/absence, for each grid cell, are likely to be correlated over time within individuals. For this reason, Generalized Estimating Equations (GEEs; Hardin and Hilbe, 2003) were used to generate estimates of precision, such as standard errors and confidence intervals for model predictions. Under this scheme, model residuals within animals were considered correlated while independence was assumed between animals. GEE-based Wald tests were used to assess the statistical significance of each covariate.

Use of the Fehmarnbelt focal study area (FEHM)

Models predicting the probability of animal presence within FEHM were fitted using Binomial GLMs with GEE-based estimates of precision. Intercept only models were used to give average probabilities (and associated estimates of precision) for animal presence within FEHM across years, seasons and tagging locations. In addition, a model including tagging location was used to generate predictions for animal presence for each tagging location across the years and seasons surveyed. Separate models were also fitted for each animal found within FEHM to quantify the average probability of these animals being inside the area (with GEE-based estimates of precision) across seasons and years.

Use of space by animals tagged in the Belt Sea and elsewhere in central and northern Danish waters

In all grid cells where fitting a model including year and/or season and/or tagging location was possible, Binomial based GLMs coupled with GEEs were used to obtain estimated probabilities with relevant covariates entering the models as factors for maximum flexibility.

Defining local populations

The aim of this analysis was to identify if there was any evidence that sub-sets of animals tagged at a particular location showed a similar use of space. If they did, this could be considered as evidence for the existence of local populations within the “demographically significant” population units identified by Wiemann et al. (2010).

We generated isotopically smoothed kernels to summarise the use of space for each individual animal using the call bkde2D in the kernsmooth library of the statistical-computing environment R (http://CRAN.R-project.org). The first 10 locations for each animal were excluded from this smoothing process.

We then created an index of distance (here defined as the complement of spatial overlap) between two porpoises (say, i and j)

$$\sum_{x} \sum_{y} (s_{i,x,y} - s_{j,x,y})^{n} . \qquad \text{Equation 2.1}$$

where x and y are grid cell coordinates, and n is an integer. In this index, $s_{i,x,y}$ is the kernel-smooth estimate of usage of the cell with the coordinates x , y by the ith porpoise. We examined a number of different values for n, and concluded that a value of 2 was most informative.

Equation 2.1 was then used to create a matrix of all pairwise distances between animals, and k-means clustering was used to search for branching patterns in the data. The branches of the dendrogram were then colour-coded by tagging location to help detect patterns. The underlying hypothesis is that pairs of animals which show a similar use of space should have a low value for Equation 2.1 and should, therefore, cluster together.

Biological importance of the Fehmarnbelt focal study area

We used two methods of data selection to address question 4 (does FEHM have a specific function in the annual cycle of harbour porpoises?). One method was to select all locations of animals which belong unambiguously to the two population units identified by Wiemann et al. (2010). There were 24 animals from the Skagerrak (SKA) that met this criterion, and 45 from the Belt Sea (BELT). The second method was to select animals that were tracked during both winter and summer seasons. Thirteen animals satisfy this condition. This included three animals that had been tagged in the southern Kattegat, a region of transition between the two population units identified by Wiemann et al. (2010). Sveegard et al. (2010) assigned these three animals to their Skagerrak group (Teilmann, pers comm) on the basis of the proportion of time they spent in the northern Kattegat and Skagerrak. The second method allowed us to compare the areas used by each individual in summer and winter, and to visualize their seasonal movements. Shorter tracks would not have provided this information because they would have over represented one part of the year and created a biased impression.

Annual and diurnal patterns in distribution of the tagged porpoises were considered in the context of water depth and sea surface temperature for each of the three population units. Optimum interpolation sea surface temperature data was used (available on the site of National Oceanic and Atmospheric Administration (Reynolds et al., 2002; http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.html)) to visually inspect the patterns and attempt to explain the movements of harbour porpoise.

Habitat choice of porpoises in the Fehmarnbelt focal study area

In order to address question 5 (what is the habitat choice of porpoises in FEHM?), analysis proceeded according to the methodology developed in Aarts et al. (2008). We initially used an exploratory approach with Generalised Linear Mixed Model (GLMM) using random intercepts for each individual porpoise, Binomial errors and a logit link function. The telemetry data (indexed by time, individual and capture location) for all locations that were obtained within the FEHM were complemented with control locations uniformly randomly selected from within FEHM. This gave a combined set of response data consisting of 0s and 1s. Each telemetry point was augmented by 10 control locations.

We carried out forward model selection with all single variable terms (water depth, distance to shore, substrate type, mean shipping intensity averaged over 2009-2010, mean salinity and temperature at 10 m depth, stratification depth and strength, daily mean discharge of salinity (kg/s) between Rødbyhavn and Puttgarden, mean east-west and north-south current velocities for surface and bottom layers, mean eddy activity and vertical current velocity at 10 m depth on the day and at the exact position of the porpoise or control location) followed by model checking (diagnostics, goodness of fit) of the resulting model. We then introduced interactions between bathymetry and the oceanographic variables remaining in the model, and investigated the need for random slopes in the response to different covariates. To examine the importance of individual variation, we introduced random effects to the response of several of the more important covariates. Subjective assessment of individual variation, carried out by comparing the variance of the fixed effects with the variance of the random effects, indicated that differences between the responses of different individuals were relatively small.

At a second stage, we applied more flexible Generalised Additive Modelling (GAMs) using the subset of environmental covariates that were deemed to be most relevant from the GLMM stage of the analysis. We experimented with these models by adding/removing covariates and investigating interactions (tensor-products) between depth and oceanographic variables.

The hydrographic data for the tagging period (1997-2010) used in the analysis originates from the FEHY regional model (Appendix 7.4).

What proportion of tagged porpoises have been tracked swimming under the Little Belt, Great Belt and Öresund bridges?

Satellite tracks of 82 animals were used, of which four animals were omitted due to too few locations. The satellite tracks from each individual were visually inspected and the number of crossings underneath the three main bridges (Oresund, Great Belt and Little Belt) and through the seven straits (Fehmarnbelt, Langeland, Samsø, Ǽbeløgård, Aerö, Sletterhage, Helsingborg) were counted. If it was not possible to identify which strait was used to get from one transmitter location to the next, that crossing was excluded from the analysis.

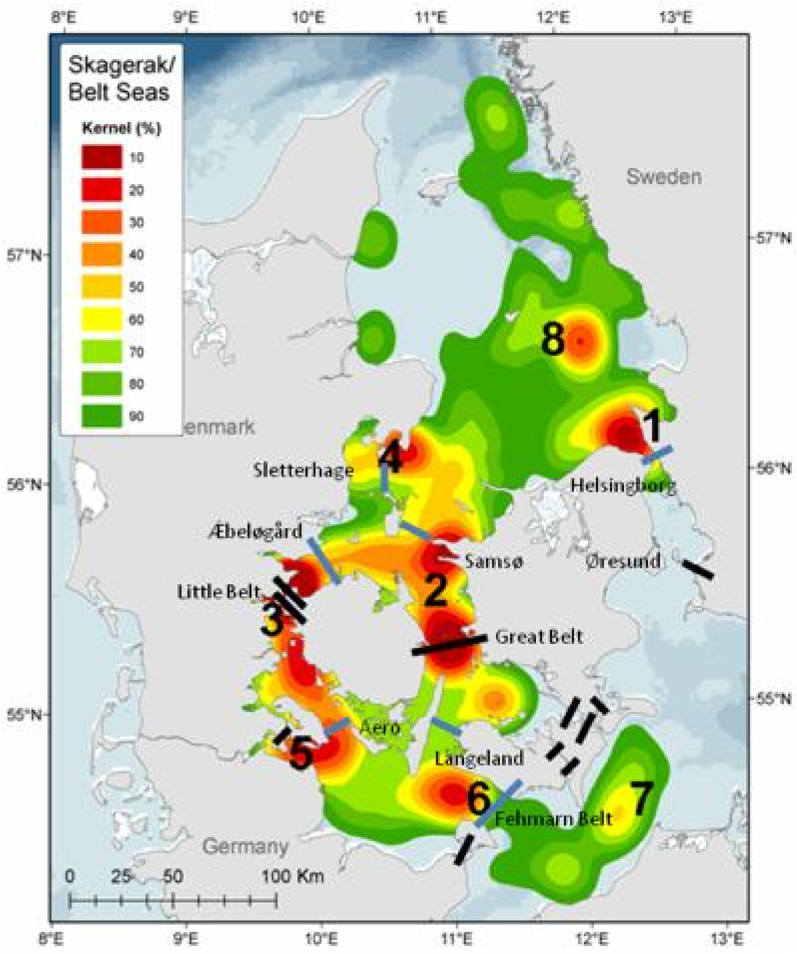


Figure 2.2-3 **Places of concentration of satellite tagged harbour porpoises in Inner Danish waters (from Sveegaard and Teilmann, 2008 with modifications). Black bars indicate existing bridges. Blue bars indicate straits without bridges.**

2.2.3. Results

2.2.3.1. Use of the Fehmarnbelt focal study area (FEHM)

How much time do porpoises spend within the Fehmarnbelt focal study area compared to the rest of their home range?

There were 5855 filtered locations in the main study area from 82 animals. Table 7.1-1 (Appendix 7.1) provides a summary of the number of locations per individual by tagging site. Only 26 animals visited FEHM, and only one of these (m012) was tagged outside the Belt Sea.

Figure 2.2-4 shows the filtered locations for all animals for each of the tagging locations. Figure 2.2-5 shows the probability that each animal provided a daily location within FEHM, corrected for the effects of year of tagging and season (see section 2.2.3.2). In this context, daily location means the probability that any one of the daily locations provided by a satellite tagged animal will be in FEHM. So, for example, ~10% of all daily locations provided by animals tagged in the Belt Sea came from FEHM. There is wide variation in this probability among individuals, with some having probabilities that are close to zero but others (e.g. m981) showing probabilities as high as 0.60, suggesting that they spent around half their time within FEHM.

The probability that an animal tagged in the Belt Sea will provide a location within FEHM is 0.105, with confidence limits of 0.073-0.149 (Figure 2.2-6). The equivalent value for an animal tagged at Fjellerup is 0.001 (confidence limits 0.000-0.007), suggesting that animals from the northern Kattegat spend little or no time in FEHM.

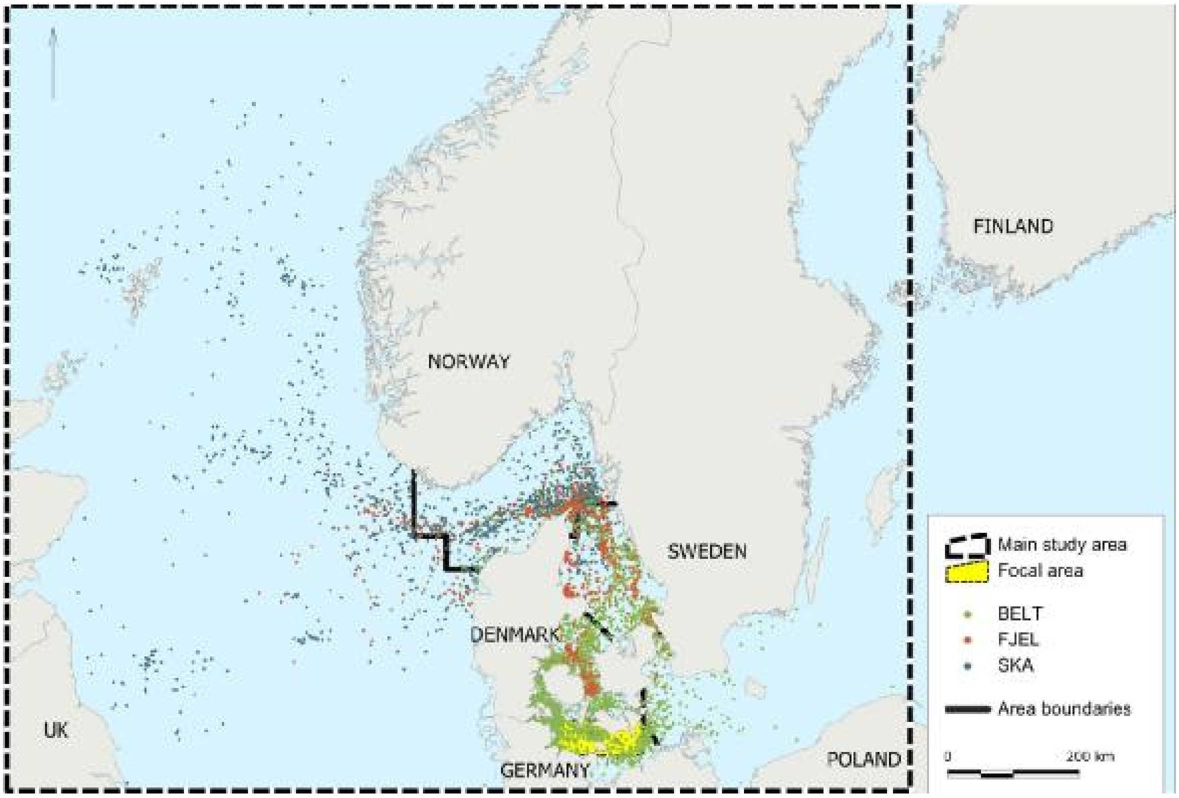


Figure 2.2-4 **Filtered locations for all 82 harbour porpoises tagged between 1997 and 2010, coloured by tagging location. BELT = green; FJEL = orange; SKA = dark blue. The Fehmarnbelt focal study area in shown in yellow.**

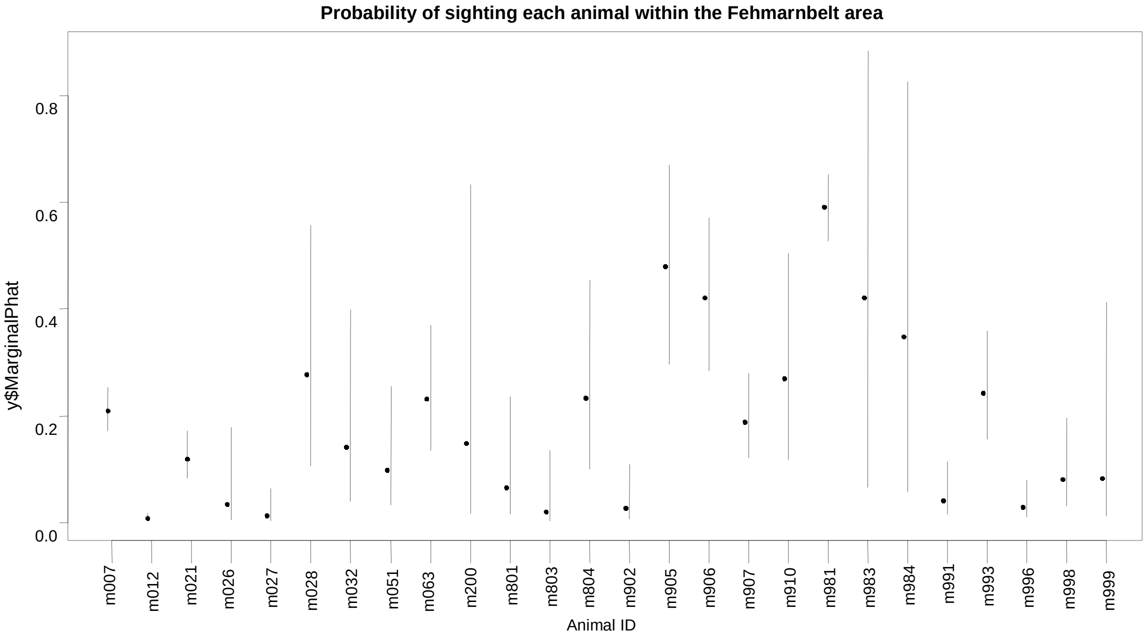


Figure 2.2-5 **Probability that each of the tagged animals gave a daily location in the Fehmarnbelt focal study area, corrected for the effects of season and year of tagging. Vertical lines indicate the confidence region for each estimated probability.**

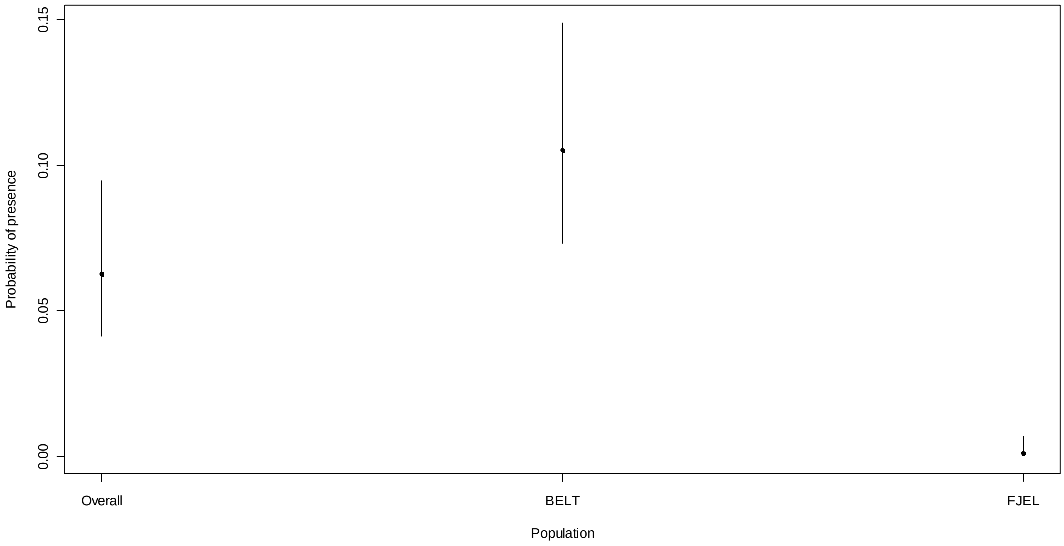


Figure 2.2-6 **Probability that animals tagged in the Belt Sea (BELT), and at Fjellerup strand (FJEL) provided a daily location within the Fehmarnbelt focal study area, together with a probability for both tagging locations combined (Overall). Vertical lines indicates the confidence region for each estimated probability.**

2.2.3.2. What factors affect the probability that a porpoise provides a location within the Fehmarnbelt focal study area?

There was evidence for a highly significant effect of tagging location (GEE based χ^2=15.71,df =1, p<0.0001), a significant effect of year (GEE based χ^2=*22.96*, df=10. p=0.011), and non significant effect of season (GEE based χ^2=7.07, df = 3, p=0.07) on the probability that a porpoise tagged in either the Belt Sea or at Fjellerup would give a daily location in FEHM. The effects of year and season on this probability for animals tagged in the Belt Sea is summarised in Figure 2.2-7. The significant year effect means that probabilities in at least two years differ from each other. This is while accounting for all other things retained in the model. It does not necessarily mean probabilities in each year are all different from each other. In years where tags were applied in all seasons, probability of presence in the FEHM tended to be highest in winter. However, the analysis of tracks of individuals followed both summer and winter show that at least some of them leave the Belt Sea for winter and stay in warmer waters (see Chapter 2.2.3.5 and Figure 2.2-24).

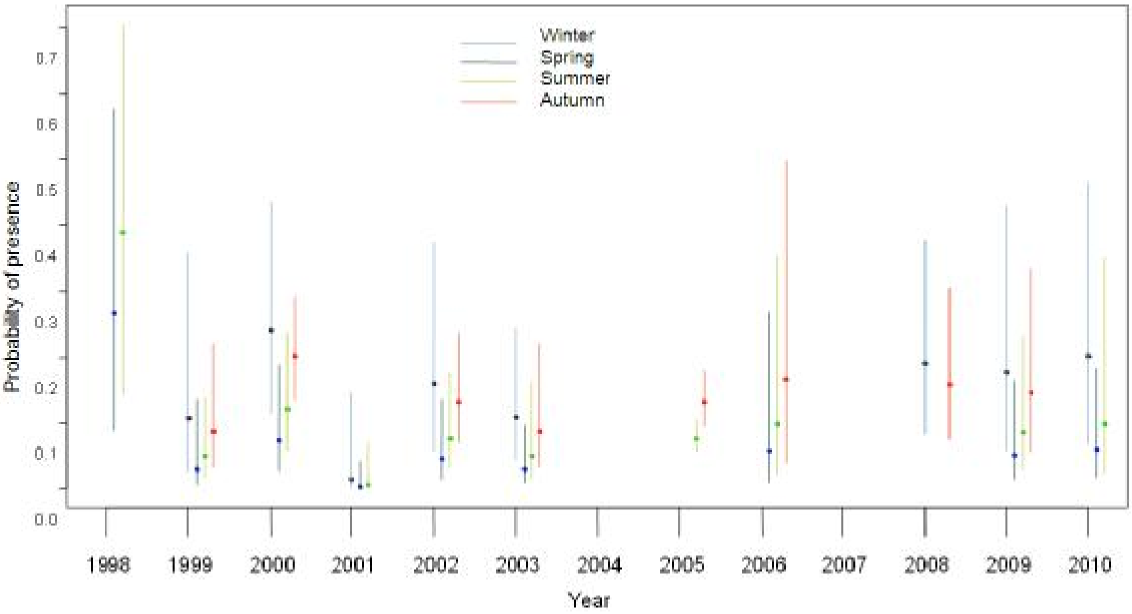


Figure 2.2-7 **Estimated probability that a harbour porpoise tagged in the Belt Sea provided a daily location in the Fehmarnbelt focal study area by season for each of the years in which tags were applied.**

2.2.3.3. Use of space by animals tagged in the Belt Sea and elsewhere in central and northern Danish waters

How do home ranges of porpoises tagged in the Belt Sea compare to home ranges of individuals tagged elsewhere in the Baltic?

The analyses conducted in relation to question 1 (section 2.2.3.1), and question 3 (section 2.2.3.3) clearly indicated that there was a great deal of individual variation in the distribution of animals tagged at each of the three locations. The nature and effect of this variation would be lost if information from all animals tagged at the same site was pooled, for example to create a single kernel for their use of space. We therefore adopted an approach to question 3 (how do the home ranges of porpoises tagged in the Belt Sea compare to home ranges of individuals tagged elsewhere in central/northern Danish waters?) that took account of individual differences and allowed us to calculate the uncertainty associated with estimates of the way in which animals from different tagging locations used the waters of the Baltic Sea.

Figure 2.2-8 shows how the probability that a tagged animal will provide a location in a particular grid cell varies across the study area, averaged across all tagging locations, years and seasons. Figure 2.2-9 shows the uncertainty associated with these probabilities, represented by the ratio of the confidence interval to the probability of detection (which can be thought of as a representation of the coefficient of variation of these values). In general, the highest probabilities are in the Skagerrak and Belt Sea, confirming the importance of these areas for harbour porpoises in the Baltic.

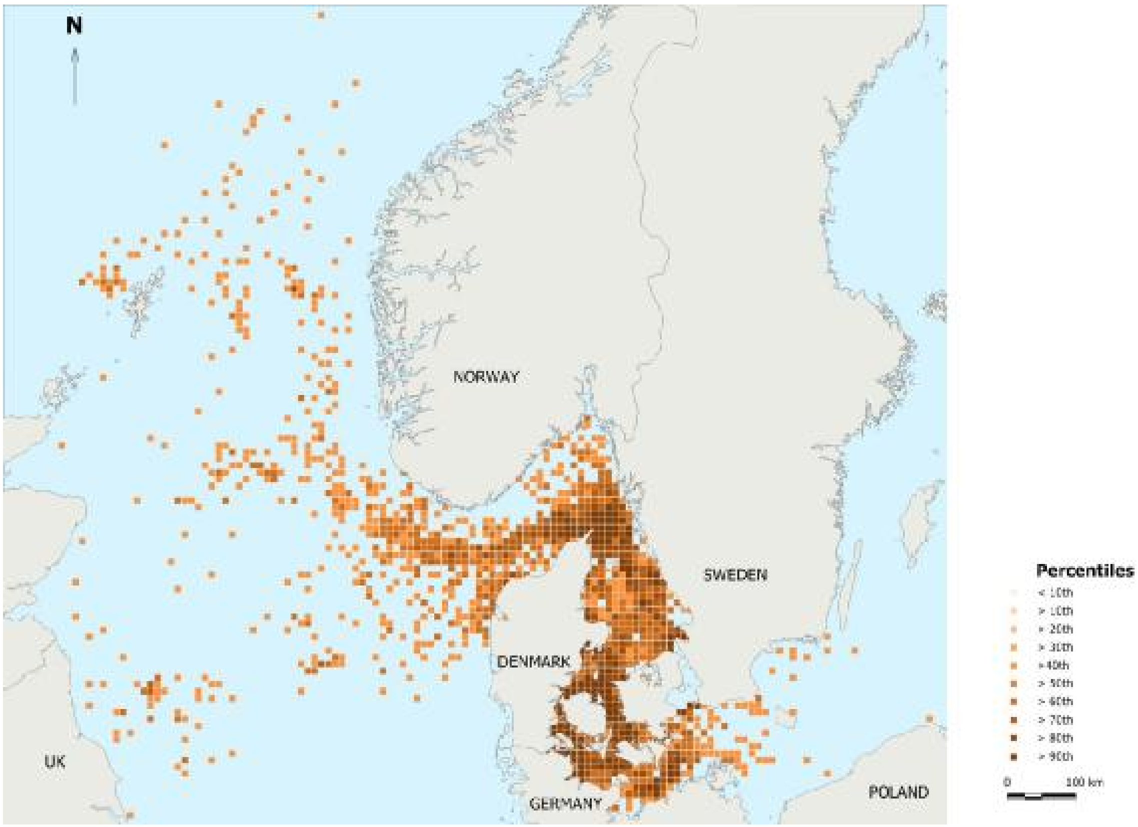


Figure 2.2-8 **Probability that a satellite-tagged harbour porpoise will provide a location in a particular part of the study area, averaged across tagging locations, years and seasons.**

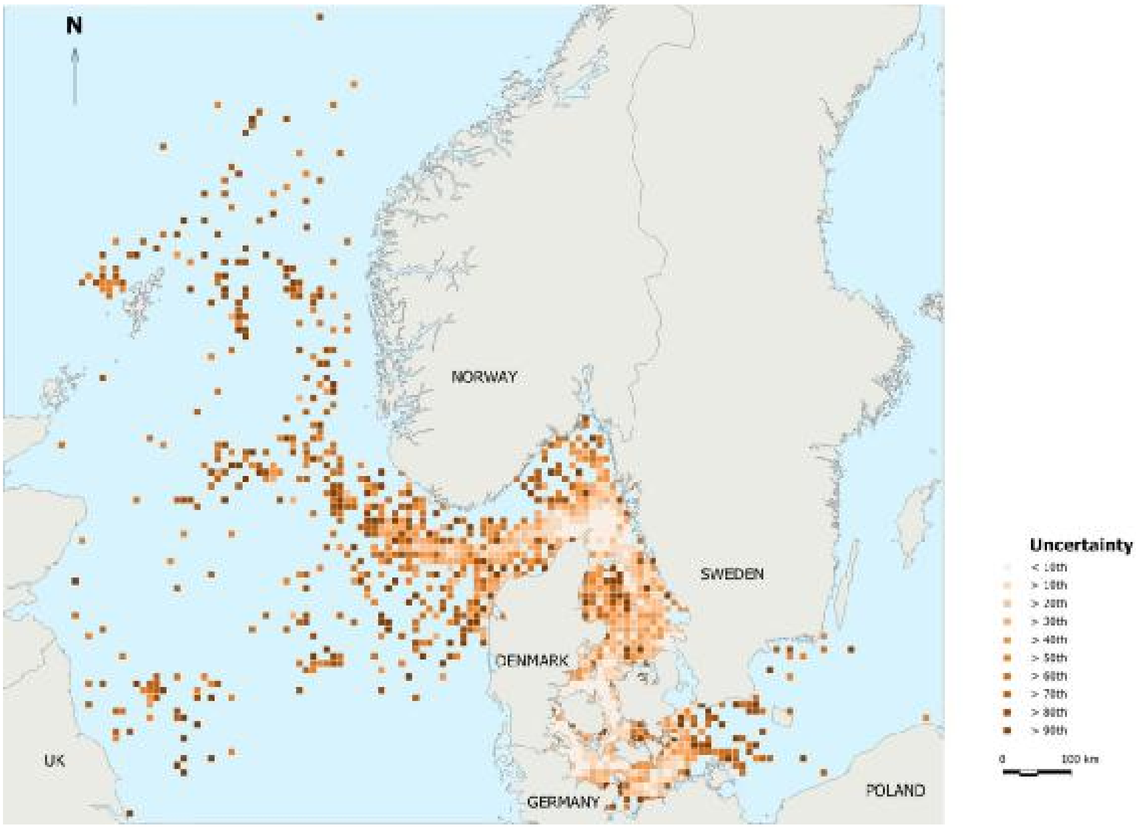


Figure 2.2-9 **Uncertainty (represented by the ratio of the confidence interval to the probability of detection) associated with the estimates of the probability that a satellite-tagged harbour porpoise will provide a location in a particular part of the study area, averaged across tagging locations, years and seasons.**

Figure 2.2-10 shows these same probabilities coded by the tagging location of the porpoises that provided the *majority of data* for each cell. Animals tagged in the Skagerrak are most likely to be located in the Skagerrak and North Sea, animals tagged in the Belt Sea are most likely to be located there, and animals tagged at Fjellerup in the northern Kattegat show a use of the study area that is intermediate between that of animals from the other two tagging locations.

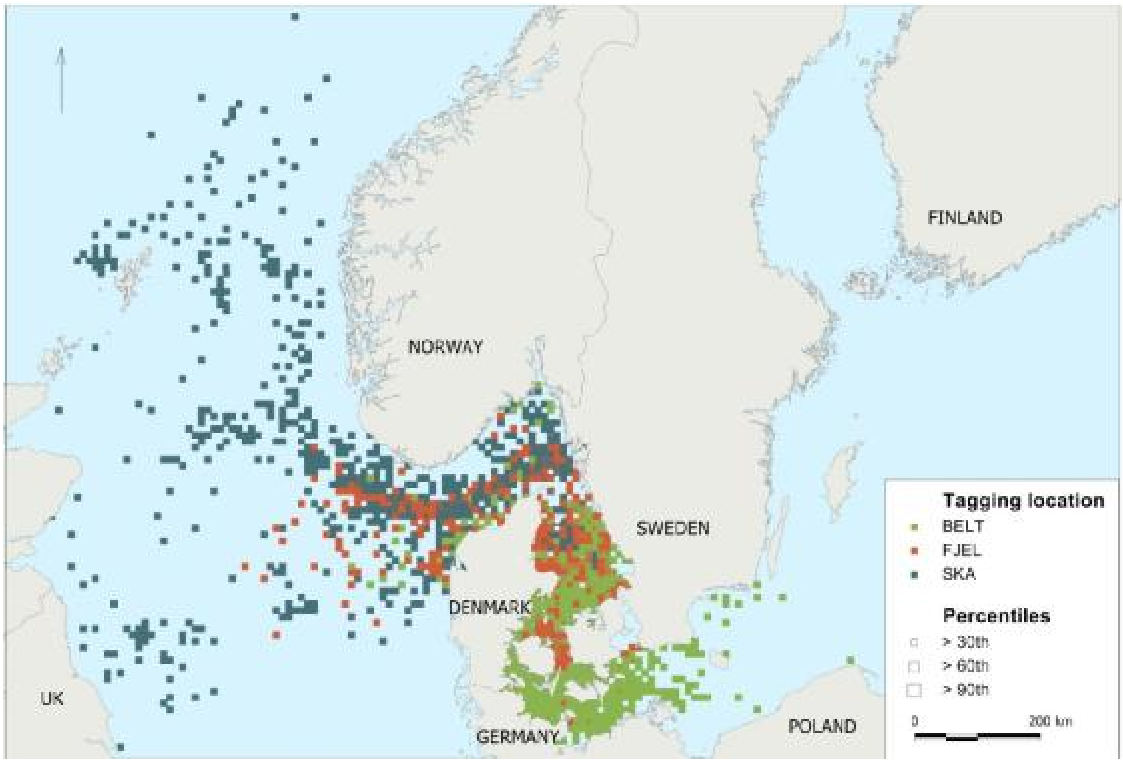
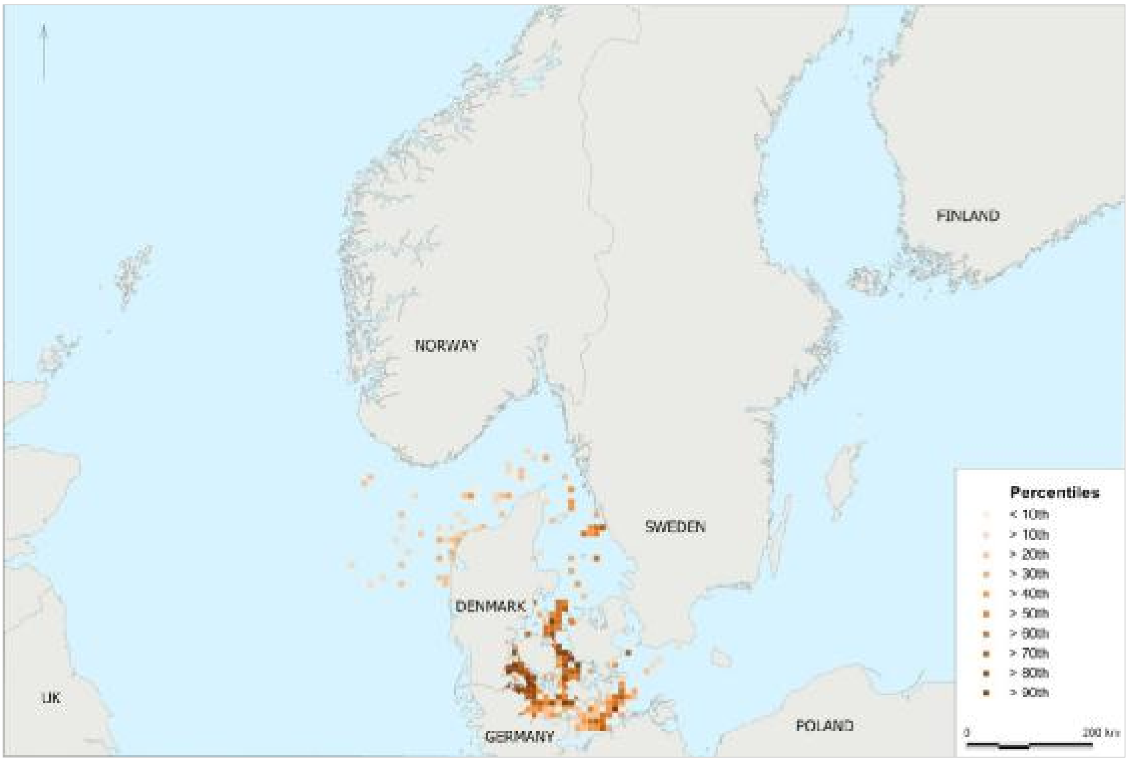


Figure 2.2-10 **Probability that a satellite-tagged harbour porpoise will be located in a particular part of the study area. Grid cells are colour-coded by the tagging location that provided most data for each cell.**

Figure 2.2-11 to Figure 2.2-14 show how the use of the study area varies among seasons for animals from the three different tagging locations. For the combined data of all tagged animals, there appears to be rather little variation between seasons in the way in which animals tagged in the Belt Sea used the study area. In all seasons the highest probabilities are in the Belt Sea area. However, the analysis of movements of individuals from the Belt Sea tracked in summer and winter gives examples of a clear pattern of seasonal movements (Chapter 2.2.3.5).Animals tagged at Skagen, in the Skagerrak, show a more marked seasonal variation with cells in the North Sea more likely to be used in the winter and autumn, and cells in the northern Kattegat more likely to be used in the spring. Once again, the distribution of animals tagged at Fjellerup is intermediate between that of animals from the other two tagging sites. They are more widely dispersed than animals that were tagged in the Belt Sea, but there is no clear evidence of seasonal changes in distribution.

As noted at the beginning of this section, it is important to understand the level of uncertainty that is associated with the estimate of the probability that a tagged porpoise will be located in a particular grid cell in a particular season. This is shown in the bottom row in Figure 2.2-11 to Figure 2.2-14. The greatest uncertainty is associated with the use of the Belt Sea by animals tagged in the Skagerrak, and the use of the northern Kattegat by animals tagged in the Belt Sea. There is more widespread uncertainty about the way in which animals tagged in the northern Kattegat used the study area.



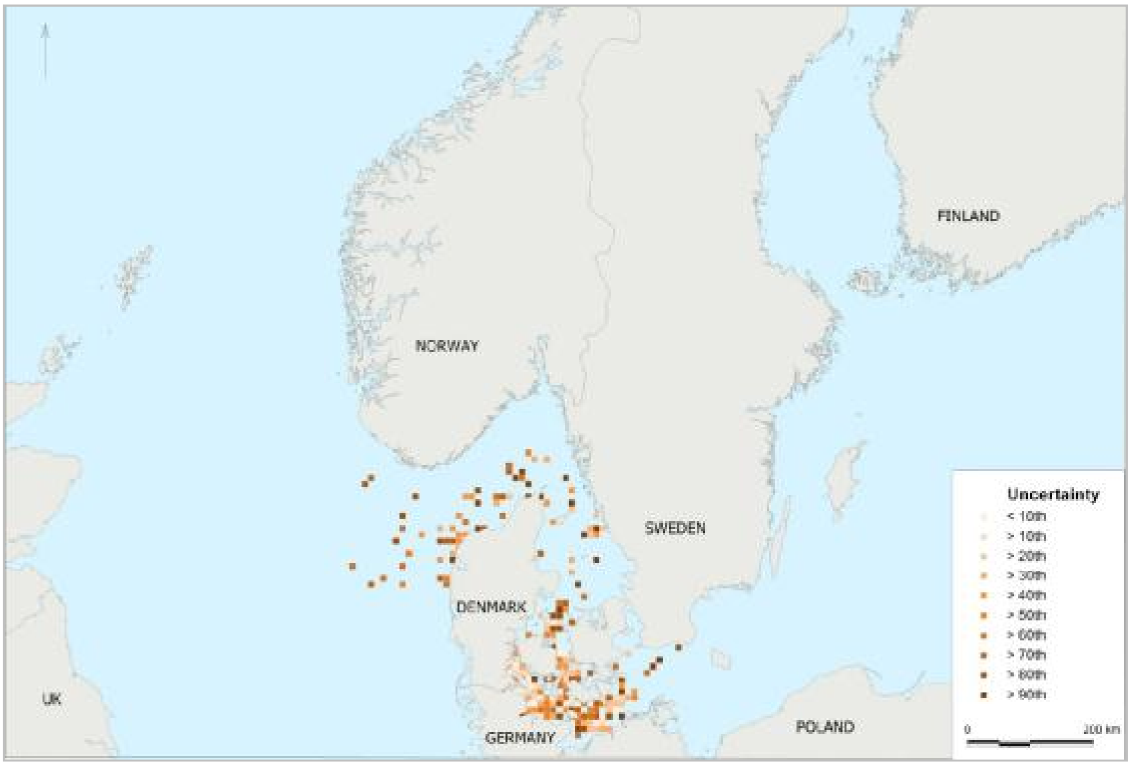


Figure 2.2-11a **Variation (top) in the probability that a harbour porpoise tagged in BELT will be located in a particular part of the study area in the winter. Respective uncertainty (represented by the ratio of the confidence region to the probability of location) associated with the estimates of the probability of locating a satellite-tagged harbour porpoise in different parts of the study area shown on the bottom.**

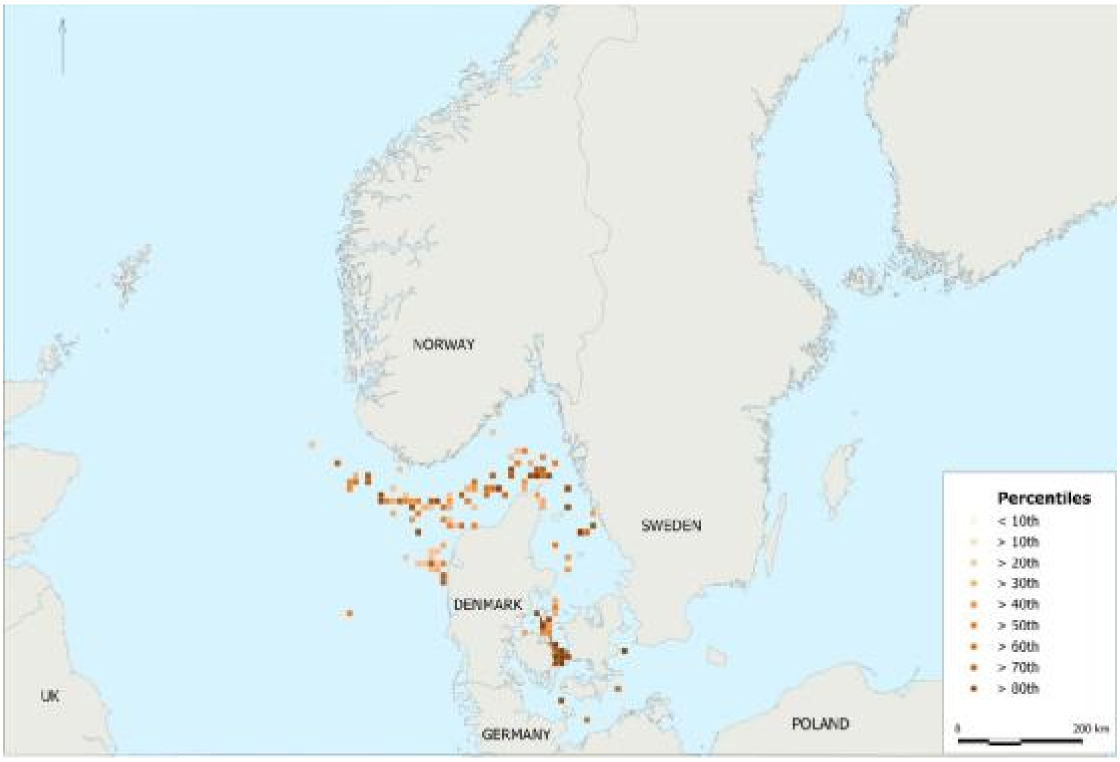


Figure 2.2-11b **Variation (top) in the probability that a harbour porpoise tagged in FJEL will be located in a particular part of the study area in the winter. Respective uncertainty (represented by the ratio of the confidence region to the probability of location) associated with the estimates of the probability of locating a satellite-tagged harbour porpoise in different parts of the study area shown on the bottom.**

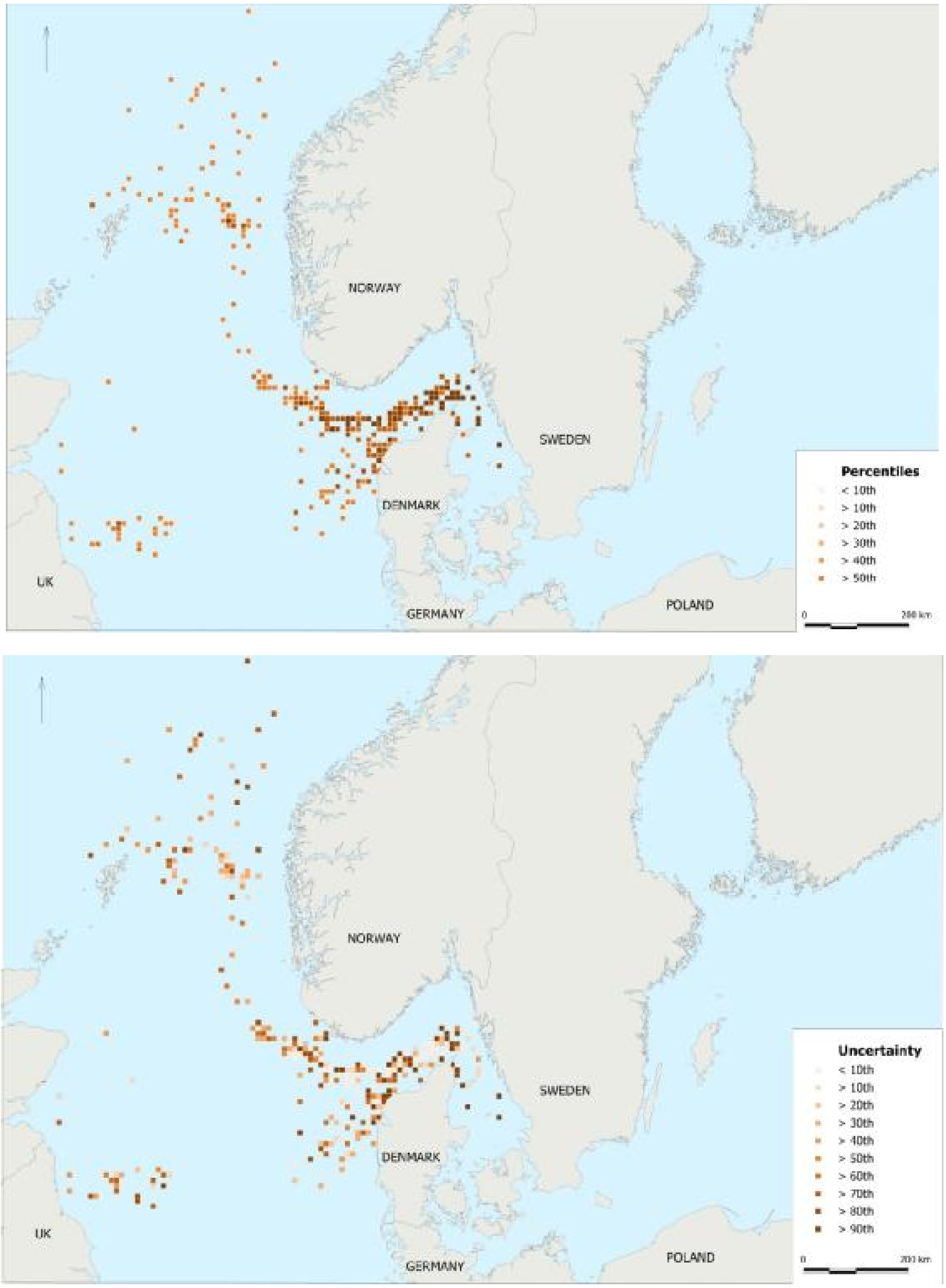


Figure 2.2-11c Variation (top) in the probability that a harbour porpoise tagged in SKA will be located in a particular part of the study area in the winter. Respective uncertainty (represented by the ratio of the confidence region to the probability of location) associated with the estimates of the probability of locating a satellite-tagged harbour porpoise in different parts of the study area shown on the bottom.

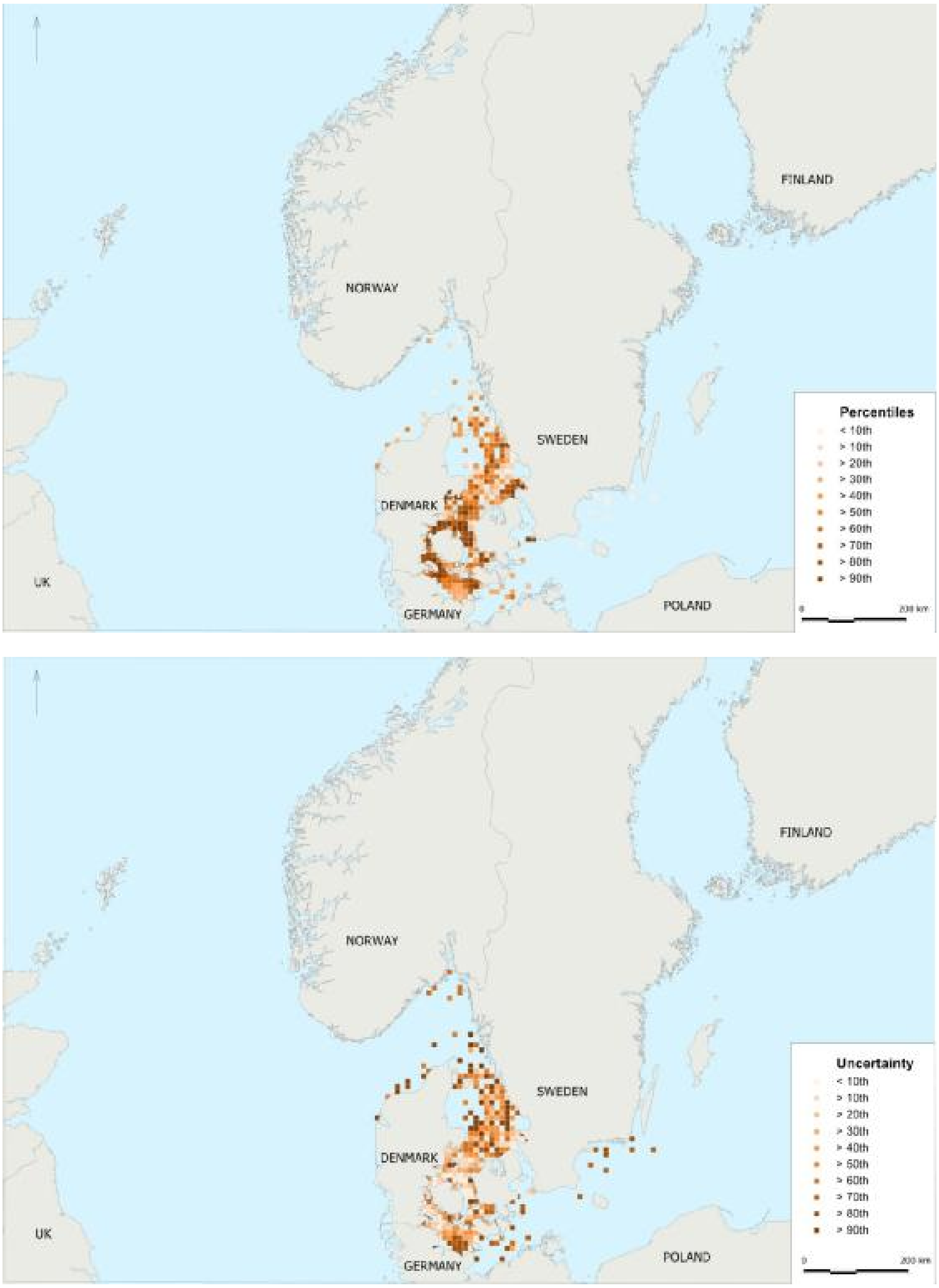


Figure 2.2-12a **Variation (top) in the probability that a harbour porpoise tagged in BELT will be located in a particular part of the study area in the spring. Respective uncertainty (represented by the ratio of the confidence region to the probability of location) associated with the estimates of the probability of locating a satellite-tagged harbour porpoise in different parts of the study area shown on the bottom.**

Figure 2.2-12b **Variation (top) in the probability that a harbour porpoise tagged in FJEL will be located in a particular part of the study area in the spring. Respective uncertainty (represented by the ratio of the confidence region to the probability of location) associated with the estimates of the probability of locating a satellite-tagged harbour porpoise in different parts of the study area shown on the bottom.**

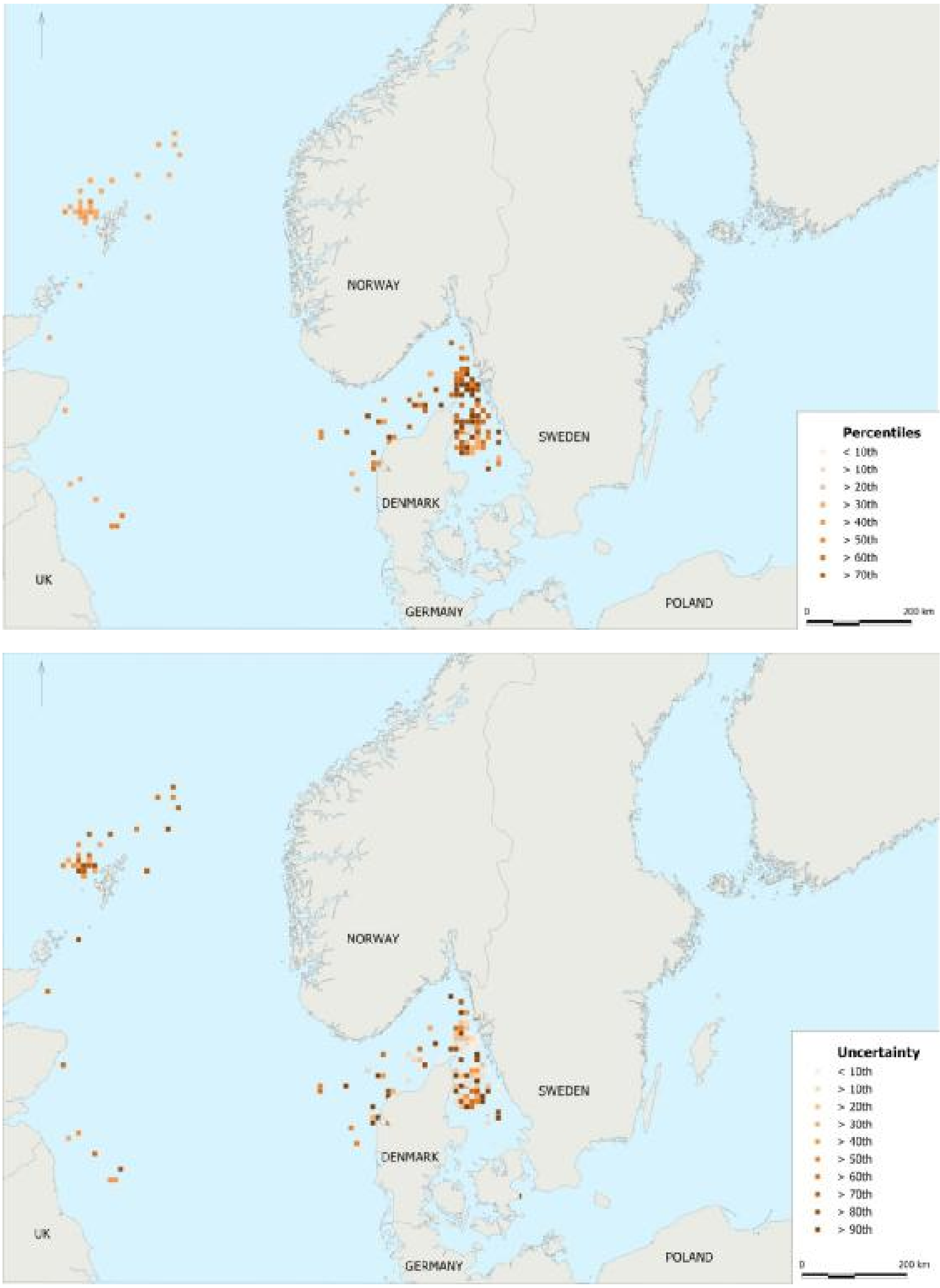


Figure 2.2-12c Variation (top) in the probability that a harbour porpoise tagged in SKA will be located in a particular part of the study area in the spring. Respective uncertainty (represented by the ratio of the confidence region to the probability of location) associated with the estimates of the probability of locating a satellite-tagged harbour porpoise in different parts of the study area shown on the bottom.

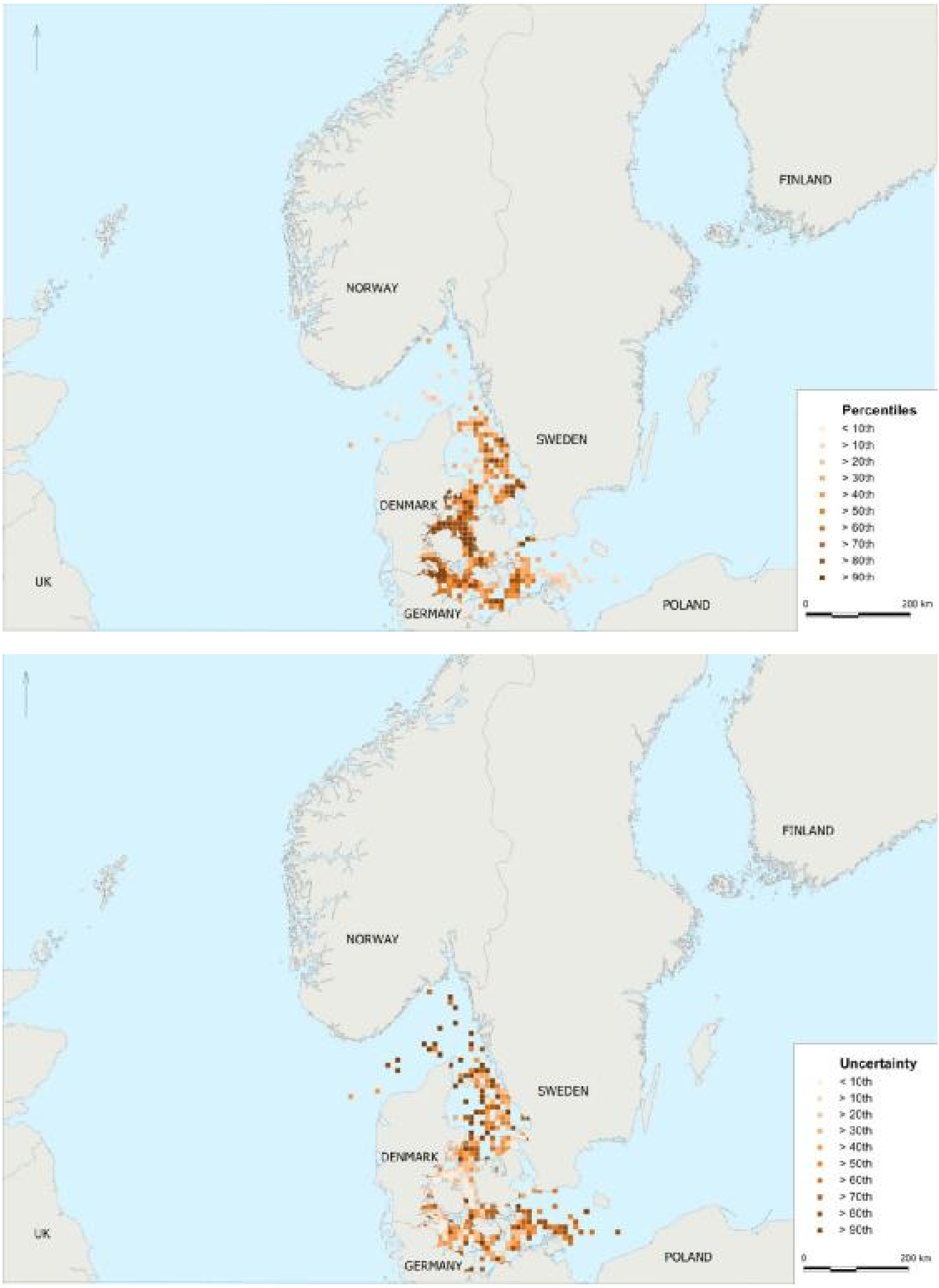


Figure 2.2-13a Variation (top) in the probability that a harbour porpoise tagged in BELT will be located in a particular part of the study area in the summer. Respective uncertainty (represented by the ratio of the confidence region to the probability of location) associated with the estimates of the probability of locating a satellite-tagged harbour porpoise in different parts of the study area shown on the bottom.

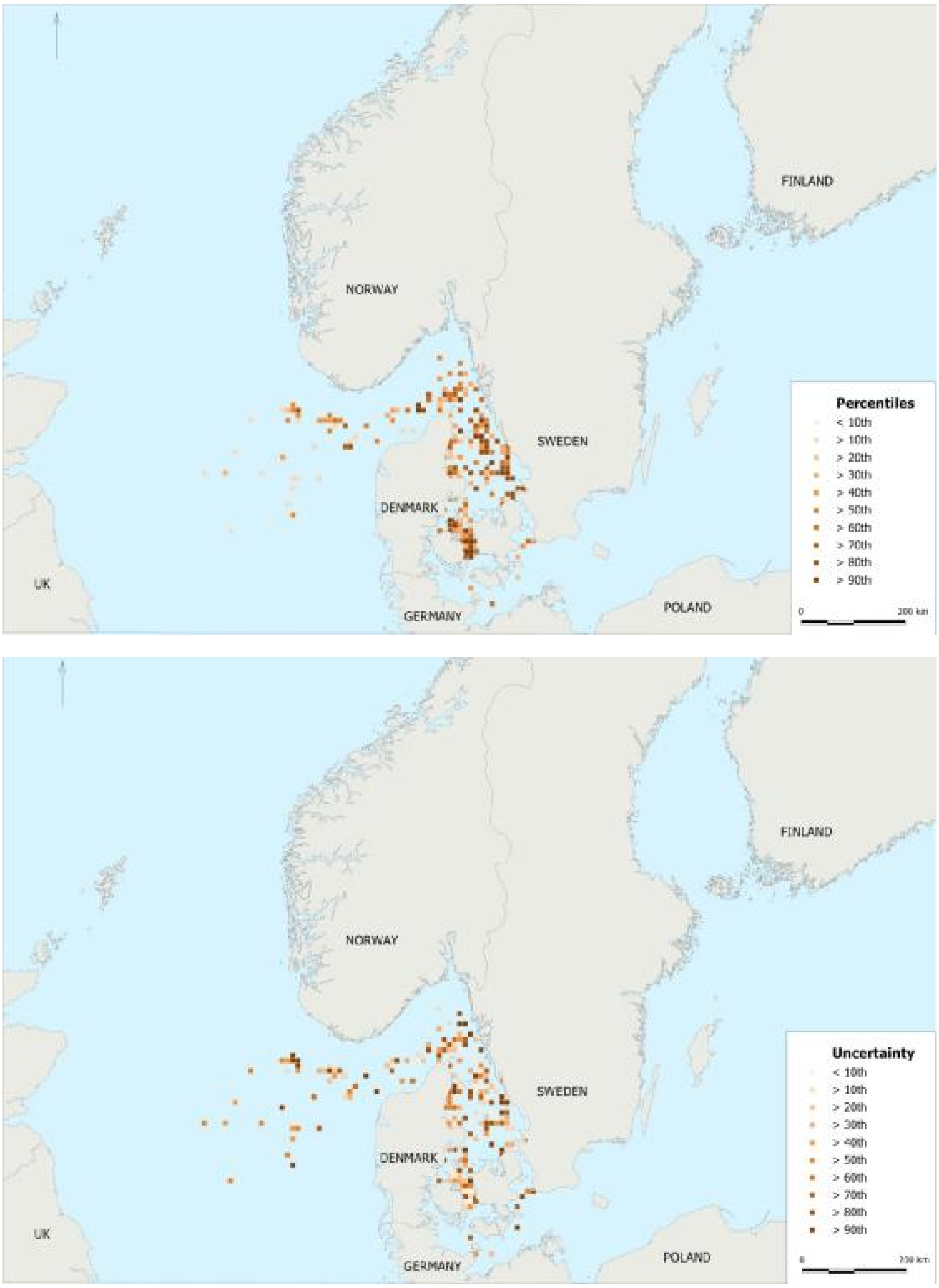


Figure 2.2-13b Variation (top) in the probability that a harbour porpoise tagged in FJEL will be located in a particular part of the study area in the summer. Respective uncertainty (represented by the ratio of the confidence region to the probability of location) associated with the estimates of the probability of locating a satellite-tagged harbour porpoise in different parts of the study area shown on the bottom.

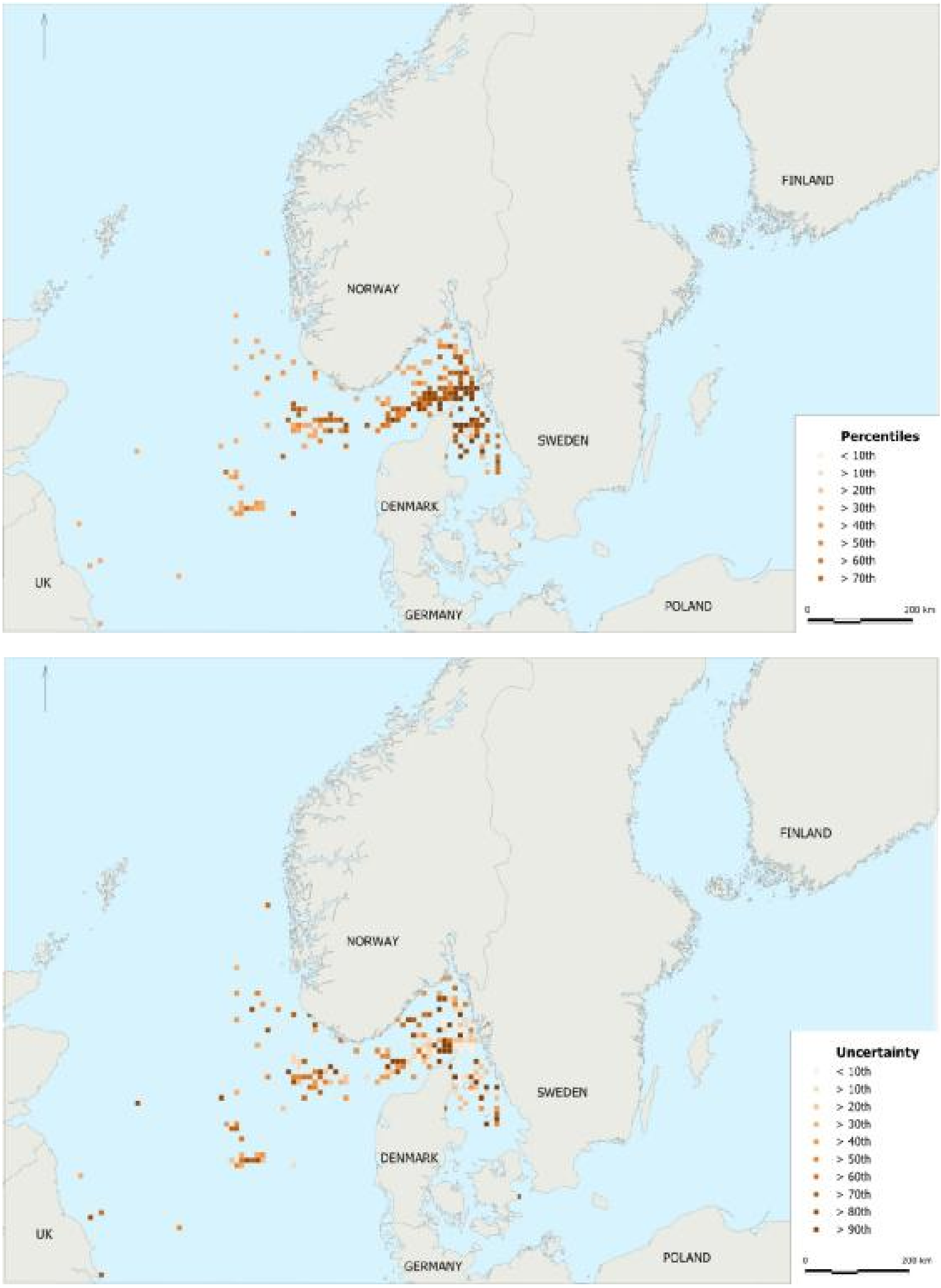


Figure 2.2-13c Variation (top) in the probability that a harbour porpoise tagged in SKA will be located in a particular part of the study area in the summer. Respective uncertainty (represented by the ratio of the confidence region to the probability of location) associated with the estimates of the probability of locating a satellite-tagged harbour porpoise in different parts of the study area shown on the bottom.

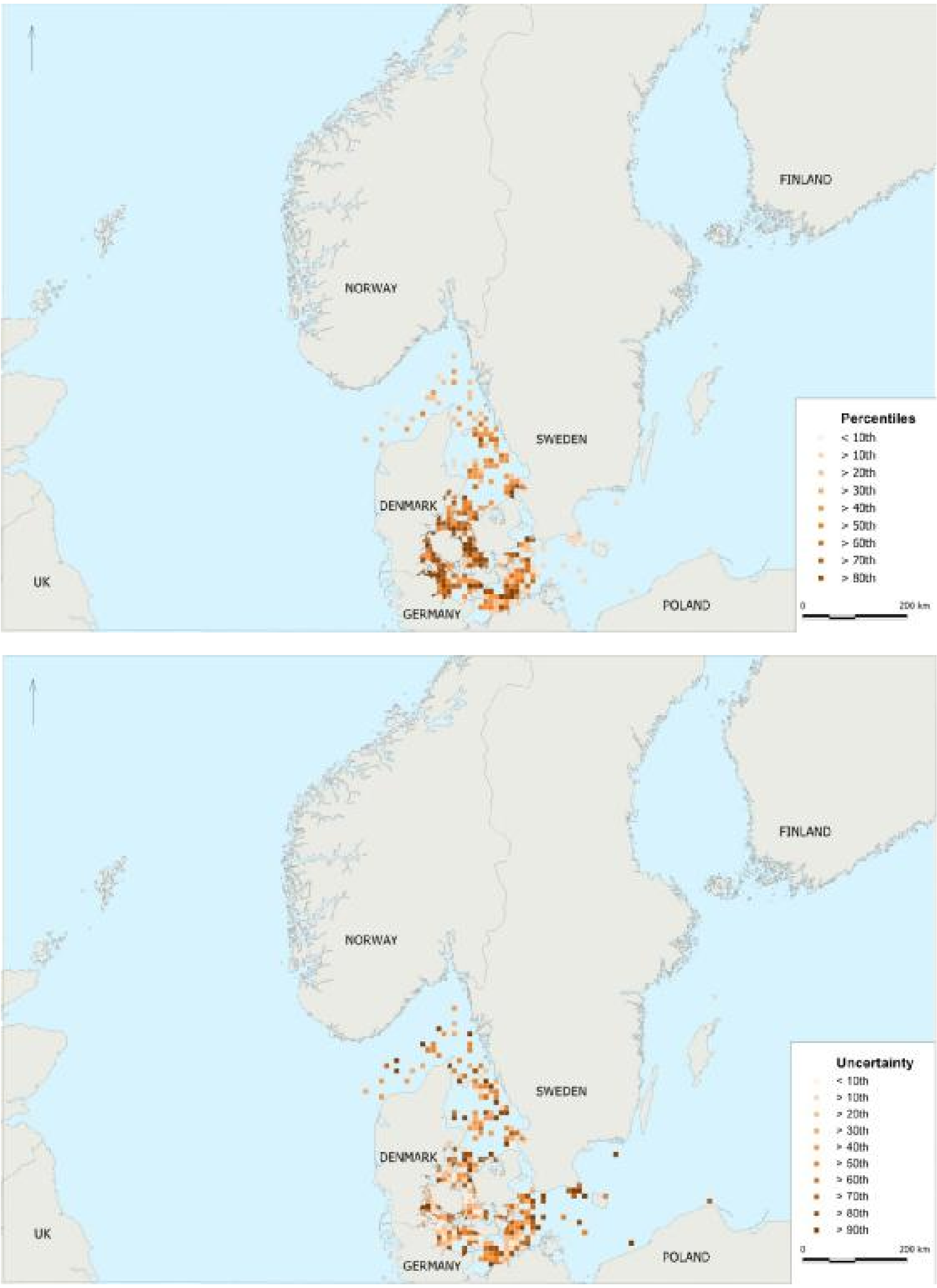


Figure 2.2-14a Variation (top) in the probability that a harbour porpoise tagged in BELT will be located in a particular part of the study area in the autumn. Respective uncertainty (represented by the ratio of the confidence region to the probability of location) associated with the estimates of the probability of locating a satellite-tagged harbour porpoise in different parts of the study area shown on the bottom.

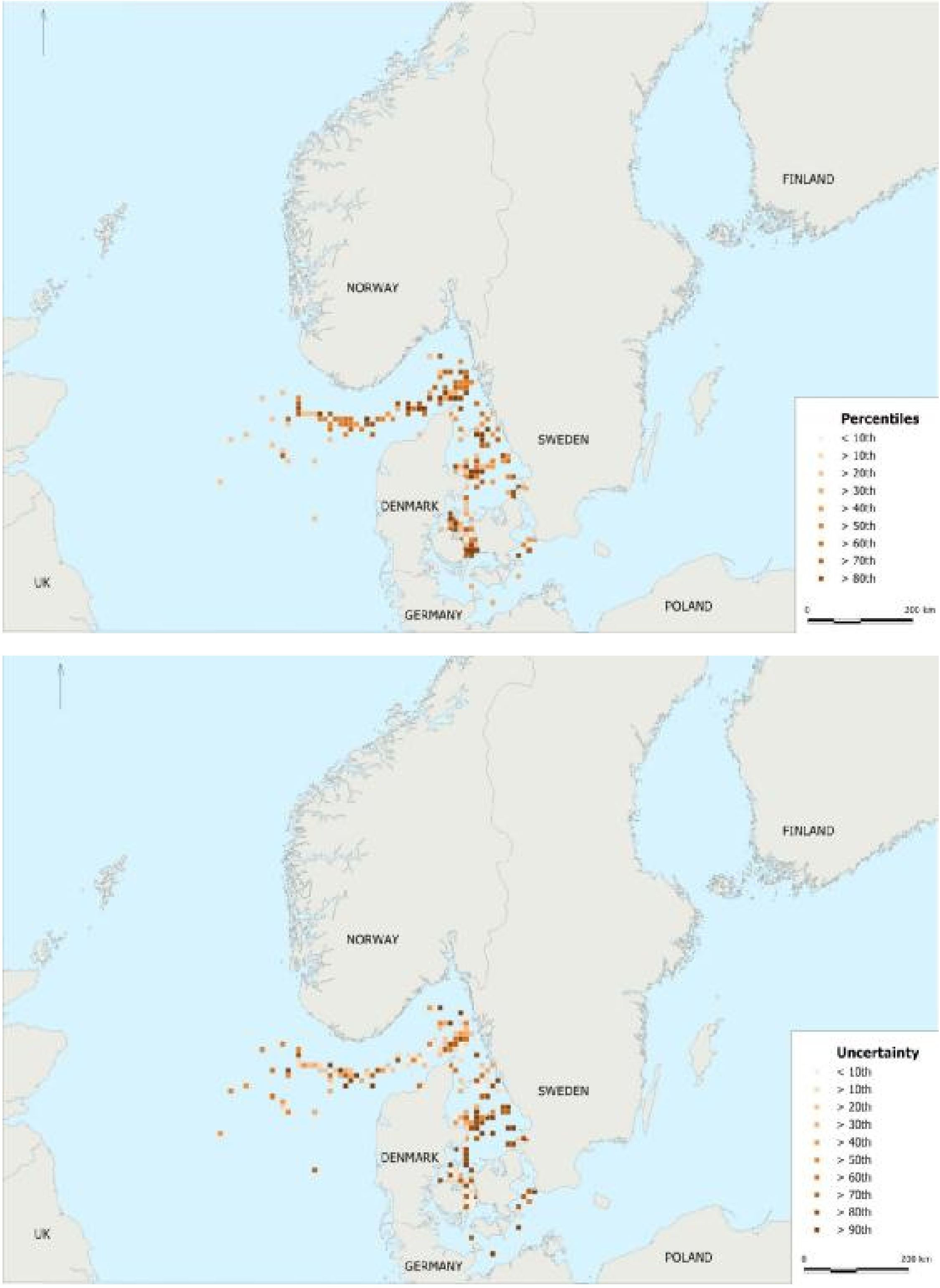


Figure 2.2-14b **Variation (top) in the probability that a harbour porpoise tagged in FJEL will be located in a particular part of the study area in the autumn. Respective uncertainty (represented by the ratio of the confidence region to the probability of location) associated with the estimates of the probability of locating a satellite-tagged harbour porpoise in different parts of the study area shown on the bottom.**

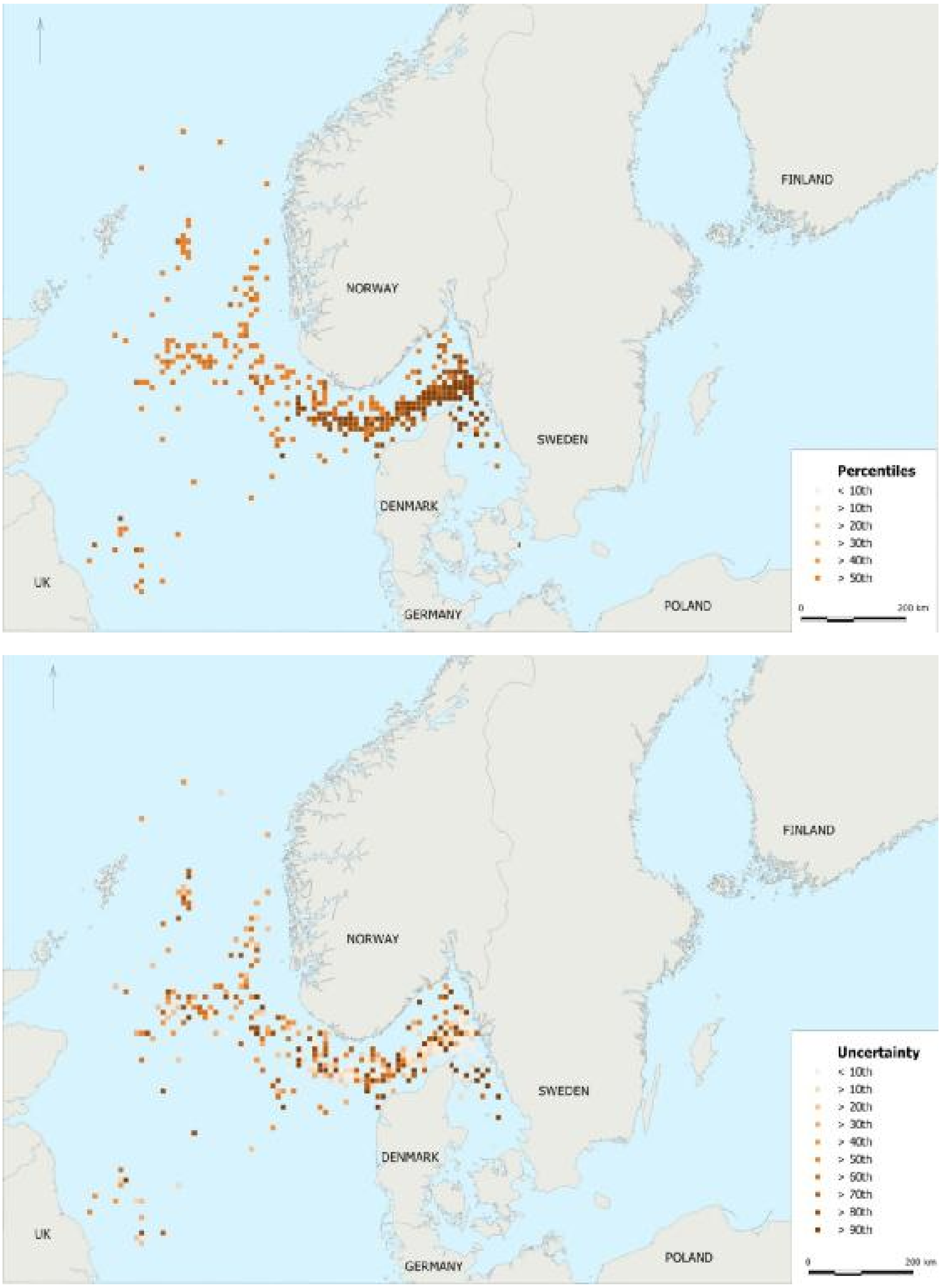


Figure 2.2-14c Variation (top) in the probability that a harbour porpoise tagged in SKA will be located in a particular part of the study area in the autumn. Respective uncertainty (represented by the ratio of the confidence region to the probability of location) associated with the estimates of the probability of locating a satellite-tagged harbour porpoise in different parts of the study area shown on the bottom.

The analysis we performed allowed us to identify those parts of the study area where season, year of tagging, and tagging location has a significant effect on the probability that a satellite-tagged porpoise was located. These areas are shown in Figure 2.2-15 to Figure 2.2-17. There is no clear pattern to the effect of season and year, although it appears (unsurprisingly) that both are more likely to be significant factors in grid cells that provided relatively large numbers of locations. However, there does appear to be a clear pattern in the effect of tagging location, which is most likely to be a significant factor in the Skagerrak and northern Kattegat, and in the waters to the north of the Great and Little Belts.

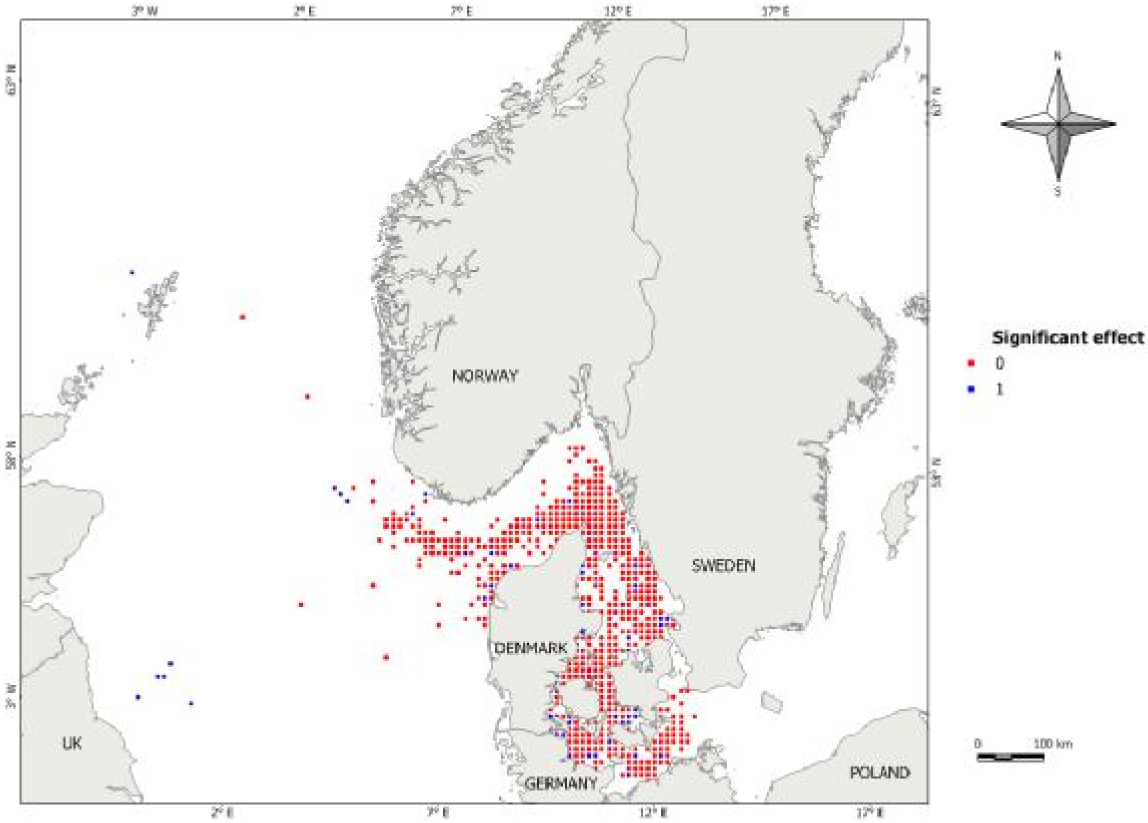


Figure 2.2-15 **Effect of season on the probability that a satellite-tagged harbour porpoise will be detected in different parts of the study area. Grid cells where the season had a significant effect are shown in blue.**

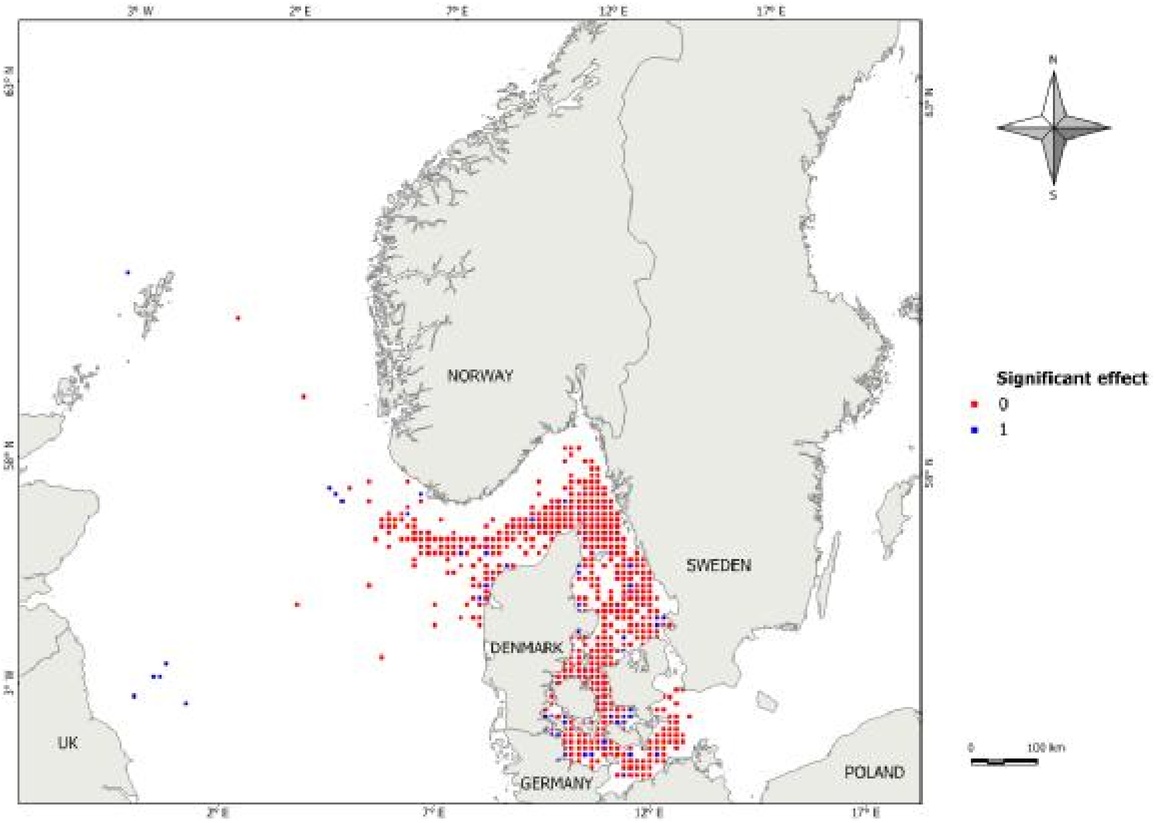


Figure 2.2-16 Effect of year on the probability that a satellite-tagged harbour porpoise will be detected in different parts of the study area. Grid cells where year had a significant effect are shown in blue.

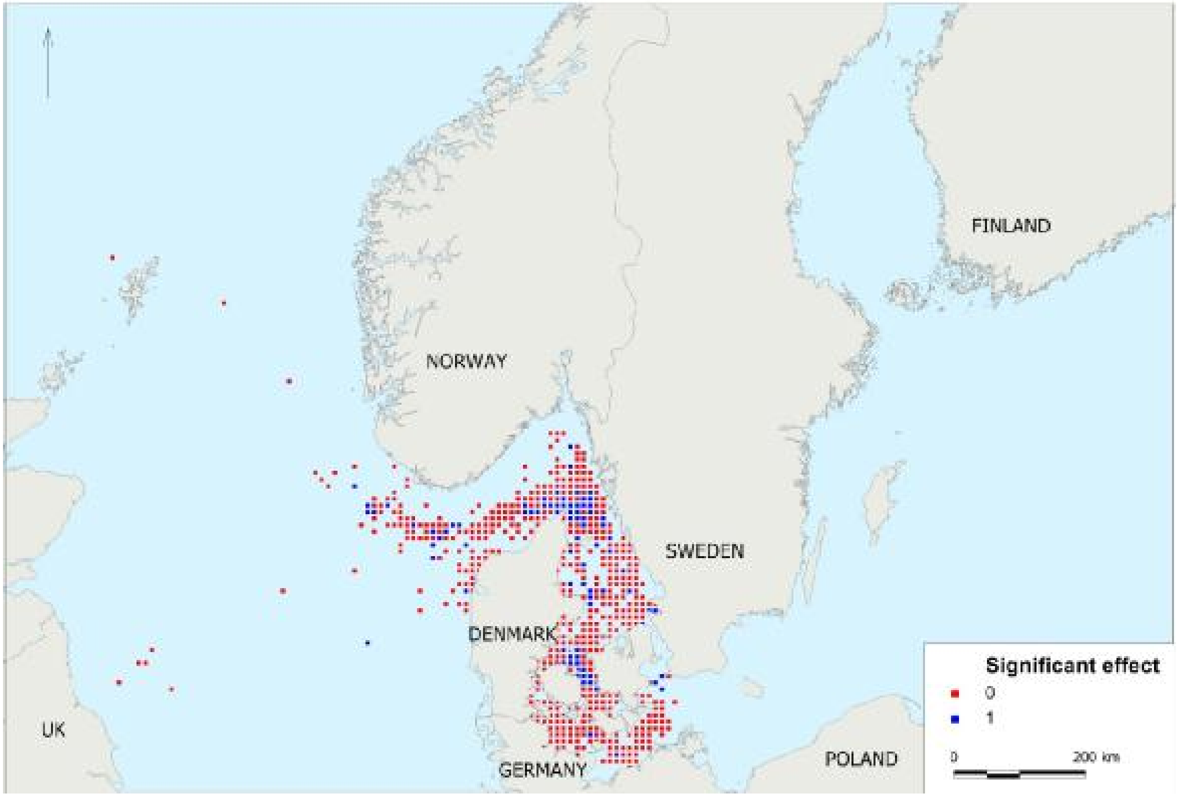


Figure 2.2-17 **Effect of tagging location on the probability that a satellite-tagged harbour porpoise will be detected in different parts of the study area. Grid cells where tagging location had a significant effect are shown in blue.**

2.2.3.4. Identifying local populations

The dendrogram constructed using the distance measure described by Equation 2.1 (Figure 2.2-18) provided no evidence for the presence of local populations within the population units identified by Wiemann et al. (2010). The only clearly identifiable clusters involved the individuals m994, m995 and m996. All of these animals were tagged in the Belt Sea. However, the main characteristic of their use of space is that all remained close to the site at which they were tagged throughout the period that their tags were functioning.

Because there is evidence that some of the animals tagged in the Skagerrak and the Belt Sea use different parts of the study area in summer and winter, the analysis was repeated using only locations obtained in June and July, and during December and January. However, neither of the resulting dendrograms (Figure 2.2-19 and Figure 2.2-20) provided any evidence of local population structure.

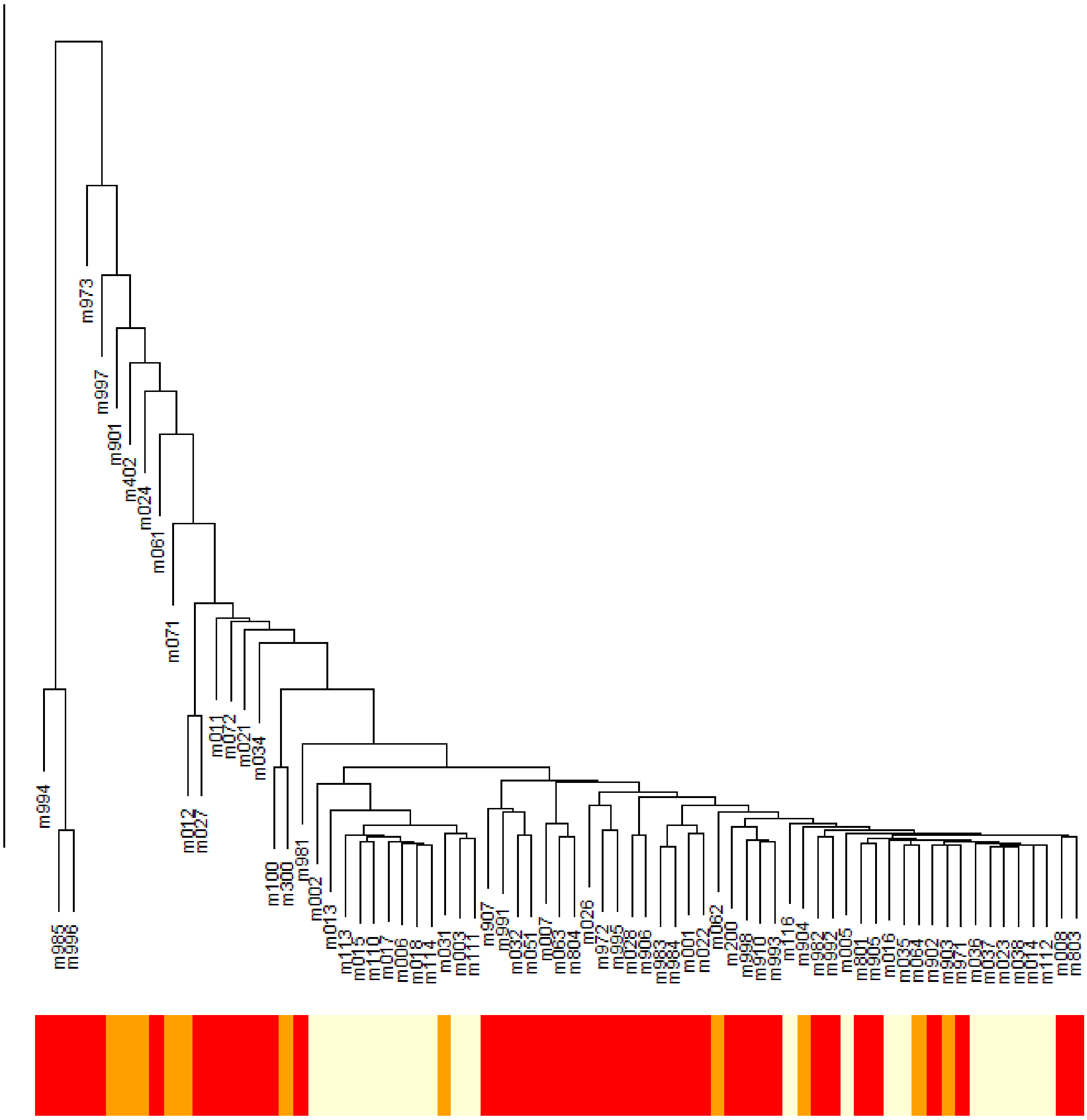


Figure 2.2-18 Dendrogram based on the differences between home ranges of all tagged harbour porpoises. Home ranges were estimated by kernel smoothing all location data (subject to the constraints mentioned in the text) for each individual. Colour coding indicates the site at which animals were tagged. BELT = red; FJEL = orange; SKA = cream.

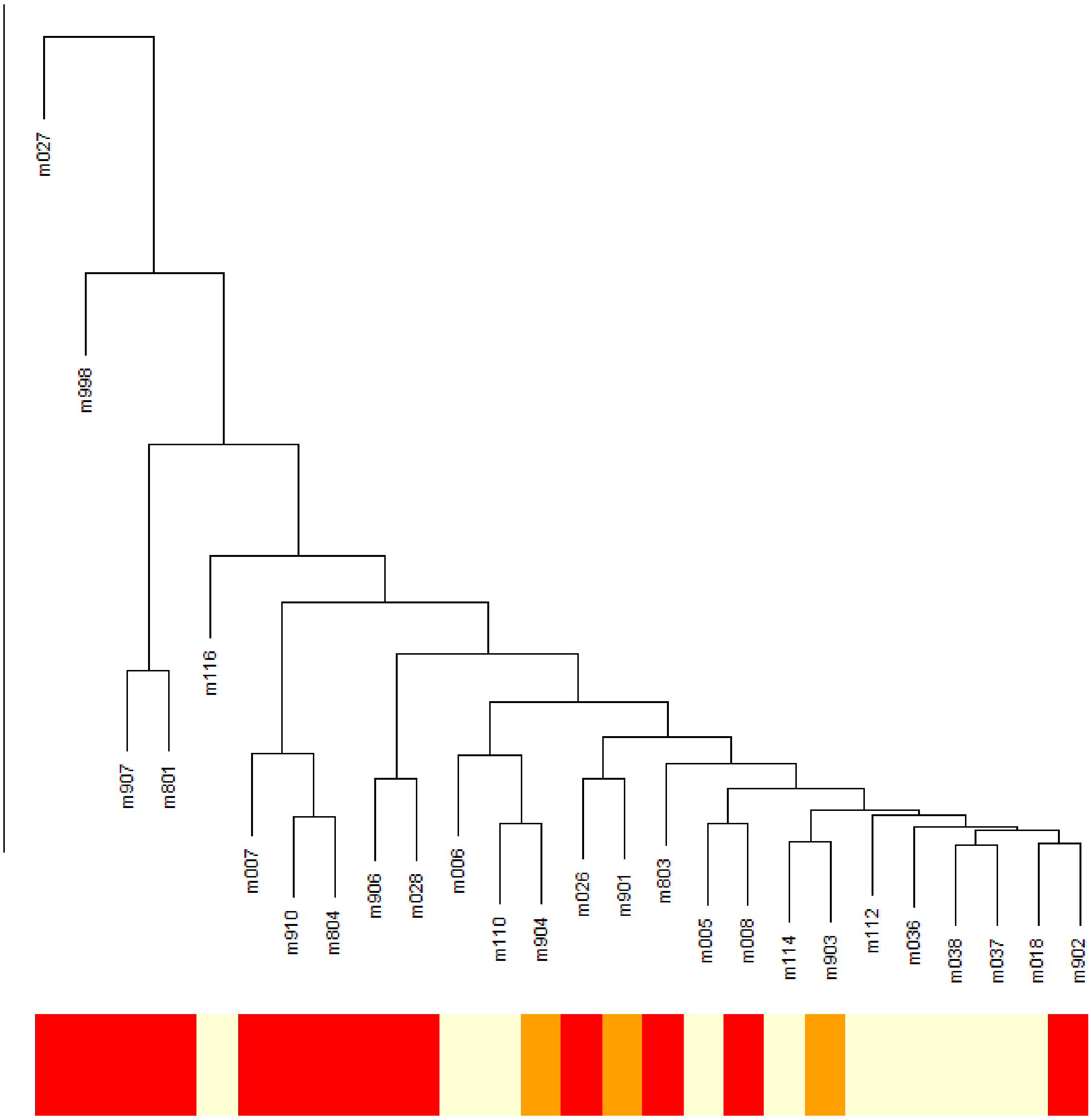


Figure 2.2-19 Dendrogram based on the differences between home ranges of all tagged harbour porpoises in winter. Winter home ranges were estimated by kernel smoothing all locations (subject to the constraints mentioned in the text) in December and January. Colour coding indicates the site at which animals were tagged. BELT = red; FJEL = orange; SKA = cream.

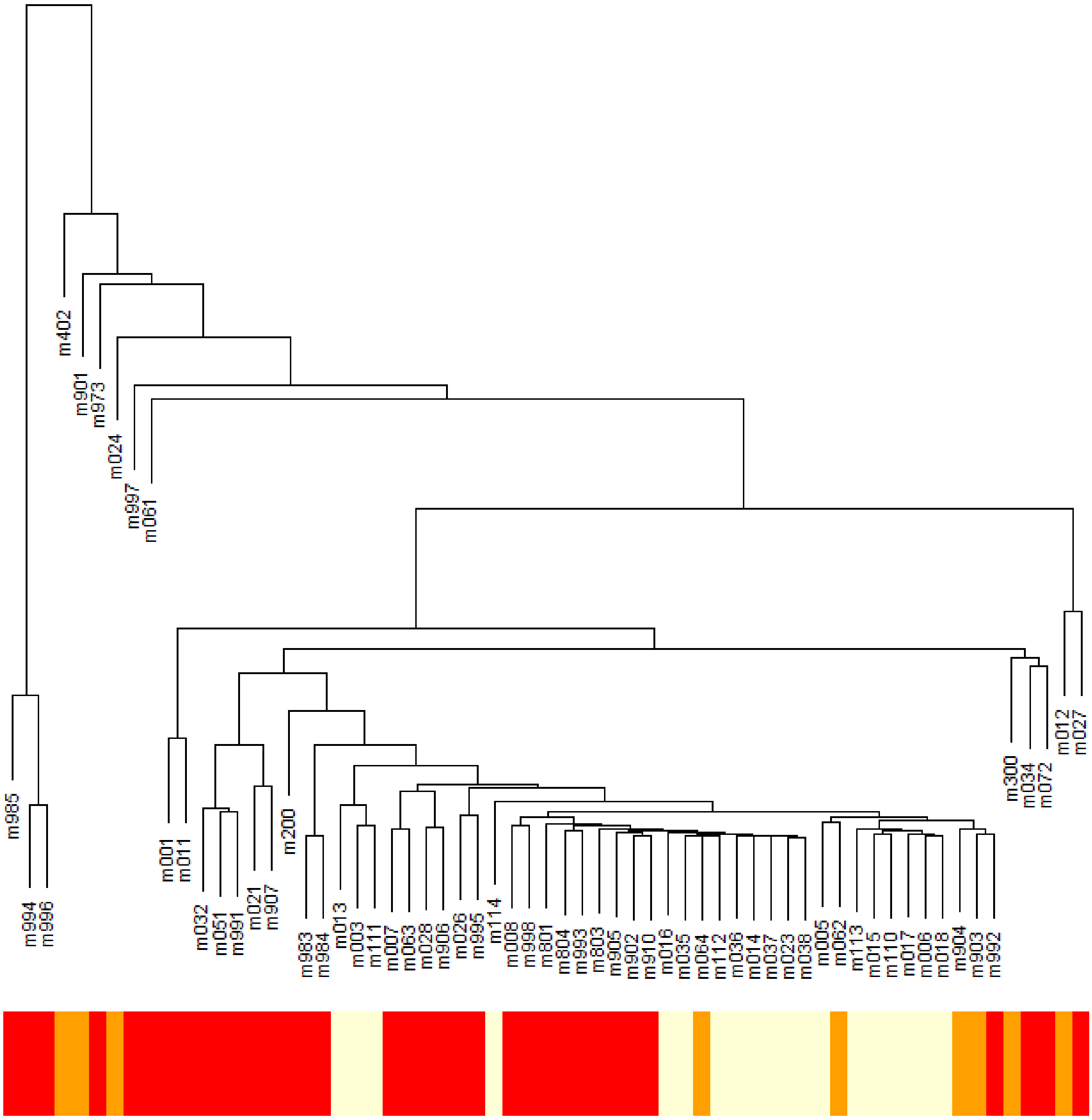


Figure 2.2-20 **Dendrograms based on the differences between home ranges of all tagged harbour porpoises summer. Summer home ranges were estimated by kernel smoothing all locations in June and July. Colour coding indicates the site at which animals were tagged. BELT = red; FJEL = orange; SKA = cream.**

2.2.3.5. Biological importance of Fehmarnbelt focal study area

The annual dynamics of environmental parameters for animals from the Kattegat and Inner Danish Waters populations

Throughout the year, porpoises from the SKAG population were located in deeper waters and further away from the coastline than porpoises tagged in the Belt Sea (Figure 2.2-21). Both male and female porpoises from the BELT population unit spent the winter months further away from the coast and in deeper waters than they did in summer, although females tended to stay closer to the coast for both seasons (Figure 2.2-21).

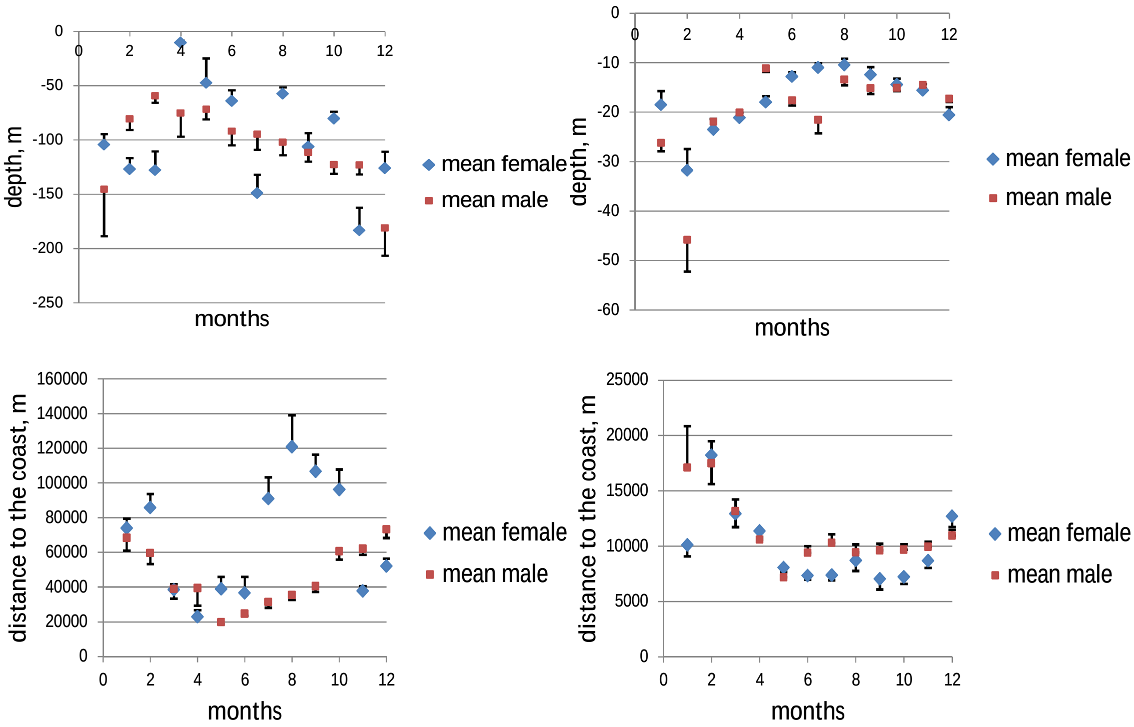


Figure 2.2-21 **Variation over time in the mean depth and distance to the coast for 24 male and female harbour porpoises tagged in the Skagerrak (left) and 45 animals tagged in the Belt Sea (right) population units. Bars indicate standard errors.**

The decrease in water temperature during the winter affects the three groups of harbour porpoises inhabiting Inner Danish Waters differently (Figure 2.2-22). Between October and February, the BELT animals tend to occur in colder waters compared to the other two groups. Some of the BELT animals spend winter in the Belt Sea, and some stay close to the west coasts of Jutland peninsula and southern Norway. Animals from SKAG group move further away from the coast into open North Sea to the areas with warmer water. In summer months, the BELT animals move to the warmer areas. Water temperature of the Belt Sea varies in different years with a difference of some 20°C between winter and summer temperatures in any one year; some winters are mild and others harsh, in which a significant proportion of Fehmarnbelt will be covered by ice and water temperatures are sub-zero. This temperature difference may influence the strategy of winter movements of harbour porpoises in different years.

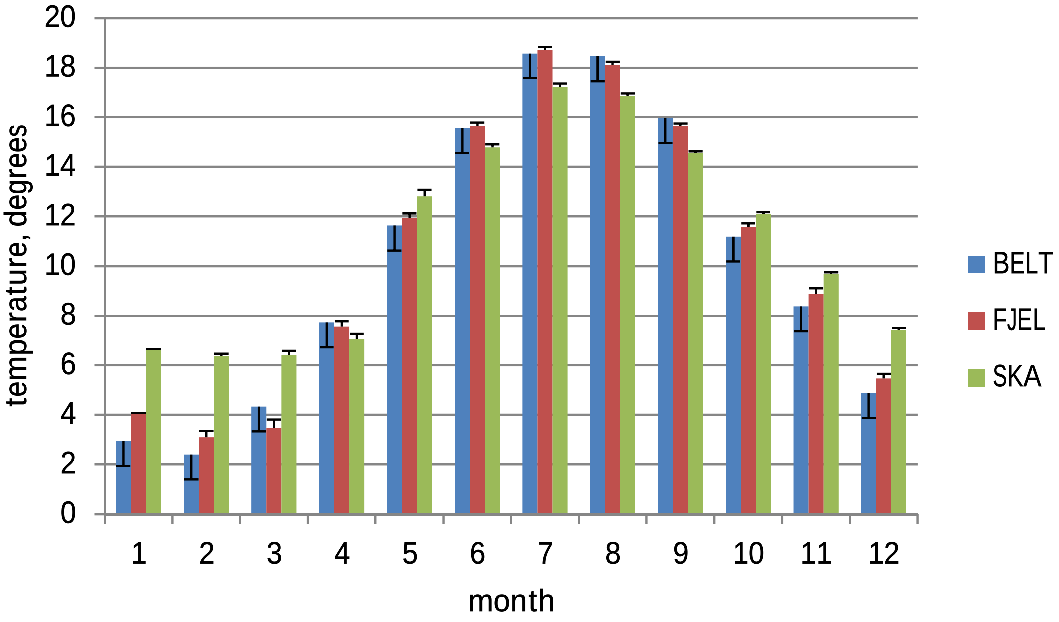


Figure 2.2-22 **Mean sea surface temperature at the locations of harbour porpoises. Bars show SE. All locations are included.**

Seasonal movements of individual harbour porpoises

Maps of the locations of 13 individual harbour porpoises tracked throughout the summer and winter are shown on Figure 7.1-1 (Appendix). Seven of these animals were tagged in the northern Kattegat/Skagerrak, and six were tagged in the Belt Sea and southern Kattegat. These animals used the study area in different ways in summer and winter. The seven animals that spent the summer in the northern Kattegat (m05, m06, m018, m110, m112, m903, and m904, Figure 7.1-1A) moved west into the Skagerrak during the winter. None of these animals was ever detected in FEHM. Of the six animals that spent the summer in IDW, four (m008, m801, m901 and m902; Figure 7.1-1B) moved north into the Skagerrak and two (m910, m998; Figure 7.1-1C) moved further south in IDW. The last two animals were also the smallest individuals among the tagged animals and may have been juveniles. Three of the six animals that spent the summer in IDW spent some time in FEHM.

Two of the animals that were in IDW at the start of the winter moved to the Skagerrak later in the winter. Four of the porpoises that spent at least part of the winter in the Skagerrak moved south along the western coast of the Jutland peninsula in spring or out into the open North

Sea. However, after a few days, m008, m801, and m901 returned to the Skagerrak and then moved south into IDW.

Male m901 returned to the same summer area during two consecutive years. In contrast, male m902, which was marked in the same year as m901, showed large scale summer movements across the whole of IDW.

Our analysis indicates that from three populations of harbour porpoises presented in this study only the BELT population regularly inhabits the Fehmarnbelt area (Figure 2.2-14). Maps of seasonal movements of individuals from the BELT population (Figure 7.1-1, Appendix) show a tendency of porpoises to leave their summer range for the winter. Figure 2.2-23 shows the 30 years mean sea surface temperature for the Eastern North Sea, IDW and Western Baltic Sea; it can be seen that in winter the area of Fehmarnbelt is on average 2 - 4 degrees colder in comparison to surrounding areas. Figure 2.2-24 shows that in winter the temperature recorded at the position of the animals was higher than the one measured in the Belt Sea. This clearly indicates that during wintertime animals from the BELT population occupy waters with warmer temperatures than the Belt Sea. From 45 tagged porpoises from BELT population it was possible to identify the start of the autumn movements for 11 animals; the average sea surface temperature at the beginning of winter movements was 5.6°C (n=11, SD=2.380). Three more animals were tracked throughout the winter but it was not possible to clearly identify the beginning of movements.

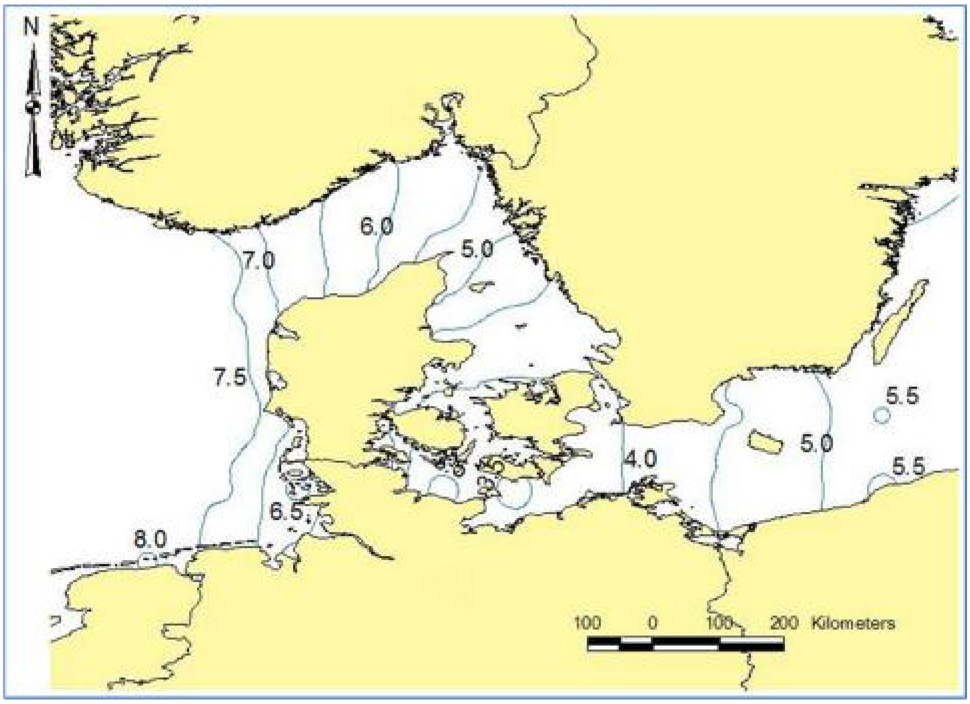


Figure 2.2-23 **Thirty years mean sea surface temperature (SST) of December. Isotherms are drawn every 0.5 degree. Data source http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.html.**

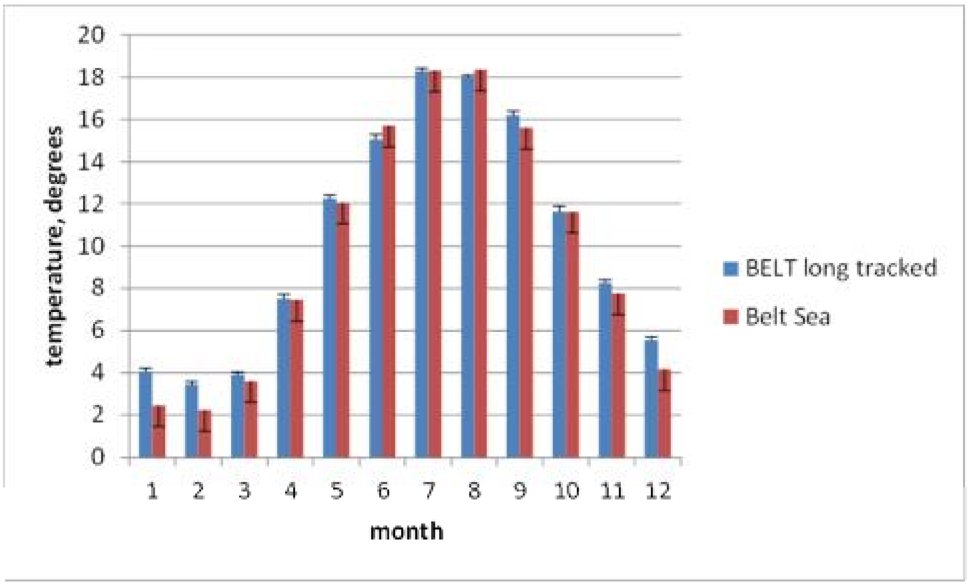


Figure 2.2-24 **Annual dynamics of sea surface temperature in Belt Sea (red) and dynamics of sea surface temperature experienced by 6 long tracked harbour porpoises from the BELT population (blue). Bars show SE.**

Daily movements of individual porpoises

A significant relationship was found between the distance covered by porpoises during a day and water temperature; the colder the water, the greater the distance that porpoises travel (all locations, Spearman correlation, r=-0.133, p=0.000, n=5855). During winter months, porpoises from Belt Sea travel longer distances per day (ANOVA, F=15.798, p=0.000) (Table 2.2-2).

Table 2.2-2 Mean daily distance covered by harbour porpoises measured every month of the year

Month	Mean daily distance, km	N	Std. Deviation
Jan	14.43	136	15.12469
Feb	15.70	136	13.16769
Mar	18.31	122	20.46961
Apr	24.73	378	25.48947
May	14.81	567	17.31451
Jun	12.78	499	14.87104
Jul	14.57	352	15.77659
Aug	11.35	209	12.67716
Sep	17.19	170	21.46127
Oct	10.52	299	11.93375
Nov	13.32	314	13.73447
Dec	14.26	230	15.55822
Total	**15.09**	**3412**	**17.4247**

2.2.3.6. Habitat choice of porpoises in the Fehmarnbelt focal study area

The usage of the Fehmarnbelt by harbour porpoises as predicted by a GAM, including depth, vorticity and current gradient at the bottom and the East West current component at the surface, is shown in Figure 2.2-25. There is a strong relationship between harbour porpoise usage and increasing depth from the coast; although the marginal plot shows widening confidence intervals indicating greater uncertainty beyond ~30 m. There were relatively few locations of porpoises in waters deeper than 30 m but there are also comparatively few deep water (>30 m) areas within the region. The usage model takes into account not only the frequency of presences in a particular type of environment, but also the prevalence of these conditions in the environment as a whole. Where a ‘habitat’ is limited (such as deep water) but animals still occur in it, the effect is to increase the usage metric. Therefore, the fact that there are only a few observations of porpoises in deeper water is likely to be a reflection of the broader lack of deeper waters; the usage model predicts that if there were more areas of deeper water then it is likely that harbour porpoises would use these areas. Areas of strong current gradients and westward moving surface water current also appear to increase the probability of a harbour porpoise occurring. Eddy activity at depth (vorticity) was also a predictor of harbour porpoise locations. The significant covariates were then used to predict the distribution of harbour porpoise in January 2009 and July 2009 (Figure 2.2-27 and Figure 2.2-28). The aim of this was to look at patterns of within year variability, using January and July to represent winter and summer. The predicted plots are remarkably similar and this may be due to the dominating effect of the static covariate, depth. Also, means in vorticity, current gradient and U velocity are not necessarily very good representations of winter and summer conditions because of the short averaging time (1 month), the large variability of these variables and the general absence of a clear seasonal trend in these three variables.

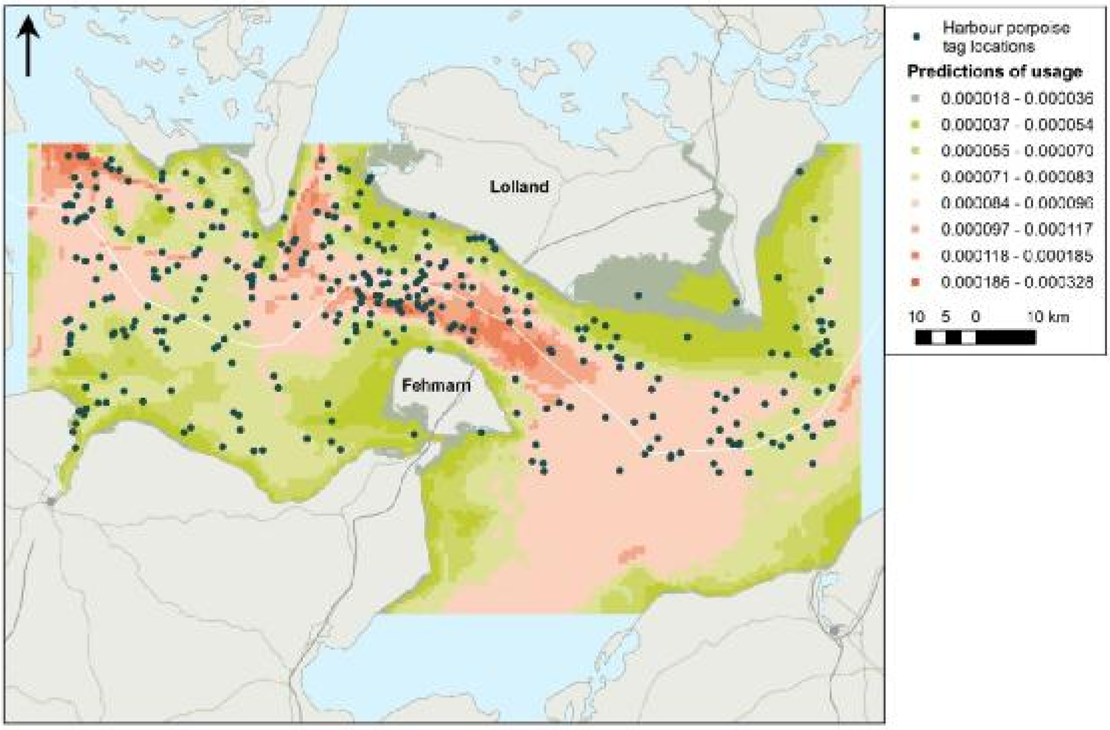


Figure 2.2-25 **Predicted usage of harbour porpoise locations in the Fehmarnbelt focal study area using all retained covariates for data over all years (1997-2010).**

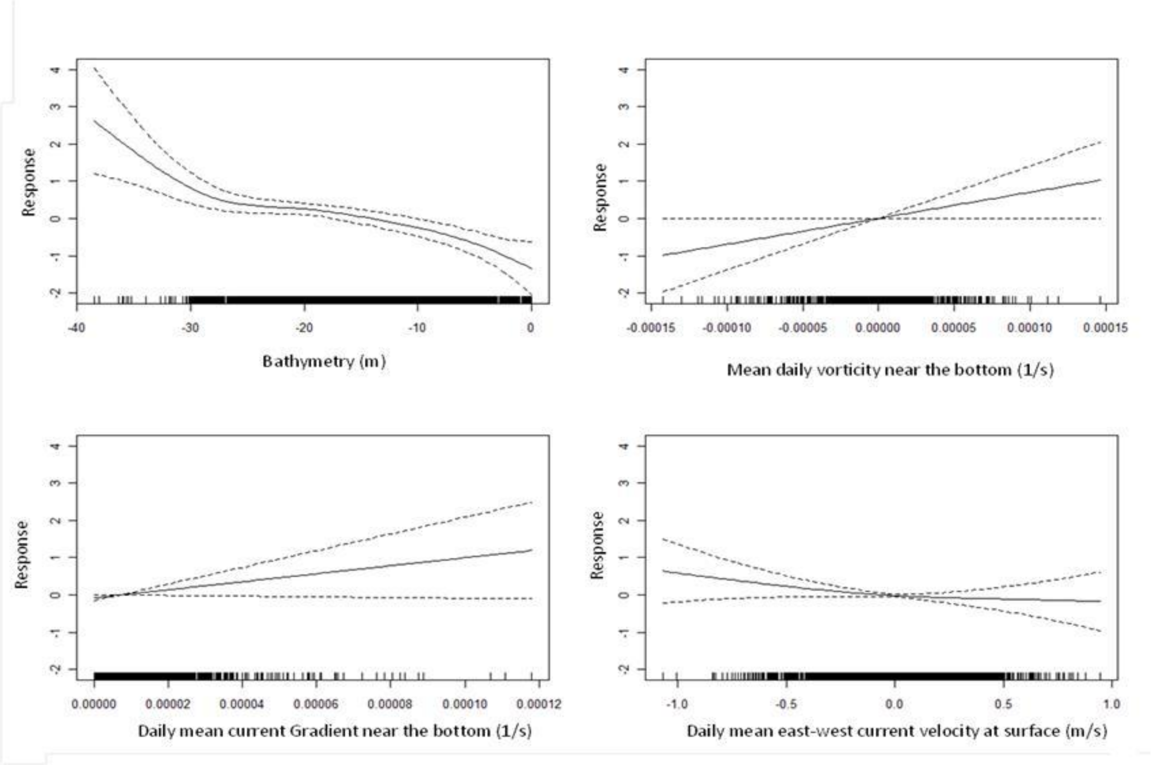


Figure 2.2-26 Marginal plots of the relationship between the probability of obtaining a location inside the Fehmarnbelt focal study area from a harbour porpoise fitted with a satellite tag and. Bathymetry (top left), vorticity (top right), current gradient (bottom left) and velocity bottom right).

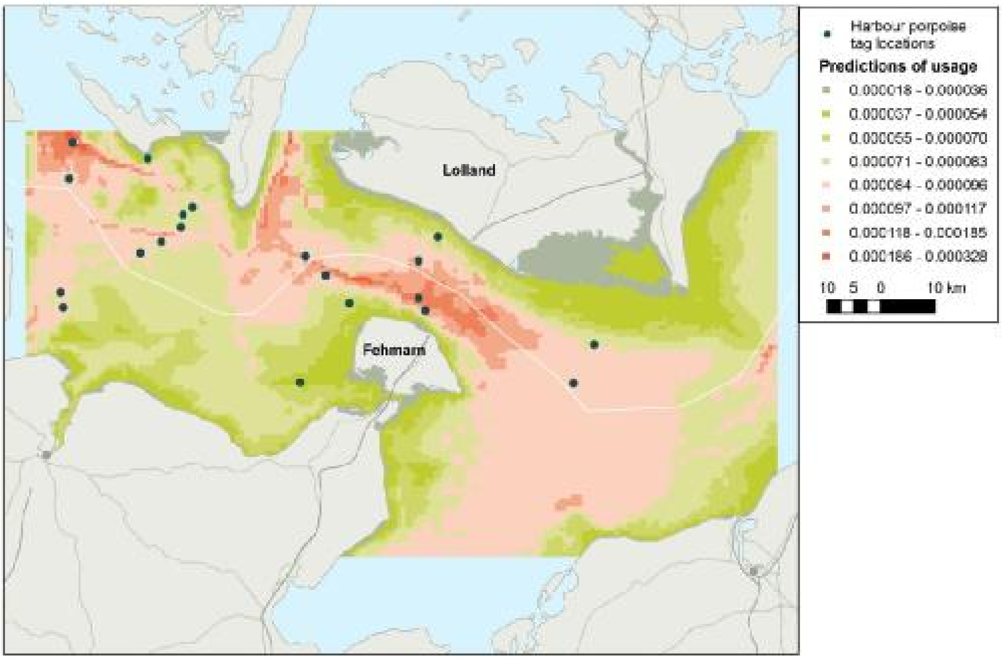


Figure 2.2-27 Predicted usage of harbour porpoise locations in the Fehmarnbelt focal study area using all retained covariates for January.

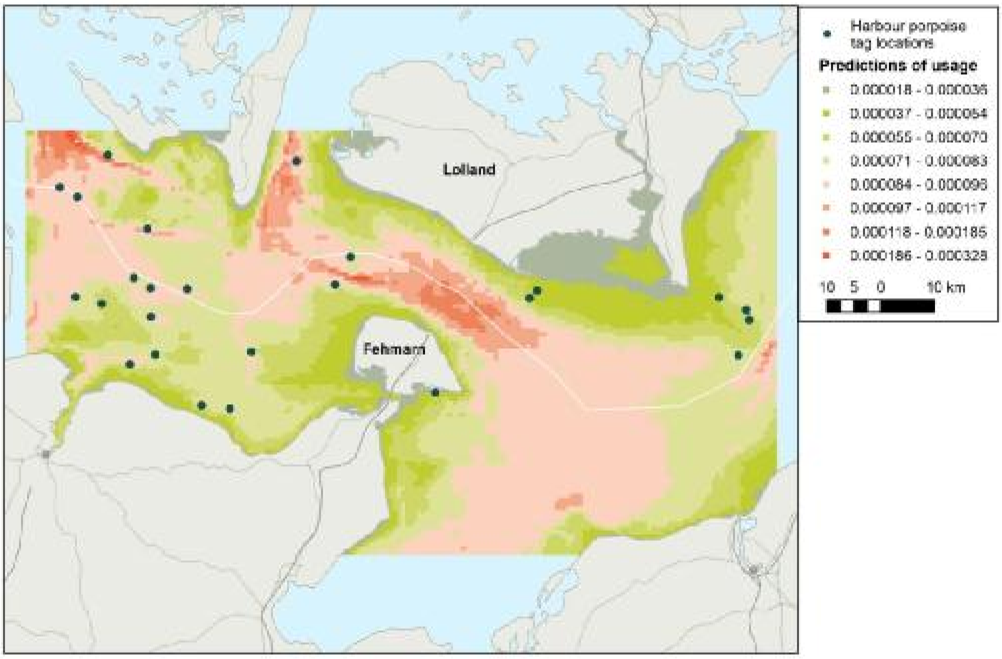


Figure 2.2-28 Predicted usage of harbour porpoise locations in the Fehmarnbelt focal study area using all retained covariates for July.

2.2.3.7. Do porpoises swim under bridges?

Bridges could potentially act as barriers to the movements of marine mammals. In order to investigate the potential barrier effect, we looked at how often tagged harbour porpoises cross existing bridges in the region (Figure 2.2-29). The number of crossings per animal under the Little Belt bridge is the lowest from the whole range of selected locations (Appendix, Table 7.1-3). The Little Belt was crossed only six times by five porpoises. This is especially remarkable because there are two areas with some of the highest densities of harbour porpoise locations in IDW to the south and to the north of the Little Belt (Figure 2.2-3). The Øresund Bridge was crossed seven times by five animals, but the strait north of Øresund Bridge (Helsingborg) was crossed much more often: 24 times by 11 animals. The Great Belt Bridge was crossed 43 times by 23 animals. Most of the tracked animals crossed it only once, but three animals crossed it more than three times.

In most cases, bridges are located in the narrow straits. In Inner Danish Waters, straits have specific hydrological features (see Discussion), and may be used by porpoises differently than areas of open water (Figure 2.2-3). In order to separate the influence of bridge and the strait itself we compared the number of crossings of straits with and without bridges. The maximum number of crossings was recorded for the strait at Samsø (86 crossings) followed by the straits south (Aerö) and north (Ǽbeløgård) of the Little Belt, with 70 and 56 crossings respectively. The next most used locations were Langeland and Fehmarnbelt with 51 and 47 crossings.

The strait at Langeland, south of the Great Belt, could be directly compared with the Great Belt Bridge as long as they both are crossed by the same animals (see Table 7.1-3). 23 animals crossed the Great Belt Bridge and 22 crossed Langeland; 20 animals crossed both straits, 12 animals crossed both straits only once during large scale movements. Four animals at Langeland and two animals at Great Belt Bridge crossed the straits more than four times; this might be the indication that the straits are used regularly by these animals.

Two porpoises crossed the smaller strait Grønsund, which could be an alternative pathway for porpoises during the potential construction period of the Fehmarnbelt Bridge.

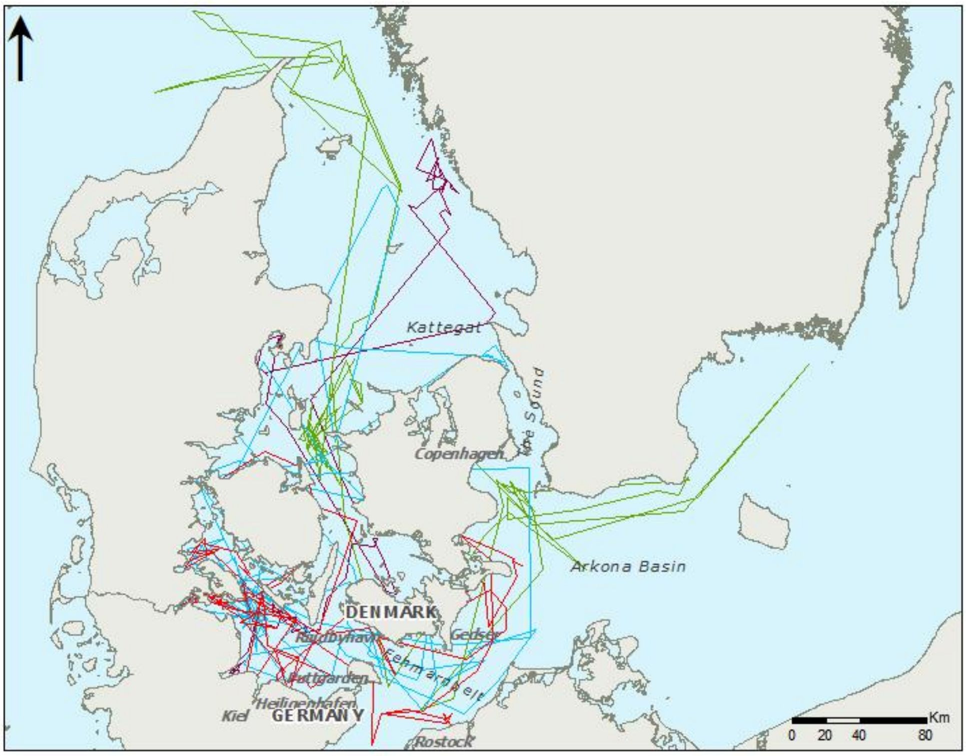


Figure 2.2-29 Examples of harbour porpoise tracks crossing bridges and straits.

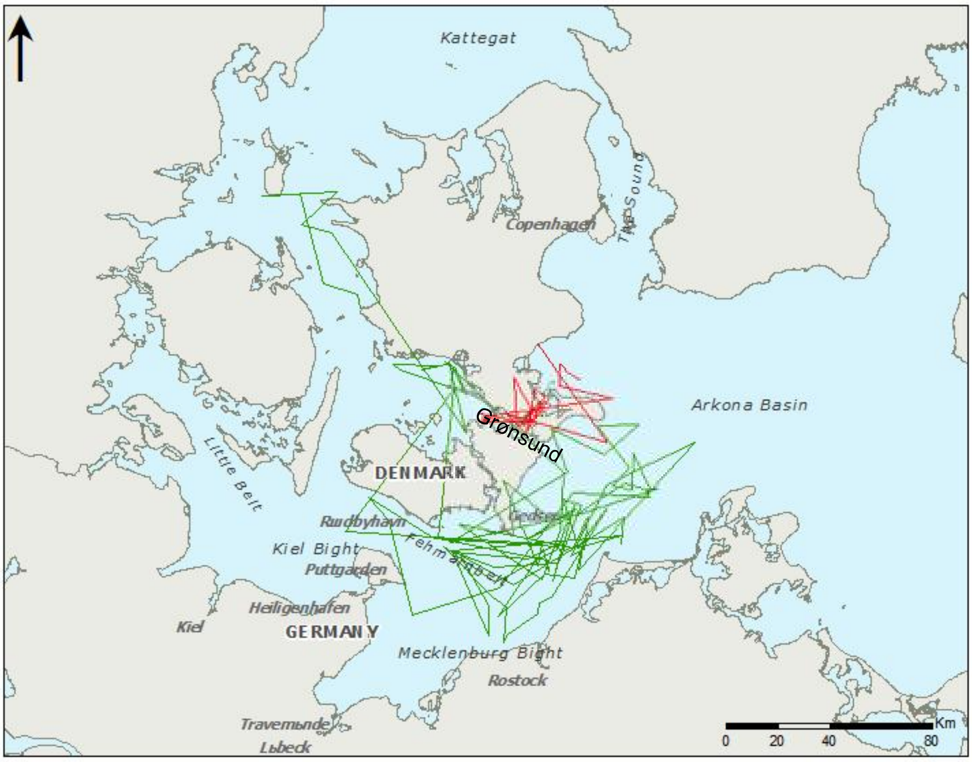


Figure 2.2-30 Two harbour porpoises crossed the Grønsund (m063 and m072).

It has been shown that adult harbour porpoises have smaller home ranges than juveniles (Sveegaard et al., 2010). From the tagged animals analysed, there was one record of simultaneous tracking of a mother/ calf pair (see Figure 2.2-31). Both porpoises were tagged at the Great Belt Bridge on the 11th May 1998. Just after release they moved straight to the northern entrance of the Sound, stayed there for a short while and then passed back through the Great Belt again into the Fehmarnbelt area. In 41 days of tracking they covered about 600 km and visited three main straits of the Inner Danish Waters – Great Belt, Sound and Fehmarnbelt. 12 days (ca. 25%) were spent moving between straits and for the rest of the time they stayed close to the straits of Sound and Fehmarnbelt.

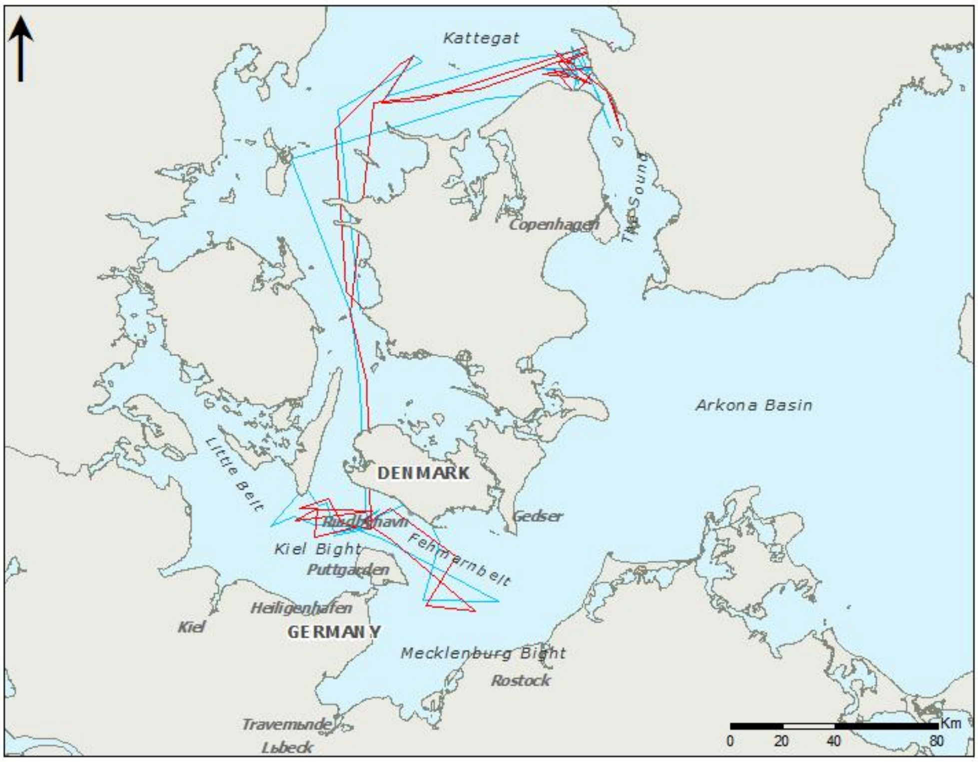


Figure 2.2-31 Movements of female (m983, blue) and calf (m984, red) marked at the Great Belt bridge between May and June 1998 (both animals were marked on the 11th May and tracked for 41 days).

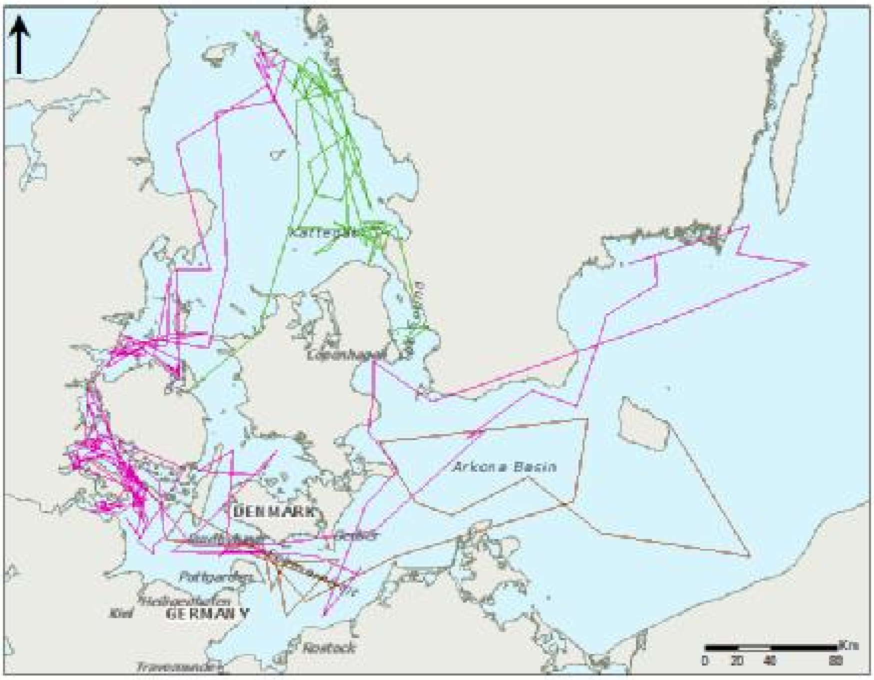


Figure 2.2-32 Movements of three small harbour porpoises (up to110cm) tagged, (green – m001 (26th March 2000, 138 days), brown – m905 (25th September 2009: 40 days), violet – m998 (28th July 1999: 253 days)).

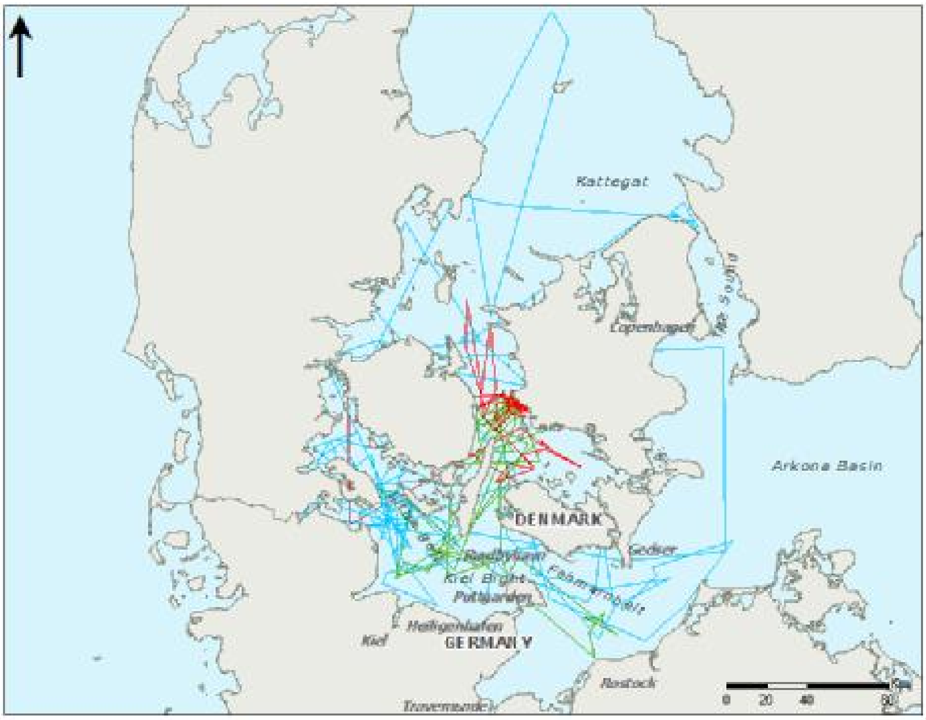


Figure 2.2-33 **Movements of other three small harbour porpoises (up to110cm) tagged (blue – m910 (2nd November 1999: 304 days), red – m027 (27th September 2002: 153 days), green – 06th October 2002: 28 (81 days)).**

The calving season varies from region to region, but in most areas calving takes place from May to August (Dizon, 2002). Harbour porpoises at birth are usually about 70-75 cm long and weight 5 kg. From the tagged animals, seven were small animals, up to 110 cm, and were likely following their mothers; they belonged to the Belt Sea group and its tracks are shown in Figure 2.2-32 and Figure 2.2-33). Five out of the seven juveniles crossed Fehmarnbelt or stayed in the Fehmarnbelt area. Sometimes they travelled across large areas and the general pattern of their movements give little indication that mother-calf pairs differ in movements and choice of areas from other adult porpoises.

2.2.4. Discussion

2.2.4.1. Use of the Fehmarnbelt focal study area

Analysis of satellite tagging data indicates that harbour porpoises tagged in the Skagerrak, and, therefore, probably part of the SKAG population unit identified by Wiemann et al. (2010), are extremely unlikely to use the Fehmarnbelt focal study area (FEHM). The same is true for animals tagged in the northern Kattegat, which are likely to include animals from both the SKAG and BELT population units. However, the probability that an animal tagged in the Belt Sea, and therefore likely to be part of the BELT population unit, will provide a location within FEHM is relatively high (approximately 0.1) compared to porpoises tagged in other areas.

It is tempting to conclude that this last probability implies that animals in the BELT population unit will, on average, spend 10% of their time within FEHM, if it can be assumed that the 45 animals captured in the Belt Sea were a representative sample from this population unit. However, this would be misleading because only about half of the animals tagged in the Belt Sea (25 out of 45) spent any time within FEHM, and there was great variability in the probability that these animals were detected in FEHM. This implies that construction of the Fehmarnbelt bridge could affect certain individuals in the BELT population unit much more than others.

Any evaluation of the impact of bridge construction on harbour porpoises from the BELT should take account of the variable amount of time individual animals spend in FEHM, for example by re-sampling from the distribution of probabilities of locating an animal in this area shown in Figure 2.2-5.

2.2.4.2. Use of space by animals tagged in the Belt Sea and elsewhere in central and northern Danish water

Our detailed analysis of the effects of tagging location on the probability that satellite-tagged animals were located in different parts of the study area provided support for Wiemann et al. (2010)'s conclusions, with animals tagged in the Skagerrak, and therefore likely to be part of the SKAG population unit, making much greater use of the North Sea and Skagerrak waters than those tagged in the Belt Sea, particularly in autumn and winter. Animals tagged in the Belt Sea, and therefore likely to be part of the BELT population unit, were most likely to be detected in IDW throughout the year. Animals tagged in the Kattegat showed behaviour that was intermediate, supporting Wiemann et al.'s conclusion that the Kattegat is a transition zone between the two population units. This was further supported by the higher levels of uncertainty associated with the probabilities of detection for animals from this tagging location. The few locations in the Inner Baltic, east of Bornholm, tended to be from small (immature) porpoises tagged in the BELT area. These observations further support the existence of a third Inner Baltic population.

2.2.4.3. Identifying local populations

None of the analyses we performed of data from satellite tagging provided any evidence for the existence of local populations within the BELT population unit. This may seem surprising given the significant effect of tagging location on the probability that tagged porpoises were detected in different parts of the study area. However, the statistical analysis used to define local populations was very different from that used to look at the effect of tagging location on the use of space.

We did take account of the effects of individual variation in the analysis of the effects of tagging location, year of tagging and season, but this was treated as a "nuisance" variable and we did not try to draw any inferences about the way in which different individuals used the study area. However, we treated locations from neighbouring grid cells by each individual as if they were uncorrelated.

For the analysis of local populations, we focused on individual differences in the distribution of satellite locations, taking account of the correlation between the usage of neighbouring grid cells but we did not include information on precisely where the animals had been tagged. This analysis confirmed the high levels of individual variation detected in the previous analysis, and also indicated that there was considerable difference in the use of space by individuals tagged at the same location. This suggests that telemetry data is unlikely to be particularly useful for detecting additional population structure within the BELT population unit.

2.2.4.4. Biological importance of the Fehmarnbelt focal study area

The locations of the animals that were tracked throughout the summer and winter demonstrate that some of Baltic harbour porpoises undertake regular seasonal movements. During these movements they have to cross a large number of straits of different widths between islands in IDW. At least three of the six porpoises from the BELT population unit (m998, m910, and m902) crossed the Fehmarnbelt focal study area. In addition, m801 visited areas east and west of the Fehmarnbelt in consecutive years and, therefore, probably also crossed the focal area. Unfortunately, the transmitter stopped working when the animal approached the focal area in the second year. The lowest density of porpoises in the Fehmarnbelt area in winter found during visual surveys also indicates seasonal movements (Chapter 2.3.4). On this basis, we conclude that the Fehmarnbelt is an important transit area for harbour porpoises from the BELT population unit.

Four out of the six BELT animals that were tracked throughout the summer and winter spent at least part of the winter in the Skagerrak. This is consistent with historical data and data from passive acoustic detectors, which indicate that the number of animals in the Belt Sea decreases in winter. Sveegard et al. (2010)'s analysis of the seasonal distribution of harbour porpoises used seasonally averaged kernels and, therefore, did not detect the seasonal movements of some BELT animals to the Skagerrak in winter. This may be because winter locations are under-represented in the data set. Our own analysis of seasonal distribution of porpoises detected by passive acoustic sensors show clear seasonal pattern, but it was not consistent between locations (Chapter 2.6.4.1).The remaining two BELT animals whose tags continued to transmit throughout the summer and winter spent part of winter in IDW and this will also have contributed to the difference between this analysis and that of Sveegard et al. (2010).

Sveegaard et al. (2010) found that immature porpoises from both population units had home ranges that were larger than mature animals. The home ranges of juveniles were up to four times that of adults in the SKAG population unit and up to twice that of adults in the BELT. They found no difference between the home ranges of BELT males and females, but found that SKAG males had larger home ranges than females. They suggested that the latter difference may be a consequence of the low number of female porpoises tagged in SKAG (Sveegaard et al., 2010).

One of the potential regulators of the seasonal movements of porpoises is water temperature. Water temperature in winter is an important factor for marine mammals, especially if they live in cold waters that might freeze. The direct threat is that animals could be trapped under the ice and die, so we would expect animals to move to warmer locations or change their behaviour in order to remain in ice-free waters. The individual histories showed that porpoises change their locations between summer and winter. Temperature might be one of the main reasons for these changes. For example, male m902 changed its wintering area when the water temperature dropped below 6°C, which is also the mean minimum winter temperature of North Sea water. The beginning of large-scale movements of 11 harbour porpoises was recorded when water temperature dropped to 5.6°C (Chapter 2.2.3.5) It is possible that this is the lower border for the thermoneutral zone of harbour porpoises. In the only experimental measurement of the thermoneutral zone in harbour porpoises, Kanwisher and Sandnes (1966) found that these animals are thermoneutral down to 8ºC but did not test them at temperatures below this.

Some studies have also shown that water temperature influences seasonal movements of prey. For example, relationships have been found between herring movements and water temperature; herring undertake regular seasonal migration between spawning areas in Danish Straits/Western Baltic to Kattegat/Skagerrak/eastern North Sea; this fish species is one of the most common prey for harbour porpoises in the region (Krovnin and Rodionov 1992; Corten

2001; Kvamme et al., 2003; Payne et al., 2009a; Payne et al., 2009b) and therefore, it may be expected that harbour porpoise movements are influenced by those of their preferred prey.

Direct analysis of the relationship between distribution of harbour porpoises and their prey is difficult due to the limited amount of data on fish distribution. However, Sveegaard (2011) presented the model of densities of harbour porpoises in Skagerrak and Kattegat in relation to the density of herring based on the satellite telemetry data of porpoises and acoustic surveys of herring during summer months (June-August). Both number of porpoise locations and mackerel density are strongly correlated with the herring densities after taking into account that data recorded in areas close to each other are inherently similar. Furthermore, herring densities are strongly correlated with bathymetry when the effect of spatial dependency in measurements is adjusted for (Sveegard, 2011). The relationship between porpoises and fish distribution during other parts of the year has not been studied in detail.

2.2.4.5. Habitat choice of porpoises in the Fehmarnbelt focal study area

We were able to predict porpoise usage of locations within FEHM where satellite-tagged harbour porpoises were detected using a small number of environmental covariates (depth, vorticity and current gradient at the bottom and East-West current component at the surface). The predicted usage in the region tended to increase from the coast up to about 30 m depth; the marginal plot showed an increasing trend beyond 30 m even though there were few locations in areas of this depth. There is great uncertainty surrounding the predicted usage in these areas. The usage model takes into account the habitat type where animals were detected in the context of the availability of that habitat type from the wider area (e.g. deep water), so in the prediction, a few locations in a limited habitat will be represented as a high usage area. The predicted usage closely mirrors the bathymetry of the area and there were no tendencies for animals to aggregate in certain water depths. This could indicate that these animals use Fehmarnbelt for travelling and are not targeting specific areas for foraging. There was some evidence from the marginal plots that increased harbour porpoise occurrence might also be expected in regions of intermediate depths, where fronts and upwellings are active, but the impact of these variables seems to be limited.

As can be seen in Figure 2.2-25, the harbour porpoise usage map predicts high usage of areas to the west of the proposed alignment; an area which is also predicted to have high densities based on the results of the aerial surveys (Chapter 2.3) and shown by the detections from the PODs (Chapter 2.6). The predicted usage to the south-east of the area is somewhat higher than might be expected had the results of the density-surface model of the aerial survey data been extrapolated. However, there was limited aerial survey coverage in the south-east, and modelled density was not predicted in this area, making comparison to the usage predictions difficult. It is important to recall that usage is a measure of occurrence in relation to availability of different environments as compared to density which is a measure of numbers. Potentially, there could be few animals in a particular area that are consistently present and, therefore, provide many locations over a period of time, so will be represented as high usage areas. This scenario could arise if animals are preferentially using an area for transiting. However, this was not likely to be the case for this usage analysis as there were few locations for the predicted higher usage to the south-east. It is possible that the usage model has extrapolated a relationship that fits the abundant data in the 0 - 30 m water depth, i.e. increasing usage with increasing depth. This can happen with relatively few data such as were recorded in the south-east region. However, as the south-east habitat has comparable depths to other areas further north, where animals were detected, the model is predicting usage based on the availabilit9:y of similar habitat. It is important to point out that the uncertainty in the model is reflected by the very wide and expanded confidence intervals in the model predictions as water depth increases beyond 30 m.

Hydrodynamics and water structure are believed to be important factors determining the distribution of harbour porpoises. The importance of fronts, eddies, upwellings and downwellings have been shown to be important for many species of plants and animals (Owen, 1981), and Johnston et al. (2005) have shown the influence of eddies on the distribution of satellite tagged harbour porpoises in the Bay of Fundy. They found that harbour porpoises prefer to use areas at the tips of islands or close to straits where eddies are formed. Similar relationship between porpoises and currents has been described for the eastern North Sea (Skov and Thomsen, 2008).

We were unable to include the presence of eddies in the statistical modelling of the distribution of porpoises in FEHM undertaken within this project. However, the results of the modelling show that vorticity at depth did have some predictive power for the distribution of harbour porpoise. We also examined outputs from some published models describing the water flow through the Danish straits, Kattegat and Skagerrak, and compared them with the distribution of harbour porpoises tracked with satellite telemetry.

Sayin and Krauss (1996) presented a numerical model that describes the flow of water through the Danish straits, of which there are four in IDW: Little Belt, Great Belt, Fehmarn Belt and Sound. The direction of currents transporting water across these straits varies depending on the direction and speed of the wind, and the tidal regime. Two sills, the Darss Sill at the entrance to the Belt and the Drogden Sill at the entrance to the Sound, prevent North Sea water from entering the Baltic Sea. Long term measurements at both sills show that on average about three times as much salt water comes through the Darss Sill as through the Drogden Sill (Fischer and Matthäus, 1998). The Great Belt and Fehmarn Belt are the most important straits to bring salt water to the Baltic Sea (Jakobssen et al., 2010). The current through the Sound is more constant and directed towards the Kattegat and North Sea, whereas the direction of the currents through the Belts are more variable and depend on weather conditions (Sayin and Krauss, 1996).

The waters of the Little Belt and Great Belt are well mixed during stormy weather and partly mixed under calm weather conditions. In contrast, water in the Sound is not well-mixed (Pedersen, 1993). This reflects the presence and strength of eddies and fronts that cause mixing of water within the straits. In the case of the Sound, turbulence starts to appear north of the strait in Kattegat waters (Sayin and Krauss, 1996).

There is quite good correspondence between the distribution of the porpoise locations and maps of currents and salinity gradient, which reflect the formation of eddies. Porpoises occur in high numbers within the Little Belt and Great Belt – the areas of intensive mixing of salt and fresh waters. In the Sound, porpoises are rarely present within the strait itself, but many locations were obtained from the area where fresh water from the Sound mixes with salt water in the Kattegat.

Another important area for harbour porpoises is the Skagerrak. A model of hydrological parameters for the coasts of southern Norway and Skagerrak was published by Røed and Fossum (2004). For 2000 and 2001, the model predicts areas with high energy eddies at two locations – north of the tip of Jutland at Skagen and in the area in front of Hanstholm. The areas of high energy eddies coincide well with an area used by BELT harbour porpoises in winter. The model shows that the areas with high energy eddies are constant over several years and also have a marked seasonal variation of eddy energy – in winter the kinetic energy is 4 - 20 times higher than during the rest of the year. A number of porpoises from the SKAG population unit stayed in the transition zone between the Kattegat and Skagerrak in the summer; this is an area where the model of Winkel-Steinberg et al. (1992) predicts two stationary eddies.

The structure of the currents in the Danish straits is highly variable and depends a lot on weather, tidal regime and many other parameters. Because of this, it is logical to suppose that porpoises do not follow these changes precisely. Animals may prefer to stay in areas where the general probability of the appearance of eddies is higher. Edren et al. (2010) applied a maximum entropy model to the same dataset from satellite telemetry as we used here, and found that bottom salinity was one of the most important factors. We speculate that the distribution of porpoises is connected to bottom salinity because bottom salinity is an important factor for eddy formation (Gill, 1977; Sayin and Krauss, 1996) through dome-shaped rotation, which starts with rotation of high density water at the bottom under the condition of strong density gradient (Gill, 1977). In the absence of more suitable hydrological data, a good measure of the hydrodynamic quality of a particular porpoise location may be the distance from the location to the narrowest part of the nearest strait, with the width of a strait being measured from coast to coast.

Danish straits have very specific hydrological conditions that create the environment for spawning grounds and migratory corridors for fish, and in turn, it creates the habitat for harbour porpoises.

2.2.4.6. Do porpoises swim under bridges?

In order to move between the Baltic and North Sea, porpoises have to cross several straits in IDW. Some of these straits have bridges. The only bridge-free passage between the two seas is through the western part of the Øresund, where there is a tunnel under the strait. Thus, any porpoise in the Belt Sea has to pass under bridges as it moves through the Little Belt or Great Belt. The satellite tracking data show that, in general, porpoises crossed straits with bridges less often than straits without bridges. However, there may be bias in these data as a result of the locations and times of the tag deployment.

Only 5 tagged porpoises moved through the Little Belt, despite the fact that the areas south and north of the bridge are heavily used by porpoises (Teilmann et al., 2008). It is one of the shallowest and narrowest straits, and it is crossed by two bridges, so it is difficult to differentiate between the effects of the bridges and the effects of the specific hydrological conditions.

The Øresund Bridge was also crossed infrequently (7 times by 5 animals). This bridge does not cross the whole strait; the western part of the link goes in the tunnel and Øresund Bridge crosses only the eastern part of it. So, potentially it offers animals that do not want to cross under the bridge an opportunity to move through the strait. However, the available data do not show a preference of porpoises to cross the strait at this location. The strait at Helsingborg, 50 km north of the Øresund Bridge, was crossed 2-3 times more often than the other straits. Porpoises stay inside of the Sound and after spending some time there turn back to Kattegat.

The Great Belt Bridge was crossed 43 times by 23 porpoises. One possible explanation is that this strait is located in the central part of IDW and it is one of the widest straits. It might be the most convenient place for porpoises to move from sea to sea. The animals living close to the bridge tend to stay at one side of it and modelling of a barrier effect supported the idea that the behaviour of the porpoises could be a general result of habitat selection and based on natural environmental parameters not connected to the bridge. Transiting porpoises crossed the Great Belt Bridge without visible difficulties (Nabe-Nielsen et al., 2010).

The most reliable comparison of the effect of bridges on porpoise movement is between the Great Belt Bridge and the Langeland strait due to the similarity of the locations. Porpoises regularly moved through both straits. Our results indicate that transiting animals showed no reaction to the bridge. Some of the animals stayed close to the straits but sample size was too small to make a proper comparison between their home ranges and proximity of the straits with and without the bridge.

Most often porpoises cross the strait at Samsø. This could be explained by the fact that several groups of animals use this area: transit animals from Great Belt, transit animals from Little Belt, floaters moving along the northern entrances to the Danish Straits and local animals living in the area.

Other studies have been undertaken to investigate the effect of bridges in Danish waters on the behaviour of harbour porpoises (Nabe-Nielsen et al., 2010; Wollheim et al., 2010). Nabe-Nielsen et al. (2010) used the track gradient method to analyse data from 24 tagged harbour porpoises in the vicinity of the Great Belt Bridge. This method uses the gradient in a kernel density estimate for calculating how abruptly animals stop when approaching some feature in the habitat. Their analyses indicate that most of the animals that were suspected to be deterred by the bridge turn around just as abruptly in other parts of their home ranges as they do close to the bridge (Nabe-Nielsen et al., 2010). Nabe-Nielsen et al. suggested that animals turn around far from some feature in the landscape for reasons other than being deterred by the feature. They may, for example, try to optimize their search for food by turning around in order to stay in a particularly favourable area. Only one of the 24 porpoises observed close to the bridge was judged to perceive the bridge as a barrier, based on the track gradient method. This result was independent of whether they analysed for a barrier effects up to 5 km or up to 10 km from the bridge.

In the other study – and as part of the FEMNM studies (Wollheim et al., 2010) - visual observations were conducted at eight observation points along the Great Belt Bridge and four reference points 5 km from the bridge for a total of 447 hours over 16 days between July and November 2009. These yielded 380 harbour porpoise observations of 662 individuals. Of these, 19 harbour porpoises were seen directly under the bridge, crossing from one side to the other (Wollheim et al., 2010). Occasional visual observations of individually recognizable porpoises swimming under the bridge from one side to the other have also been reported (Laura Wollheim, personal communication), supporting the idea that there is no obvious avoidance behaviour of porpoises in relation to bridges.

Only first indications on the behaviour of porpoises near bridges can be given here. We conclude, based on the analysis of tracks and the studies undertaken by others that although porpoise tend to cross areas with bridges less often than areas without bridges, no apparent avoidance behaviour was observed. Thus, it could be possible that the movement patterns of porpoises are not affected much by bridges. The results on the movements of porpoises in the vicinity of bridges will be discussed more comprehensively in the Great Belt study where the behaviour of porpoises at an existing bridge was investigated in great detail.

2.2.5. Conclusions

We found that only harbour porpoises tagged in the Belt Sea, which probably belong to the Belt Sea population unit identified on genetic grounds by Wiemann et al. (2010), were likely to provide locations within the Fehmarnbelt focal study area (FEHM). The overall probability that an animal tagged in the Belt Sea would be detected in this area was around 0.10. However, this probability varied greatly among individuals and it would be misleading to apply this average probability to all individuals in the Belt Sea. Animals tagged at other locations were very unlikely to be detected in FEHM.

An analysis of the effects of tagging location, year and season on the use of the entire study area by the satellite-tagged animals indicated that animals tagged in the Skagerrak were most likely to be detected in this area and the North Sea, whereas animals tagged in the Belt Sea remained in this area. Animals tagged in the northern Kattegat showed a more variable use of the study area that was intermediate between that of animals tagged at the other two locations. These results are entirely consistent with Wiemann et al. (2010)'s analysis of genetic information from Baltic Sea harbour porpoises, which suggested that there are two "demographically significant" population units, one centred on the Skagerrak and the other centred on the Belt Sea, with a region of transition in the northern Kattegat. We could find no evidence from the satellite telemetry data for the existence of local populations within the Belt Sea population unit.

An analysis of the behaviour of a small number of harbour porpoises that were tracked throughout the summer and winter indicated that FEHM appears to be biologically important for the Belt Sea population unit.

We were able to predict the distribution of the locations obtained from satellite-tagged harbour porpoises within FEHM using a small number of environmental variables (water depth, distance from coast and current speed). There was also some evidence that vessel traffic and distance from wind farms affected this distribution. However, there is considerable evidence in the scientific literature that other oceanographic factors, particular the presence of eddies, may be important in determining the fine-scale distribution of harbour porpoises. It would therefore be useful to extend this analysis to cover a larger spatial scale and to include covariates that might indicate the presence of eddies.

The influence of the bridges on transiting harbour porpoises is hard to define without taking into account the characteristics of the straits and its bridges. Visual inspection of the satellite tracks showed that porpoises did cross straits and bridges, yet some areas were more commonly used than others. Our analysis suggests that the behaviour of harbour porpoises in the three main straits and around their bridges is likely to be influenced by a variety of factors, including the local hydrological regime, feeding conditions and the bathymetry of the Strait.

2.3. Distribution and abundance of harbour porpoises - Part 1: Design-based analysis

2.3.1. Introduction

This section presents results from the aerial line-transect surveys carried out to estimate the distribution and abundance of harbour porpoise (*Phocoena phocoena*) in the Fehmarnbelt area. There are two parts to the analysis of the aerial line-transect data: a conventional design-based analysis (this section), presenting results for each survey; and a density surface modelling (DSM) analysis, presenting a seasonal estimate of abundance and distribution, predicted over the whole study area and incorporating environmental variables. This report presents data and results for the period November 2008 – November 2010 during which 40 survey flights were undertaken.

2.3.2. Methods

Baseline surveys were conducted using the German “Standards for the Environmental Impact Assessment” for offshore wind farms (BSH, 2007) and references mentioned therein as guidance.

2.3.2.1. Survey design

The study area of the aerial surveys for marine mammals comprises 4,875 km^2. In the north it follows the coastlines of Langeland, Lolland and Falster; while in the south it extends along the German coast from Kiel in the West to offshore-areas north of Warnemünde (Figure 2.3-1). The maximum distance to the proposed alignment is approximately 70 km. Water depth is variable, but relatively shallow with depths reaching 39m. Aerial line-transect methods, following the distance sampling approach of Buckland et al. (2001; see also Diederichs et al., 2002; Thomsen et al., 2004, 2006), were carried out at least monthly.

A total of 32 parallel transects were used with a 3 km distance between transects (Figure 2.3-1). Transects were divided into two flight schemes (See appendix: Table 7.3-1 and Table 7.3-2) to be covered by two aircraft in one day, or one aircraft in two days. Note that some sections of lines cross the land at Femern; these sections are discarded from the analysis. The flight schemes were adjusted for the construction of the Rødsand 2 wind farm, and additional waypoints were added so that transects could be completed safely.

Line lengths of individual transects ranged from 24 to 64 km. Total transect length was approximately 1,600 km for a flight covering both transect schemes. For several reasons (including flight paths over active military areas, poor survey conditions or technical problems) the achieved survey effort varied amongst replicate surveys. When there were military activities in the restricted area, we were not able to survey those transects that fell within this zone. Some areas within the Kiel bight were only occasionally restricted; whereas others (e.g. Todendorf/Putlos in the Hohwachter Bight) were accessible only on weekends.

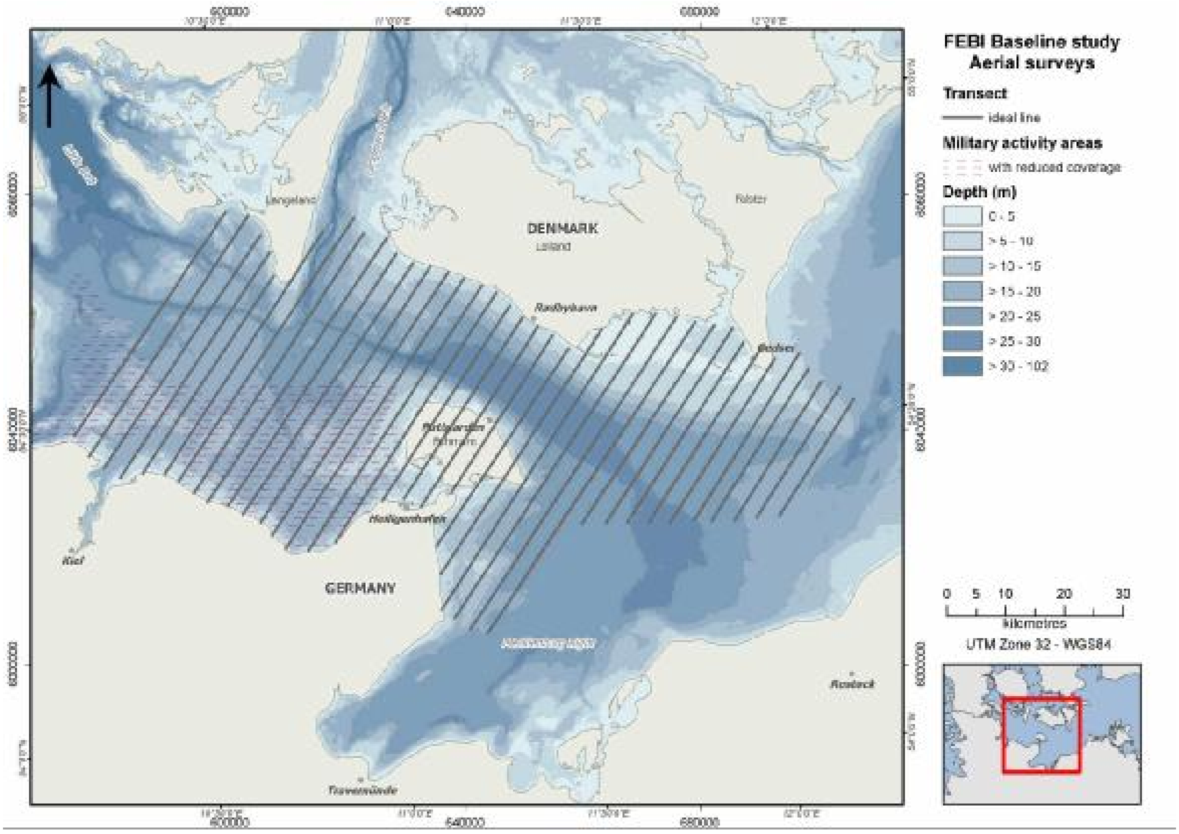


Figure 2.3-1 Position of the transect lines for the Fehmarnbelt aerial surveys. Also shown is the military area (pink) which frequently could not be surveyed due to flight restrictions.

2.3.2.2. Field methods

Three experienced observers were used during the surveys: two principal observers were placed at the bubble windows (which provide visibility directly below the plane; search angle = 0° - <90°; where 90° is directly below the plane). One control observer was placed at a flat window behind the principal observers (search angle = 0° - < 60°). The control observer switched sides on each transect, depending on sighting conditions. Observers were acoustically isolated from each other through ear plugs and headphones. From the onset of the survey, the observers searched continuously for porpoises and other sea mammals. For each sighting, the exact time was noted (UTC, synchronised with on-board GPS) and recorded on a Dictaphone. The sighting angle was measured with an inclinometer (Suunto PM 5 / 360 PC) and also recorded. From the declination angle and the aircraft altitude the perpendicular distance to the sighting was calculated (Figure 2.3-2).

Additionally, data on group size and composition (presence of calves), travel direction and the behaviour of the animals were recorded. The flight-track was logged and stored continuously in 3 second intervals by two GPS-units (see Thomsen et al., 2004, 2006, 2007 for a detailed description).

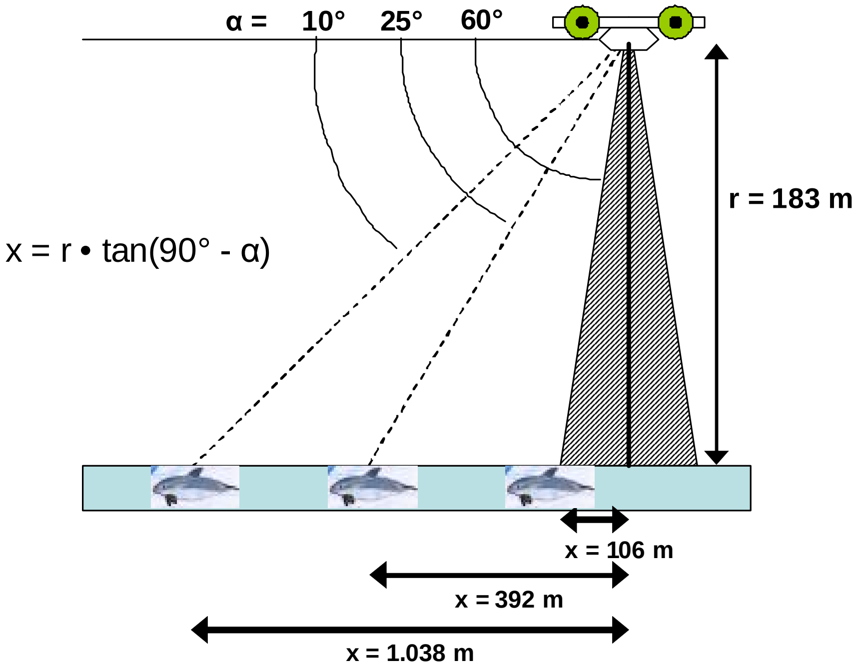


Figure 2.3-2 Standardised aerial survey method for counting marine mammals (after Diederichs et al., 2002).

Weather conditions (sea state, glare, cloud reflections, cloud coverage, precipitation and turbidity) were recorded at the start of each transect and whenever conditions changed. All vessels (including type, distance to transect and heading) and gillnets were also recorded.

Data were only collected in good or moderate survey conditions (below Beaufort Sea State 3, visibility more than 5 km) if possible. Data were collected during dedicated porpoise surveys at a flying height of 600 ft (183 m) as well as during combined porpoise / seabird surveys at an altitude of 250 ft (76 m). Survey speed was approximately 100 knots (185 km/h, 115 mph).

For safety reasons, only twin-engine high-wing planes with professional pilots were used. Plane types used were Partenavia P-68 (FLM-Aviation, Kiel; Sylt-Air, Sylt), Partenavia P-68 Observer (bioflight AS, Holte) and Britten-Norman Islander BN-2 (Air-Hamburg, Hamburg). Seating varied between planes, with the third observer sitting two rows in front of the main observers in the BN-2, or directly behind the main observers in the Partenavia.

2.3.2.3. Analysis methods

The GPS-tracks (Positions and UTC time/date) were imported into an SQL-Database (Fulmar). During import, tracks were filtered to identify transects and these were named. Gaps or mistakes (track points out of area) were corrected. All information on the Dictaphones were typed into the same database and associated by time with the track. Based on observer field notes detailing conditions, the effort and observations (possible double sightings of main observers under the plane) were assigned valid or invalid for each of the observers. For all of the control observer's sightings, potential double sightings with the main observers were defined.

A query in "Fulmar" produces access-mdbs or text-files that are previously defined in space, time, species composition and type of information. This way different types of data (Distance-import-files, GIS-compatible datasets for map production or mdbs with standardised queries for efforts, observations, densities etc.) were produced.

Density and abundance estimation

All density and abundance calculations were performed using Program DISTANCE (v6.0, release 2; Thomas et al., 2009). All effort and sightings data (from principal observers only) were exported from the FULMAR database and were grouped by date and replicate (survey) and imported into DISTANCE. Data from mammal-only flights were analysed separately from the data from bird and mammal flights.

Abundance ($\hat{N}$) was calculated using the following (standard) equation (taken from Buckland et al., 2001):

$$\hat{N} = A \times \frac{n \times s}{2 \times L \times ESW \times g(0)}$$

Where: A = study area (km^2); n = number of sightings; s = average group size; L = survey effort (km); ESW = effective half strip width; and $g(0)$ = the probability of detecting an animal on the track line, including both perception and availability bias.

We found detection probability in the immediate vicinity of the track line was lower than at some distance away from the line, suggesting that it was difficult for observers to see directly below the aircraft. We therefore performed a left truncation of the data (see Buckland et al., 2001).

Several candidate models were initially tested for fitting the detection function ($f(x)$) and estimation of effective half-strip width ($f(0) = 1/$ESW); models/adjustments were: hazard/cosine, hazard/polynomial, half-normal/cosine, half-normal Hermite and uniform/cosine).

Two methods were tested for estimating group size (s): one simply used the empirical mean; the other used size-biased regression to test for an effect of detecting larger groups preferentially at greater distances. For all data-sets, average group size ($\bar{s}$) was used to convert group density into animal density for all flights.

The probability of detecting animals on the track line [*g(0)*] was estimated independently of DISTANCE (see below for method explanation) and included as a multiplier in the DISTANCE model definition to obtain unbiased estimates of density and abundance.

Detection probability – *g(0)*

A key assumption of line-transect sampling is that animals on the track line are detected with certainty; i.e. the probability of detecting animals at zero perpendicular distance – *g(0)* – is 1. For most (if not all) cetacean surveys, this assumption is almost certainly violated, and an estimate of *g(0)* is needed to produce absolute (and unbiased) density and abundance estimates.

There are two sources of bias that need to be accounted for in analysing cetacean aerial survey data, both of which affect detection probability. These are: perception bias, and availability bias.

Perception bias arises when animals were missed by observers, even though they were available to be seen. Availability bias arises because not all animals will be at or near the surface at the time the observers pass over, and therefore are not available to be counted.

We followed the methods of Grünkorn et al. (2005) and used mark-recapture and dive data to estimate perception and availability bias; then combined the two for an estimate of g(0). This value was then added as a multiplier to the Distance projects for correction of density estimates. Data for each survey type (mammal-only surveys, combined bird/mammal surveys) were pooled across all replicates for g(0) estimation.

Perception bias *p(m)* was estimated as:

$$p(m) = \frac{N_{1,2}}{N_1}$$

Where $N_{1,2}$ is the number of duplicate sightings (seen by both main and control observers in the overlap zone); and N_1 is the number of sightings seen only by the control observer.

Availability bias was estimated by multiplying the number of sightings on each flight with the average proportion of time spent in the top metre of the water column (Teilmann, 2000). This 'total surface time' was then multiplied by the total number of sightings to give an estimate of availability bias; *g(0)* is simply a product of perception bias and availability bias (details, see Thomsen et al., 2006, 2007).

2.3.3. Results

2.3.3.1. Survey effort and encounter rate

A total of 40 full surveys were completed between November 2008 and November 2010. In some cases, effort for one complete replicate was achieved on multiple days. If survey days were undertaken in different months (i.e. March, April 2009), results were assigned to the month that the first day of surveying was carried out. Of the 22 surveys in 2009, eight flights were for mammals only (a total survey effort of 9,048 km), with the remaining 14 a combination of bird and mammal flights (16,364 km of survey effort). From February to November, 2010, a total of 9,340km and 11,290km of survey effort were flown on the mammal only and bird/mammal flights, respectively. In some cases, survey effort was slightly restricted due to the presence of a military no-fly zone.

In 2009, harbour porpoises were seen on all but one flight (December 2009); however the total number of encounters was low on other surveys primarily in the months of September to February (Table 2.3-1). Single animals were most commonly encountered. Encounter rates showed a clear seasonal pattern, with greater numbers of porpoises evident during the months of March – August inclusive. As in 2009, encounter rates were lower during winter months compared to spring and summer months in 2010.

2.3.3.2. Distribution of porpoises in Fehmarnbelt

Harbour porpoises were distributed widely throughout the survey region (2009: Figure 2.3-3, Figure 2.3-4; 2010: Figure 2.3-5, Figure 2.3-6). In 2008/2009, there were 334 sightings of 459 animals. The mammal-only data for this period indicated more sightings to the west of the alignment area, while both sets of data are suggestive of higher porpoise densities on the Danish side of the study area. The 2010 data shows that sightings (375 sightings of 484 individuals) were more numerous than in 2009 (even though there was less survey effort in 2010) with harbour porpoises occurring throughout the survey area. In contrast to the 2009 data, the 2010 data show numerous sightings off the German coast in the Kiel Bight.

The distribution of sightings suggests that harbour porpoises are more common in waters less than 30 m in depth. However, habitat preference will be modelled and discussed in greater detail in the following chapter on density surface modelling (DSM).

2.3.3.3. Harbour porpoise calves

Calves were identified as small individuals (less than half adult size) swimming closely with an adult, presumed mother. The number of calves sighted in 2009 and 2010 was comparable; a total of 18 calves during the 2009 surveys (Table 2.3-1) and 16 calves during 2010. However, for the months during which calves were observed, calves made up 13.04% of all observed individuals (18 calves from 138 individuals). However, for surveys during which calves were observed in 2010, calves accounted for only 5.5% (16 calves from 293 individulas)of individuals sighted. Most sightings of calves occurred during the warmer months May-October. In both years, sightings of calves are more numerous on the Danish side of the Fehmarnbelt, especially off southwest Lolland (Figure 2.3-3 to Figure 2.3-6).

Table 2.3-1 Survey effort (km) and sightings (prior to truncation), November 2008 - November 2010

2008/2009								
Date		**Altitude (m)**	**Effort (km)**	**Number of sightings (n)**	**Number of individuals**	**Number of Calves**	**Average group size**	**n/L**
08/11/2008		76	1,189	1	1		1	0
17/12/2008		183	840	1	1		1	0
28/12/2008		76	1,201	1	5		5	0
21/01/2009		76	1,217	4	9		2.3	0
07/02/2009 21/02/2009	18/02/2009	76	1,470	7	8		1.1	0
07/03/2009	04/04/2009	76	1,139	13	17	1	1.3	0.01
03/04/2009	06/04/2009	183	1,227	23	51		2.2	0.02
20/04/2009	21/04/2009	183	991	62	82		1.3	0.06
26/04/2009	11/05/2009	76	1,276	20	23		1.2	0.02
13/05/2009	20/05/2009	76	1,137	22	29		1.3	0.02
18/05/2009	19/05/2009	183	1,265	50	67		1.3	0.04
01/06/2009	17/06/2009	76	1,190	18	22		1.2	0.02
21/06/2009	22/06/2009	183	1,237	29	40	7	1.4	0.02
06/07/2009	15/07/2009	76	1,274	15	24	5	1.6	0.01
14/07/2009	01/08/2009	183	1,262	11	12	1	1.1	0.01
05/08/2009	09/08/2009	76	1,358	23	29	4	1.3	0.02
23/08/2009	25/08/2009	183	1,135	13	16		1.2	0.01
11/09/2009	21/09/2009	76	1,163	2	3		1.5	0
16/09/2009	21/09/2009	183	1,090	6	6		1	0.01
11/10/2009	30/10/2009	76	1,175	5	5		1.0	0
30/11/2009	02/12/2009	76	1,211	8	9		1.1	0.01
29/12/2009		76	363	0	0		0.0	0

2010							
Date	**Altitude (m)**	**Effort (km)**	**Number of sightings (n)**	**Number of individuals**	**Number of Calves**	**Average group size**	**n/L**
07/02/2010 08/02/2010	183	825	6	7		1.2	0.01
05/03/2010	76	1,001	2	3		1.5	0.002
22/03/2010 25/03/2010	76	1,180	3	3		1	0.002
06/04/2010 08/04/2010	76	1,563	17	22		1.3	0.01
08/04/2010 15/04/2010 28/04/2010	183	1,426	23	30		1.3	0.02
02/05/2010	76	1,439	43	57	1	1.3	0.03
10/05/2010	183	1,399	47	55		1.2	0.03
04/06/2010	76	1,105	24	31		1.3	0.02
05/06/2010 06/06/2010	183	1,371	41	54	1	1.3	0.03
01/07/2010 09/07/2010	183	1,164	70	97	8	1.4	0.06
06/08/2010 26/08/2010	183	1,065	16	20	1	1.2	0.01
07/08/2010	76	1,181	17	21	3	1.2	0.01
05/09/2010	76	701	6	6		1	0.01
12/09/2010	76	764	7	9		1.3	0.01
22/09/2010	183	1,110	24	30	1	1.2	0.02
10/10/2010 13/10/2010	76	1,249	12	18		1.5	0.01
15/10/2010 26/10/2010	183	981	10	14	1	1.4	0.01
07/11/2010	76	1,096	7	7		1	0.006

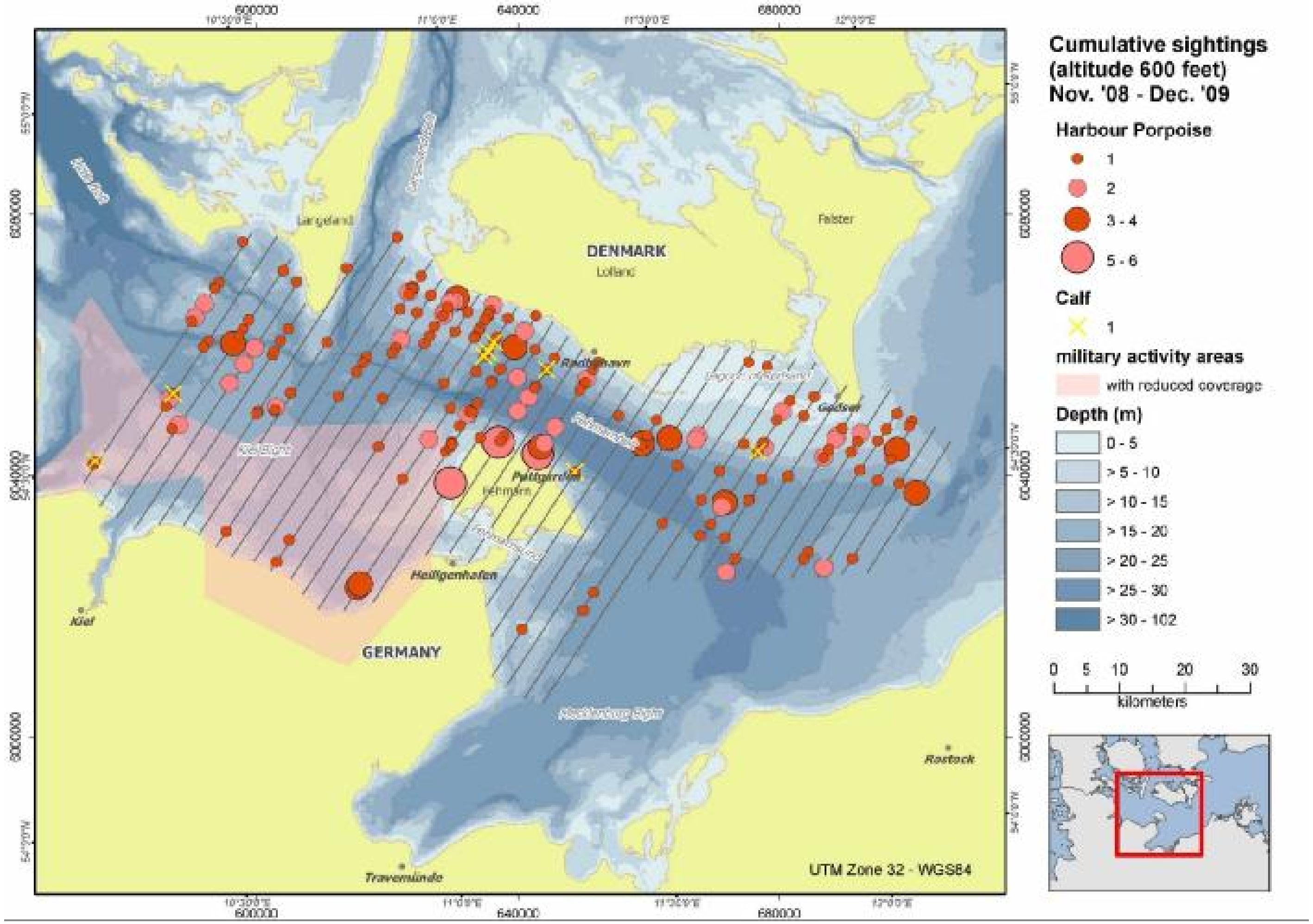


Figure 2.3-3 Locations of harbour porpoise sightings – combined for all mammal only flights, November 2008 – December 2009.

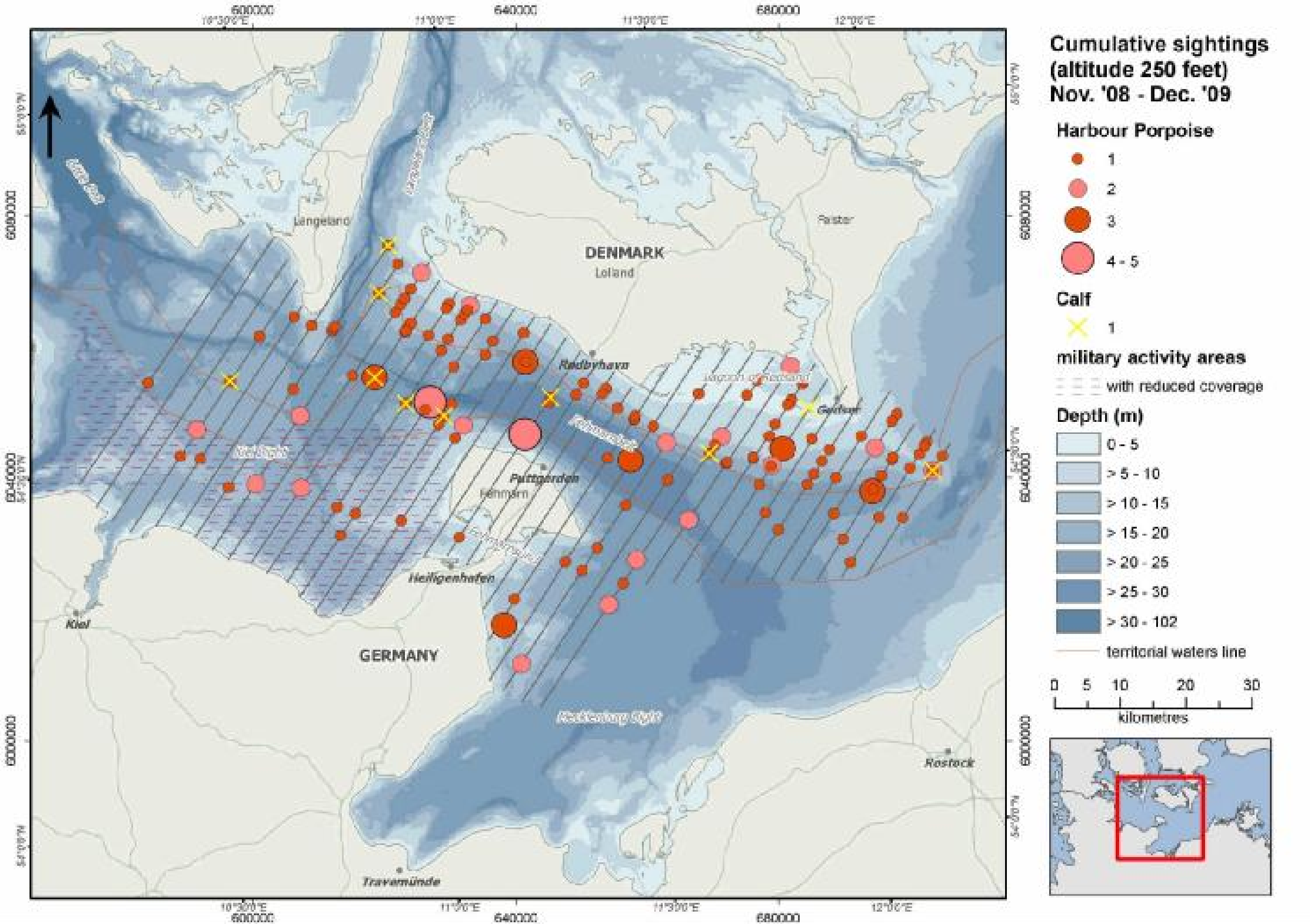


Figure 2.3-4 Locations of harbour porpoise sightings during combined bird and mammal survey flights, November 2008 – December 2009.

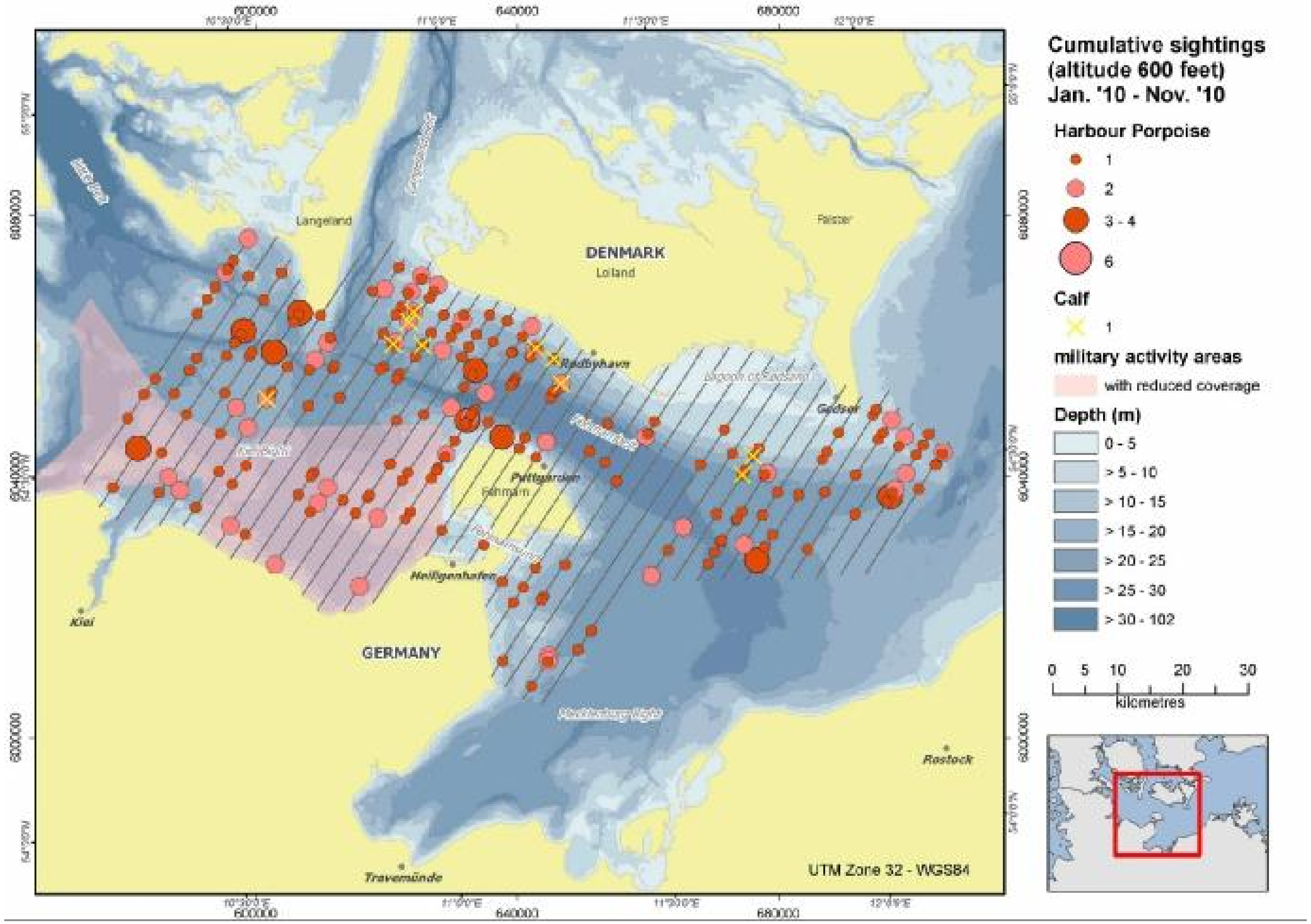


Figure 2.3-5 Locations of harbour porpoise sightings – combined for all mammal only flights, January – November 2010.

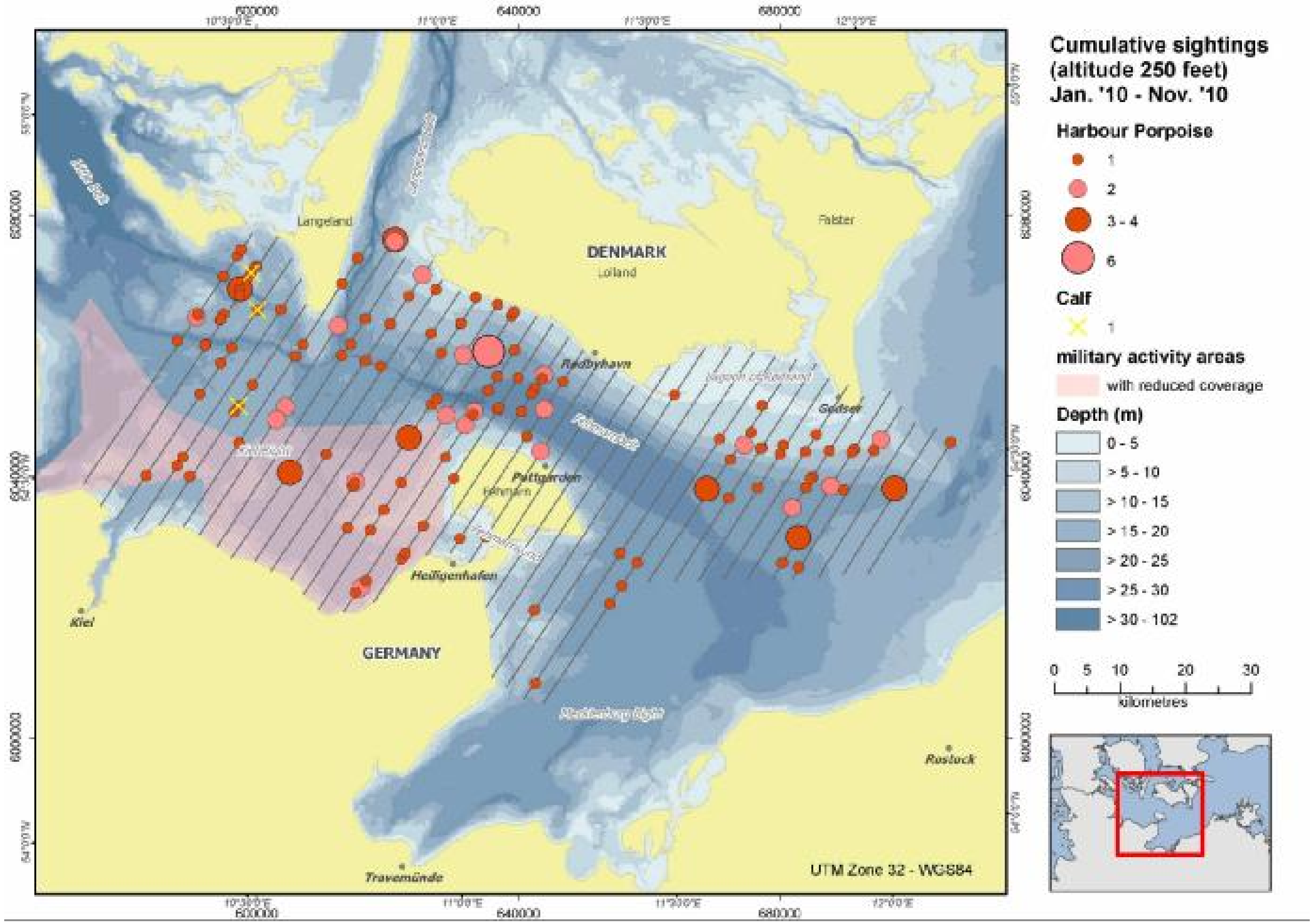


Figure 2.3-6 Locations of harbour porpoise sightings during combined bird and mammal survey flights, January – November 2010.

2.3.4. Abundance estimates

Detection probability

For 2009 data, the mammal-only survey *g(0)* was estimated at 0.30 (CV=0.11) and for bird/mammal surveys *g(0)* was 0.27 (CV=0.17). For the 2010 data, the mammal-only survey *g(0)* was estimated at 0.32 (CV=0.06)and for bird/mammal surveys *g(0)* was 0.31 (CV=0.11) (see Table 2.3-2 for estimation process).

Table 2.3-2 Estimate of g(0) for all survey flights for 2008-2010 surveys. Surface time = time duration that individual spent at the surface, N1 = Number of valid controll sightings, N1,2 = Number of resightings.

Mammal only flights, Nov 2008 - Dec 2009					
Month	**Sightings**	**Surface time**	**Total surface time**	**N1**	**N1,2**
December	1	0.44	0.44	0	0
April	23	0.44	10.12	0	0
April	62	0.44	27.28	6	4
May	50	0.45	22.5	11	10
June	29	0.39	11.31	7	6
July	11	0.41	4.51	8	1
August	13	0.44	5.72	3	3
September	6	0.39	2.34	1	1
Total	195	3.4	84.22	36	25
Availability bias	*84.22/195 = 0.43*				
Perception bias	*25/36 = 0.69*		*g(0)*	*0.43 x 0.69 = 0.30*	
Mammal Bird flights, Nov 2008 - Dec 2009					
November	1	0.44	0.44	0	0
December	1	0.44	0.44	0	0
January	4	0.44	1.76	0	0
February	7	0.44	3.08	1	0
March	13	0.55	7.15	4	4
April	20	0.44	8.8	0	0
May	22	0.45	9.9	3	1
June	18	0.39	7.02	7	4
July	15	0.41	6.15	2	2
August	23	0.44	10.12	5	2
September	2	0.39	0.78	0	0
October	5	0.44	2.2	1	1
November	8	0.44	3.52	0	0
December	0	0.44	0	0	0
Total	139	6.15	61.36	23	14

Availability bias	*61.36/139 = 0.44*				
Perception bias	*14/23 = 0.61*		*g(0)*	*0.44 x 0.61 = 0.27*	
Mammal flights, Jan- Dec 2010					
February	6	0.44	2.64	0	0
April	28	0.44	12.32	3	3
May	62	0.45	27.9	11	8
June	60	0.39	23.4	13	8
July	119	0.41	48.79	27	21
August	20	0.44	8.8	3	2
September	38	0.39	14.82	10	8
October	20	0.44	8.8	5	5
Total	353	3.4	147.47	72	55
Availability bias	*147.5/353 = 0.42*				
Perception bias	*55/72 = 0.76*		*g(0)*	*0.42*0.76 = 0.32*	
Mammal Bird flights, Jan- Dec 2010					
March	4	0.55	2.2	0	0
March	3	0.55	1.65	0	0
April	29	0.44	12.76	7	5
May	78	0.45	35.1	15	10
June	31	0.39	12.09	3	2
August	31	0.44	13.64	5	4
September	8	0.39	3.12	1	1
September	10	0.39	3.9	0	0
October	15	0.44	6.6	0	0
October	8	0.44	3.52	1	1
Total	217	4.48	94.58	32	23
Availability bias	*94.58/217 = 0.44*				
Perception bias	*23/32 = 0.72*		*g(0)*	*0.44*0.72 = 0.31*	

2009 Survey data

Data from the 2009 mammal-only flights were left-truncated at 60 m, whilst data from the 2009 seabird /mammals flights were left-truncated at 30 m. After truncation, there were a total of 169 sightings from mammal-only surveys available for fitting the detection function and density estimation. The model selected was the hazard rate model. This model generated a broad shoulder near the track line (Figure 2.3-7). We took a similar approach with data from the combined bird/mammal flights, and had a total of 127 observations available for the detection function and density estimation. As with the mammal-only data, a hazard rate model (with no adjustments) was fitted (Figure 2.3-8). Resulting effective half-search width for mammal-only data was 206 m (%CV =7.10); and for data from combined surveys it was 116 m (%CV =9.04).

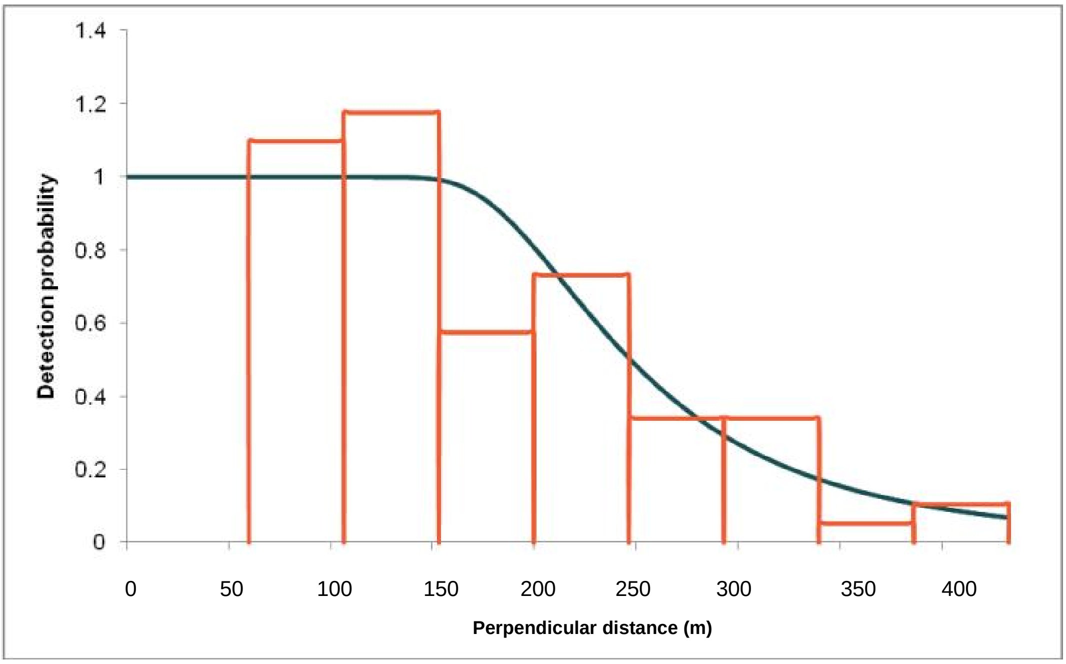


Figure 2.3-7 Fitted detection function for harbour porpoises during 2009 mammal-only aerial surveys (altitude = 183m; model = hazard rate key function; n = 169 sightings).

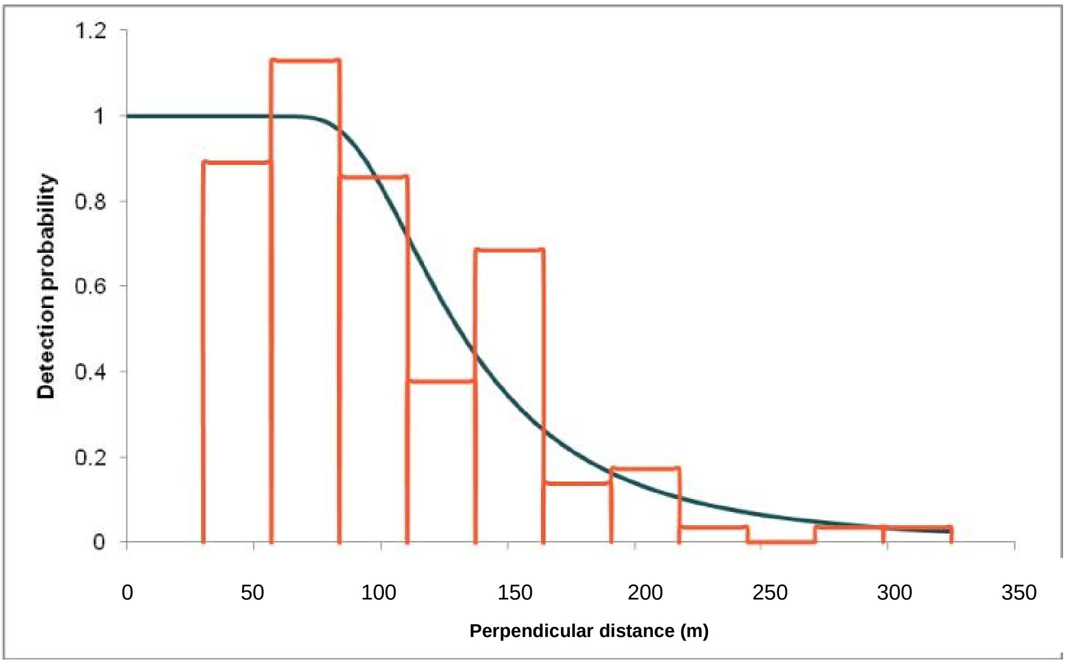


Figure 2.3-8 **Fitted detection function for harbour porpoises during 2009 bird and mammal aerial surveys (altitude = 76m; model = hazard rate key function; n = 127 sightings).**

Average group size for sightings from the mammal surveys was 1.39 (%CV = 4.11); and 1.27 (%CV = 4.36) for the data from combined bird/mammal surveys.

Density of harbour porpoises varied between months, with a tendency to be higher during summer (Figure 2.3-9). The density of harbour porpoises was highest during a dedicated mammal flight in April 2009, at 0.59 animals/km^2 (Table 2.3-3). Abundance during the colder months (November - February) was generally in the low hundreds (though note that the amount of survey effort achieved in December was at least half that of other months due to poor survey conditions), increasing to between 1,000 and 2,000 during the warmer months. Specifically, abundance estimates reached a maximum of 2,870 (95% CI = 1779 – 4631) during a mammal-only survey flight in April and a minimum of zero porpoises observed during the December surveys (note that in the case of December 2008, there were two groups observed, however these were removed during truncation and were therefore not available to be included in abundance estimates).

Table 2.3-3 **Harbour porpoise abundance estimates (*N*), %CVs and 95% confidence intervals November 2008 – December 2009**

Date	Altitude (m)	Animal density (n/km^2)	Abundance (N)	%CV(N)	95% Confidence Interval (N)
08/11/2008	76	0.02	83	102.61	15 - 467
17/12/2008	183	0	0	0	0 - 0
28/12/2008	76	0.02	82	101.02	15 - 453
21/01/2009	76	0.03	162	73.63	43 - 614
07/02/2009 18/02/2009 21/02/2009	76	0.08	403	48.19	161 - 1010
07/03/2009 04/04/2009	76	0.23	1127	35.31	569 - 2232
03/04/2009 06/04/2009	183	0.2	981	27.59	570 - 1686
20/04/2009 21/04/2009	183	0.59	2870	24.37	1779 - 4631
26/04/2009 11/05/2009	76	0.29	1393	35.3	704 - 2759
13/05/2009 20/05/2009	76	0.36	1738	31.96	935 - 3231
18/05/2009 19/05/2009	183	0.38	1858	24.66	1145 - 3015
01/06/2009 17/06/2009	76	0.31	1494	37.97	718 - 3111
21/06/2009 22/06/2009	183	0.25	1238	26.88	730 - 2097
06/07/2009 15/07/2009	76	0.24	1163	38.03	558 - 2424
14/07/2009 01/08/2009	183	0.1	506	42.11	219 - 1172
05/08/2009 09/08/2009	76	0.28	1383	31.41	752 - 2542
23/08/2009 25/08/2009	183	0.08	375	28.16	217 - 650
11/09/2009 21/09/2009	76	0.03	170	73.15	45 - 638
16/09/2009 21/09/2009	183	0.06	301	45.16	126 - 718
11/10/2009 30/10/2009	76	0.09	420	45.65	175 - 1009
30/11/2009 02/12/2009	76	0.12	571	43.63	247 - 1318
29/12/2009	76	0	0	0	0 - 0

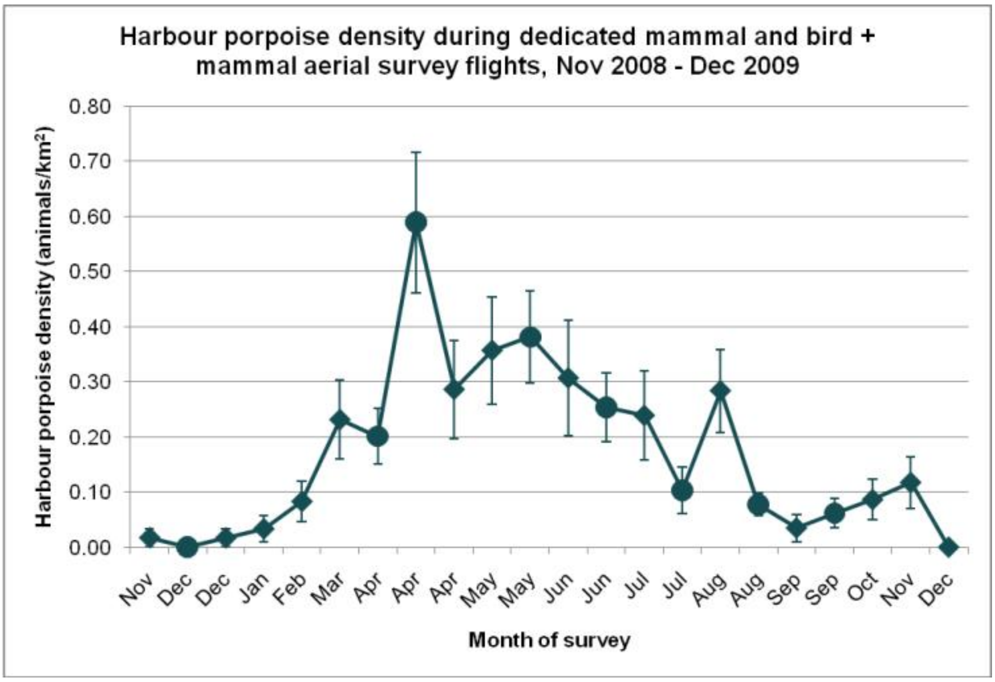


Figure 2.3-9 **Porpoise density (animals/km^2) during dedicated mammal (circle) and bird/mammal (diamond) aerial survey flights, Nov 2008 - Dec 2009 (vertical bars = standard error; note: If survey days were undertaken in different months (i.e. March, April 2009), results were assigned to the first month of the surveys).**

2010 Survey data

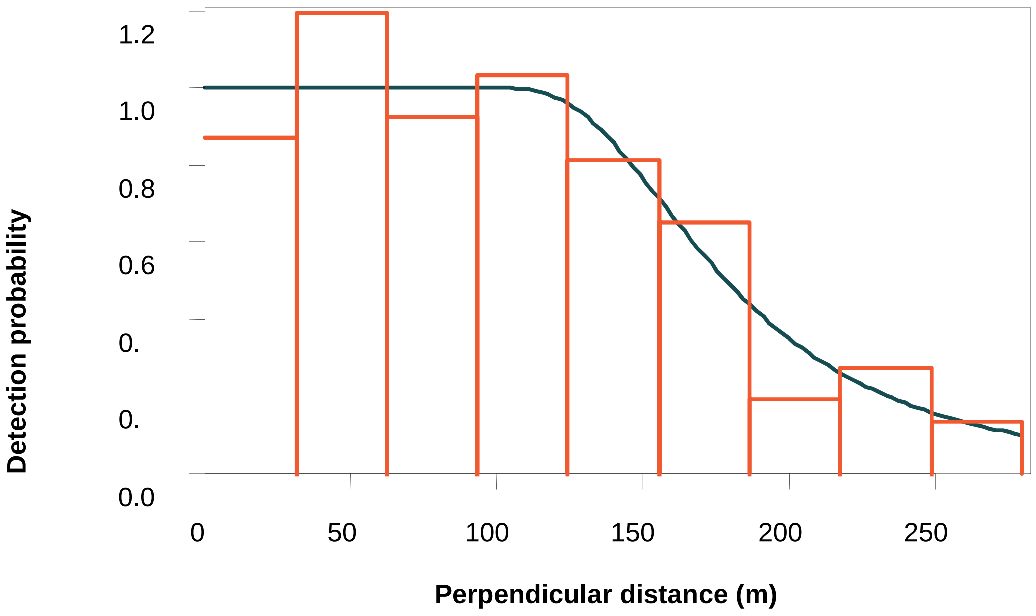
The distribution of perpendicular distances suggested that seeing the track line under the plane was less of a problem for the 2010 mammal only data (Figure 2.3-10). Therefore, no left truncation adjustment was made. The mammal only data were (right) truncated at 280m which excluded 5% of sightings leaving 224 groups.

Left-truncation was not used for 2010 mammal-bird data however, due to the shape of the distribution of the remaining distances which resulted in an unrealistic estimate of ESW. Therefore, an alternative method was used where all sightings within 40 m of the track line were deleted and then 40 m was subtracted from the remaining truncation distances – essentially the track line was moved out to 40 m. The remaining data were right truncated at 115m which excluded 5% of sightings leaving 96 groups.

A hazard rate model was selected for both the mammal and mammal/bird data. The ESW was 189m (%CV=5.0) and 49m (%CV=17.3), respectively.

Peak density was recorded during the first survey in May of 0.94 animals/km^2 (CV=0.31) which equates to an abundance of 4,597 harbour porpoises in the survey area (Table 2.3-4). As in 2009, densities tended to be higher during the summer months, between April and August with abundance estimates exceeding 2,000 animals in the area for May-July (Figure 2.3-11).

Compared to 2009 data, the abundance of animals in Fehmarnbelt between May-October in 2010 was greater (Figure 2.3-12).



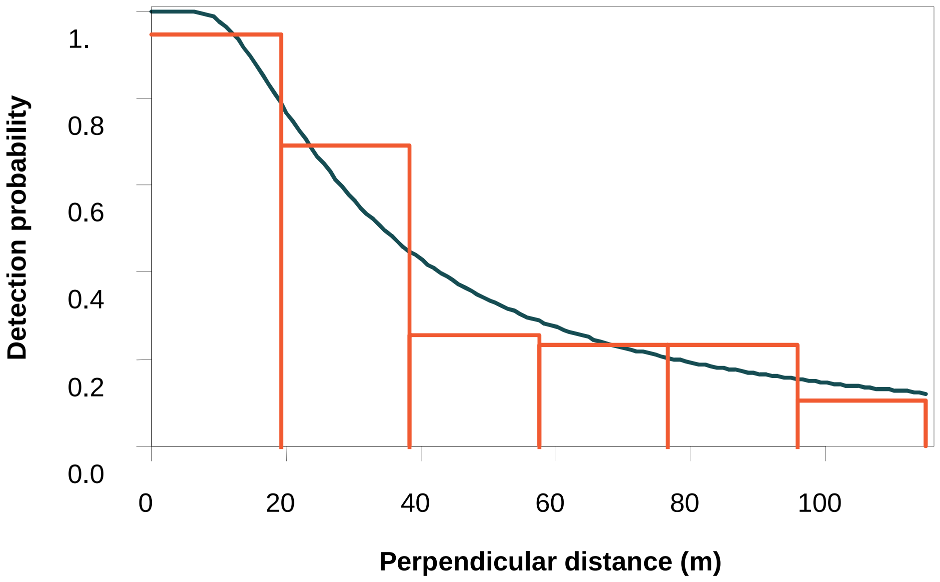


Figure 2.3-10 **Fitted detection function models for 2010 aerial surveys for harbour porpoise (above) and fitted detection function for harbour porpoises during 2010 combinden bird and mammal- aerial surveys (below)**

Table 2.3-4 **Harbour porpoise abundance estimates (*N*), %CVs and 95% confidence intervals January-November 2010**

Date	Altitude (m)	Animal density (n/km^2)	Abundance (N)	% CV(N)	95% Confidence Interval (N)
07/02/2010 08/02/2010	183	0.07	342	55.39	118-986
05/03/2010	76	0.07	322	102.34	58-1797
22/03/2010 25/03/2010	76	0.08	410	61.22	131-1283
06/04/2010 08/04/2010	76	0.42	2064	34.99	1050-4059
08/04/2010 15/04/2010 28/04/2010	183	0.17	848	33.31	440-1633
02/05/2010	76	0.94	4597	30.57	2539-8323
10/05/2010	183	0.31	1527	19.35	1039-2244
04/06/2010	76	0.66	3211	38.24	1534-6723
05/06/2010 06/06/2010	183	0.33	1587	19.53	1076-2341
01/07/2010 09/07/2010	183	0.6	2909	20.82	1922-4401
06/08/2010 26/08/2010	183	0.16	757	28.71	429-1336
07/08/2010	76	0.36	1775	46.86	728-4328
05/09/2010	76	0.19	920	62.52	278-3051
12/09/2010	76	0.17	844	64.61	246-2895
22/09/2010	183	0.21	1016	32.54	535-1928
10/10/2010 13/10/2010	76	0.37	1808	58.92	597-5477
15/10/2010 26/10/2010	183	0.12	575	39.04	269-1230
07/10/2010	76	0.09	442	59.05	145-1348

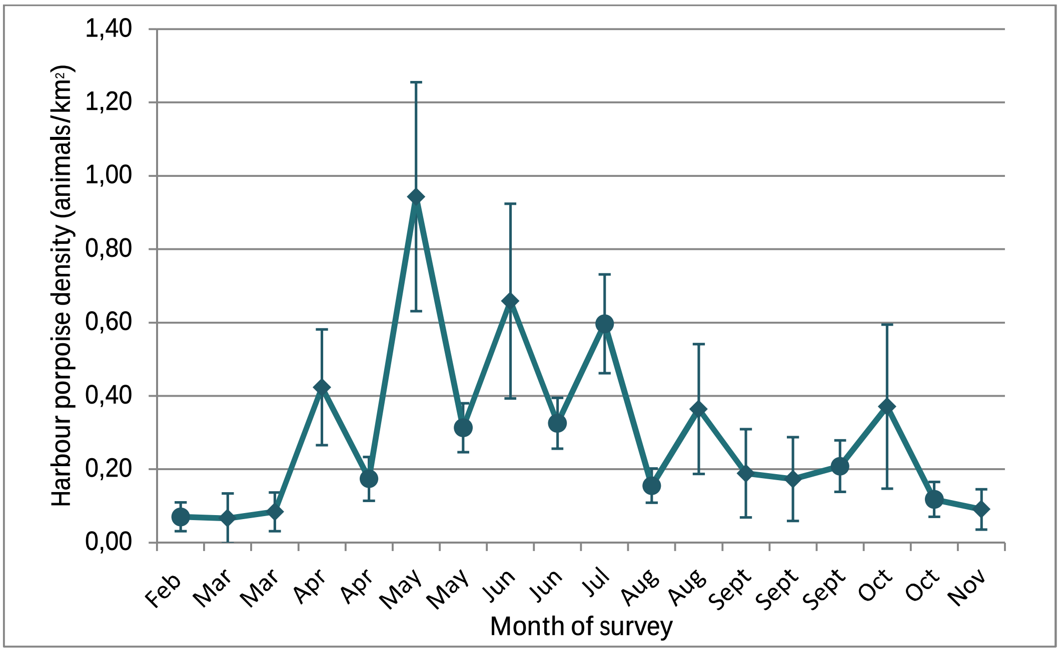


Figure 2.3-11 **Porpoise density (animals/km^2) during dedicated mammal (circle) and bird/mammal (diamond) aerial survey flights, Jan – Nov 2010 (vertical bars = standard error).**

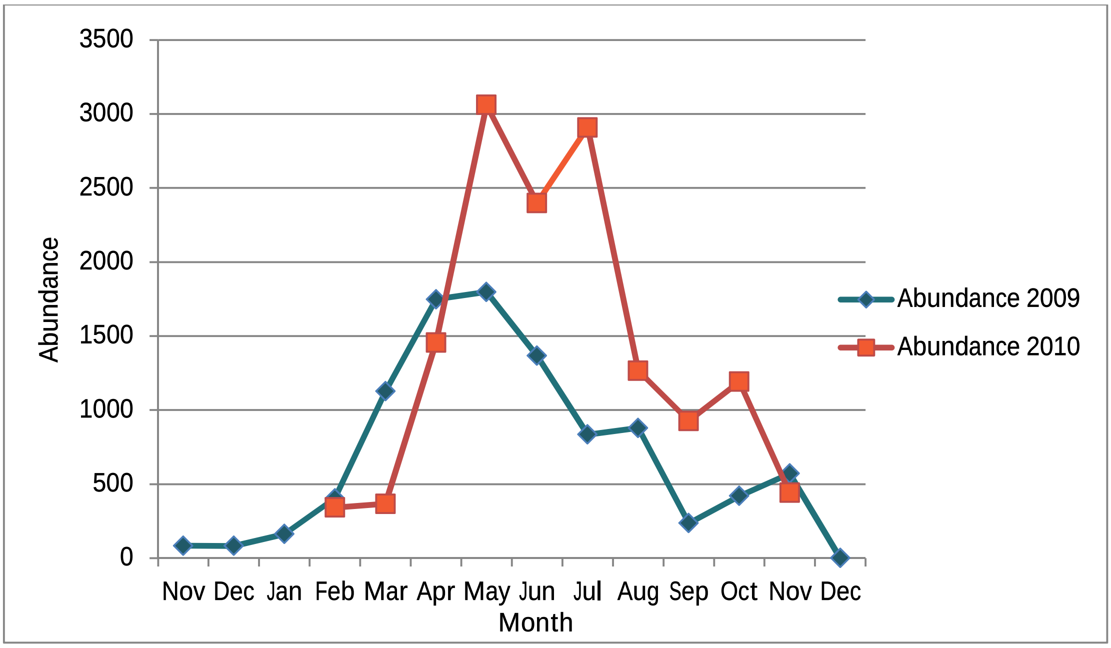


Figure 2.3-12 **Comparison of monthly (mean) harbour porpoise abundance for surveys of Fehmarnbelt in 2009 and 2010.**

2.3.5. Discussion

This chapter presented results from the design-based analysis of marine mammal aerial survey data, collected between November 2008 and November 2010. Density estimates ranged from zero animals (no sightings were made on flights during December 2008 and 2009) to 0.94 animals/km^2 in May 2010. These estimates are comparable to those in other studies (summarised in Table 2.3-5) Previously, the highest density recorded for the region was 0.64 animals/km^2 in the Bay of Kiel (Scheidat et al., 2008) and 95% of the density estimates presented in our study are between 0 – 0.65 animals/km^2. This study estimated the highest densities recorded thus far for the Fehmarnbelt; a peak of 0.94 animals/km^2 during a survey in May 2010. Unusually, Scheidat et al. (2008) recorded a higher density of 1.02 (%CV = 73) in the Baltic Proper/ Pomeranian Bight during an aerial survey in July 2002; this indicates that higher densities than would be expected (i.e. in the range for the vast majority of published estimates) do occur. These 'outlier' estimates may arise from coincidental timing of the survey with increased movement of porpoises through the survey area.

Our results are largely similar to those from previous surveys in the area. However, in comparing current results from those summarised in Table 2.3-5, there are a number of caveats to consider. None of the areas described in the previous studies overlaps exactly with the Fehmarnbelt study area. In most cases, the comparison is still useful – however in some cases (e.g. SCANS-II) the surveys referred to in Table 2.3-5 include substantial areas outside of the Fehmarnbelt, and some caution is needed when interpreting our results in light of these previous assessments.

The MINOS/+ surveys (Scheidat et al., 2008) focused only on German waters, so while the stratum described in Table 2.3-5 (which covered waters south of a line from Flensborg Fjord to Darßer Ort) encompassed the western and eastern limits of the Fehmarnbelt study area, surveys did not extend all the way to the Danish coast. Additionally, results were not presented as densities, but the abundance estimates of 980 (1995) and 1,830 (1996) suggest that densities were probably similar to those from the present surveys.

An important consideration is if, and how, results are corrected for *g(0)*. In most of the surveys described in Table 2.3-5, some form of *g(0)* correction was applied. However, this was not the case for the Heide-Jorgensen et al. (1993) results, and therefore those densities should be viewed as minimum estimates. Other surveys used either tandem aircraft (SCANS; Hammond et al., 2002), or the 'race track' method of circling back using a single aircraft (SCANS-II, 2005). While these various methods of *g(0)* may produce slightly different results, the difference between differing method of *g(0)* calculation is likely to be far less than the difference between corrected and uncorrected estimates. In fact, the results from the SCANS survey (Hammond et al., 2002) stand out as being somewhat lower than the other unbiased estimates from that time of the year; however, this is the exception.

Table 2.3-5 **Summarised results from previous systematic porpoise aerial surveys in the Fehmarnbelt area**

Authors/source	Month and year of survey	Area description	Density (animals/km^2) (%CV)	g(0) corrected	Calves[1]
Heide-Jorgensen et al. (1993)	June 1991/92	Kiel Bay	0.012 (25%) (1991), 0.032 (37.5%) (1992)	No	18% (1991)
SCANS	June-August 1994	Little Belt	0.101 (48%)	Yes	Not reported
Siebert et al. (2006)	October 1995, July 1996	Kiel and Mecklenburg Bay	Results not presented as density – see discussion	Yes	28%
SCANS-II	July 2005	Kattegat, Skagerrat, Western Baltic	0.340 (36%)	Yes	2.4%
MINOS/+ (Scheidat et al., 2008)	2002 - 2006	Kiel and Mecklenburg Bay	Kiel: 0.009 – 0.636 Mecklenburg: 0.034 (99%) – 0.345 (45%)	Yes	8.06% (2002-04); 5.56% (2004-06)
FEMM/FEBI	Nov 2008 – Dec 2009	Fehmarnbelt	0.00 (Dec ’08 and ’09) – 0.59 (24%) (April ’09)	Yes	13.04%
FEMM/FEBI	January – November 2010	Fehmarnbelt	0.07 (Feb) (55%) – 0.94 (31%) (May ’10)	Yes	5.5%

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[1] The percentage is calculated as the number of calves as a proportion of the overall number of individuals observed for the months in which calves were seen.

Finally, it is worth highlighting that systematic harbour porpoise surveys in the Baltic have, in the past, almost exclusively been undertaken during summer months. Thus the results presented here are unique in that they cover all seasons.

In general, density results from aerial surveys appear highly variable, though there is generally an obvious seasonal component. Analysis of the 2009 and 2010 data also highlights the presence of inter-annual variability in density and abundance. Despite this, the results from the present survey are within the expected range suggested by previous survey results.

Calves

Calves were observed during five surveys in 2009 and seven surveys in 2010. Calf sightings occurred in the months of March and May - October. This is consistent with typical calving periods for this species, which report most calves born between April and August (Jefferson et al., 2008). For the surveys during which calves were observed, the percentage of calves in relation to total individuals varied between the two years; calves comprising 13.04% of all observed individuals in months were calves where seen in 2009 but only 5.5% in 2010. Inter-annual variability in calf numbers has been observed in other surveys (Table 2.3-5). Results from the various datasets are highly variable – for example Heide-Jorgensen et al. (1993) reported 18% calves during the 1991 survey, but saw none the following year. Some of this variability may be due to the difficulties in identifying a calf at sea. There is a great deal of variability in body lengths of calves and whilst their length may be 50-60% of the adult female, it may be as great as 75% (Benke et al., 1998); in the case of these ‘large’ calves they are likely to be under-represented. In this study, the definition of a calf was not just based on body length but included that it was closely accompanying an adult porpoise. Despite this variability, it is clear (from previous surveys and the results presented here) that calves are sighted in the Fehmarnbelt. However, it is not possible from the current study to determine whether the area serves as a nursery ground per-sé. Indeed, while the SCANS results did not specifically present calf numbers, nor were the surveys designed to assess calf numbers, the authors observed that areas of high calf sightings tended to coincide with areas of high porpoise sightings generally (Hammond et al., 2002). The authors also noted (though they did not formally test this) that calves tended to be seen more in inshore waters. The SCANS-II surveys did not detect a large number of calves, with the overall rate (number of calves/number of individuals %) for European continental shelf waters surveyed by both ship and aircraft being just 2.55% (SCANS-II, unpublished data).

Relating calving rates to population stability requires additional analysis within a population model framework – this is beyond the scope of the work presented here. Nonetheless, comparing our data on proportions of observed calves with previous aerial surveys through the area (Table 2.3-5), it seems that occurrence of calves in the Fehmarnbelt area can be highly variable from year to year with no obvious underlying trend.

Seasonal trends

The sightings data showed a clear seasonal component in both years, with higher densities during the months of March to August. Abundance peaked in April in 2009 and in May during 2010; this spring increase in numbers may be linked to an influx of porpoises into the area and associated increased prey availability. Harbour porpoises are thought to migrate into the Baltic

Sea in early spring and out again into the wider North Sea during late autumn (Andersen, 1982). Abundance remained relatively high through to August, then in both years numbers declined in September before increasing again in October before finally tailing off to a wintertime low period. This seasonal trend was expected, and is in line with current knowledge on seasonal distribution patterns of harbour porpoise in this area. While the historical data sets presented in Table 2.3-5 generally represent summer months only, Teilmann et al. (2008) used a variety of data sets (tagged animals, visual and acoustic surveys) to investigate high-density areas of harbour porpoise in Danish waters and in the case of Fehmarnbelt suggested that peak densities occurred in April, June and December. The data presented in this chapter support year-round use of the area by harbour porpoise, and this was also apparent from the opportunistic ferry surveys where porpoises were recorded in all months (see section 2.5).

2.4. Distribution and abundance of harbour porpoises - Part 2: model-based analysis

2.4.1. Introduction

The first part of the analysis of harbour porpoise aerial survey data (see section 2.3) described a conventional distance sampling analysis using the software Distance (Thomas et al., 2009). Results were presented as density and abundance estimates for each survey (approximately monthly). These indicated a strong seasonal trend with higher harbour porpoise densities occurring during spring and summer months.

In this chapter, density surface modelling (DSM) is applied to the harbour porpoise aerial survey data to predict density and abundance over the entire study area, accounting for habitat variability. The results from this chapter should not be directly compared with the previous conventional analysis, as the goals of the two chapters differ. In the previous chapter, the objective was to produce density and abundance estimates for each survey; here, the objective is to pool data and use environmental data to examine the temporal and habitat preferences and predict density across the whole Fehmarnbelt study region. By doing so, an over-arching goal is to gain greater understanding of distribution of porpoises within the area and the habitat and environmental variables that may govern this. The model-based approach also allows density and abundance to be extracted for areas of interest within the survey area, such as protected areas or potential impact zones.

2.4.2. Methods

Data collected during 2008 to 2010 for both the mammal-only survey flights and bird/mammal (combined) survey flights are combined to estimate a single density surface model representative of all data. This model can then be used to predict density for the spatial and temporal ranges of interest. Although there were many sightings in the summer months, there were few sightings in the winter months. Therefore to investigate the seasonality of harbour porpoise density, two seasons were defined; summer (April to August) and winter (remaining months). Each dataset was prepared separately and sightings were adjusted for uncertain detection using the detection probabilities generated during the design-based analyses (see section 2.3). The datasets were then combined in order to create a density surface.

The procedure can be summarised as:

1. Survey effort data were prepared by splitting transects into approximately 1 km segments.
2. Harbour porpoise sightings and values of environmental variables were assigned to each segment.
3. A detection function model was fitted separately to the sightings of each dataset to estimate detection probability (see section on design-based analysis). The probability of detection obtained from this function and also estimates of *g*(0) were used to adjust the number of harbour porpoises sighted in each effort segment and hence, the estimated number of harbour porpoises per segment was calculated.
4. The four datasets (mammal only 2009, mammal-bird 2009, mammal only 2010, mammal-bird 2010) were joined together so that a model could be fitted to the pooled datasets instead of fitting separate models to the individual datasets. A series of Generalised Additive Models (GAMs) were fitted using the estimated number of harbour porpoises per segment as the response variable, with environmental and year and season covariates as explanatory variables.
5. Once the ‘best’ model was determined (see section 2.4.2.3) density was predicted over a grid of environmental variables which covered the temporal range and area of interest.
6. A surface of uncertainty in the density estimates was produced by bootstrapping the density estimates over the predicted surface.

2.4.2.1. Data preparation

The survey area covered an area of 4,875 km^2 (see Figure 2.4-2). Survey effort data from the 2009 aerial surveys March – August (inclusive) and all the aerial survey data for 2010 was segmented into approximately 1km sections, with each sighting assigned to the corresponding segment of effort(Table 2.4-2).

Each segment of survey effort was assigned values of static and dynamic environmental variables (Appendix 7.4). As the same transects were used for each survey, the “same” segment occurred multiple times in the database but with a different set of dynamic variables to capture the temporal variability in environmental parameters. The value of the environmental variable at the mid-point position and date/time of the segment when it was surveyed was assigned to it.

Environmental variables were either taken directly or developed through post-processing chains from static and dynamic data delivered by the FEHY and FEMA projects. The dynamic variables came from DHI’s local 3D hydrodynamic model set up by FEHY. As the number of environmental variables which can potentially be developed from the Fehmarnbelt local hydrodynamic model is very large (100+) a selection of the most feasible variables was undertaken following exploration of scale-dependencies in the sampled field data, and data ordination. Three velocity variables (U, V, and W; see Appendix 7.4 for definitions) were also transformed (by squaring) to remove the directional component whilst maintaining the relative measure of current magnitude.

The selection of environmental variables followed a step-wise approach having determined which variables were highly correlated to ensure these variables were not included in a model together.

The core environmental variables were those which reflected the stable flow and frontal characteristics of the Fehmarnbelt (pycnocline strength, northern current velocity, eastern current velocity, vertical velocity, frontal strength, eddy activity). Water depth and sediment grain size were included as static habitat variables. Although they do not represent patterns at the fine spatial scales, temperature and water column structure (pycnocline depth) were included to enable programming of models with or without seasonal trends. Salinity discharge, salinity and density were selected to reflect the periodic inflows and outflows and the movement of water masses, and hence enable different model designs for the two main flow scenarios. Salinity and its derivate density were chosen as salinity provides one of the strongest ecological gradients and water mass constituents in the Baltic Sea (Al-Hamdani and Reker, 2007). Four pressure variables were also developed: distance to land, distance to wind farms, distance to shipping lanes, and distance to the proposed alignment (as Euclidean distance to the planned alignment for tunnel and bridge options). These pressure variables should potentially enable the inclusion of any effects of human infrastructures on marine mammals in the habitat models.

2.4.2.2. Fitting the detection function (DS)

To account for imperfect detectability, conventional distance sampling (CDS) detection functions were fitted to the distributions of perpendicular distances of each sighting for each dataset. The detection functions fitted are described in (section 2.3). CDS models assume that detectability on the track line is certain (denoted by $g(0)$=1). For harbour porpoise, this assumption is unlikely to be fulfilled due to perception bias and availability bias and the estimation of $g(0)$, taking into account these biases, is described in section 2.3 (Table 2.3-2). Thus, the estimated number of animals in segment i, $\hat{\mathrm{N}}_{\mathrm{i}}$, is given by

$$\hat{N}_i = \sum_{j=1}^{J} \frac{s_{ij}}{\hat{p}_{ij}\hat{g}(0)}$$

where s_{ij} is the size of the jth group in segment i, $\hat{p}_{ij}$ is the estimated detection probability obtained from the detection function model and J is the number of groups detected in segment i. In this way, the different detection probabilities and estimates of $g(0)$ for the different datasets can be taken into account.

2.4.2.3. Density surface modelling (DSM)

Once the estimated number of animals per segment had been enumerated, the next step was to join the datasets together and then fit a series of generalised additive models (GAMs) to the combined data determine the best model with which to create a density surface.

Generalized Additive Model (GAMs)

The methods are described in detail by Hedley and Buckland (2004). The abundance of individuals in each segment (the response variable) was modelled using a Generalized Additive Model (GAM) with a logarithmic link function using the environmental covariates as explanatory variables. The general formula for the model is given by:

$$\hat{N}_i = \exp\left[\ln(a_i) + \theta_0 + \sum_k f_k(z_{ik})\right]$$

Where the offset a_i is the search area for the i^{th} segment (calculated as the length of the segment multiplied by twice the truncation distance), q_0 is the intercept, f_k are smoothed functions of the explanatory covariates and z_{ik} is the value of the k^{th} explanatory covariate in the i^{th} segment. An error distribution also needs to be specified and this generally depends on the nature of the data. In this case, a Tweedie distribution (Tweedie, 1984) was specified. The data were over-dispersed (sightings were clumped and not evenly distributed throughout the survey area) and there were a large number of segments that did not contain any sightings (Table 2.4-2). The Tweedie distributions describe a flexible family of probability distributions which can be used when the data contain many zeros (Lorance et al., 2010).

GAMs were fitted using the mgcv package (Wood, 2006) in R v.2.12.1 (R Development Core Team, 2010) and each of the explanatory variables was fitted in turn to assess its significance. More complex models were then built with the more significant variables using forward selection techniques. The improvement in the model made by the addition of variables was assessed through the change in deviance explained and the General Cross Validation score (GCV). Models with the smaller GCV score tend to do better at explaining the response variable. In order to avoid fitting unnecessarily complex smooth functions, the flexibility of the smooth functions was restricted to 5 knots for a one-dimensional function and 10 knots for a two-dimensional function. Plots of the fit of the smoothed density against each explanatory variable were visually inspected to check for unusual behaviour of the variables or interactions in the model. As the density in summer and winter in both years was of interest, factor variables were included in the model to represent year and season. The Tweedie distribution requires an index parameter to be specified which essentially determines the nature of the distribution. Here values between 1 and 2 were used to fit a Poisson-gamma type distribution. The value was chosen by changing the index parameter and refitting models in order to find the index parameter which maximised the deviance explained by the model.

The output from this stage was a “best” model which described the density throughout the survey effort in relation to key environmental variables.

Prediction grid

A grid for the prediction of density throughout the survey area was generated for each time period of interest (2009 summer and winter and 2010 summer and winter). The resolution of the grid cells was 750 m x 750 m, resulting in a grid with 8618 cells (the grid was trimmed against the coastline to remove cells over land and a small number of edge cells with zero values for dynamic variables were also removed). The centre point of each cell was assigned a value for each of the environmental variables. Values of dynamic variables were averaged over the time period of interest. Therefore, temporal resolution for prediction was comparatively coarse. Having chosen the best model, this model was then used to predict the density throughout the entire survey region, including un-surveyed areas between the transect lines. The model was applied to the predictor values of each grid cell in the prediction grid. This process generated a density and resulting abundance estimate for each cell. Total abundance within the region of interest was obtained by summing the cell abundance estimates.

The grids of corrected density estimates were exported to ArcGIS and maps of the density surface created.

Variance estimation

The variance associated with the density estimates was calculated using a bootstrap – a data-based simulation method. A sample is drawn from the original data and abundance is estimated from this bootstrap sample. This process is repeated a large number of times and the empirical variance estimated from the distribution of bootstrap abundance estimates. The 2.5% and 97.5% quantiles of this distribution provide the lower and upper limits of the 95% 'percentile' confidence interval (CI), respectively. The transect lines were used as the sampling unit and were chosen at random and with replacement. Each survey is essentially a replicate and so when a particular transect was selected to be in the bootstrap sample, then all the data, for both years and survey types, for that transect were included. To include variation due to g(0), then a bootstrap estimate of g(0) was obtained by generating a random value from a Normal distribution with mean and standard error equal to that of the estimated values for g(0) for each year and data type (Table 2.4-1).

Table 2.4-1 Estimates of availability and perception bias and an overall estimate of $g(0)$. Percentage coefficients of variation (CV) are given in parentheses

Year	Data set	Perception bias	Availability bias	$\hat{g}(0)$
2009	Mammal only	0.694 (11.1)	0.432 (1.8)	0.290 (11.2)
	Mammal and bird	0.609 (16.7)	0.441 (2.4)	0.265 (16.9)
2010	Mammal only	0.764 (6.6)	0.418 (1.9)	0.319 (6.8)
	Mammal and bird	0.719 (11.1)	0.436 (2.3)	0.313(1.3)

2.4.3. Results

2.4.3.1. Detection function

The detection functions used are described in section 2.3. The values of g(0) used are described in section 2.3 and see Table 2.3-2.

2.4.3.2. GAMs

Harbour porpoise were distributed throughout the study region but were only detected in a small percentage of the effort segments (Table 2.4-2).

Table 2.4-2 Summary of DSM data.

Year	Flight type	Survey effort (km)	Number of segments	Number of segments where HP detected
2009	Mammal only	7693	7180	154
	Bird/mammal	7401	6921	97
2010	Mammal only	9340	8946	206
	Bird/mammal	11279	11267	92
Total		35713	34314	549

In addition to the factor variables for year and season, the selected model included the variables; position (as an interaction term of X and Y coordinates), water depth, sea temperature at the bottom of the water column (3 m above the seabed) and the east-west bottom current velocity. None of the four pressure variables (distance to land, distance to wind farms, distance to shipping lanes and distance to the proposed alignment) were significant predictors of harbour porpoise distribution. All terms were highly significant (p-values all <0.01), however the model only explained 8.42% deviance. Of this, depth was the most significant accounting for 3.67% of the deviance. Figure 2.4-1 show the response variable as a function of the predictor variables.

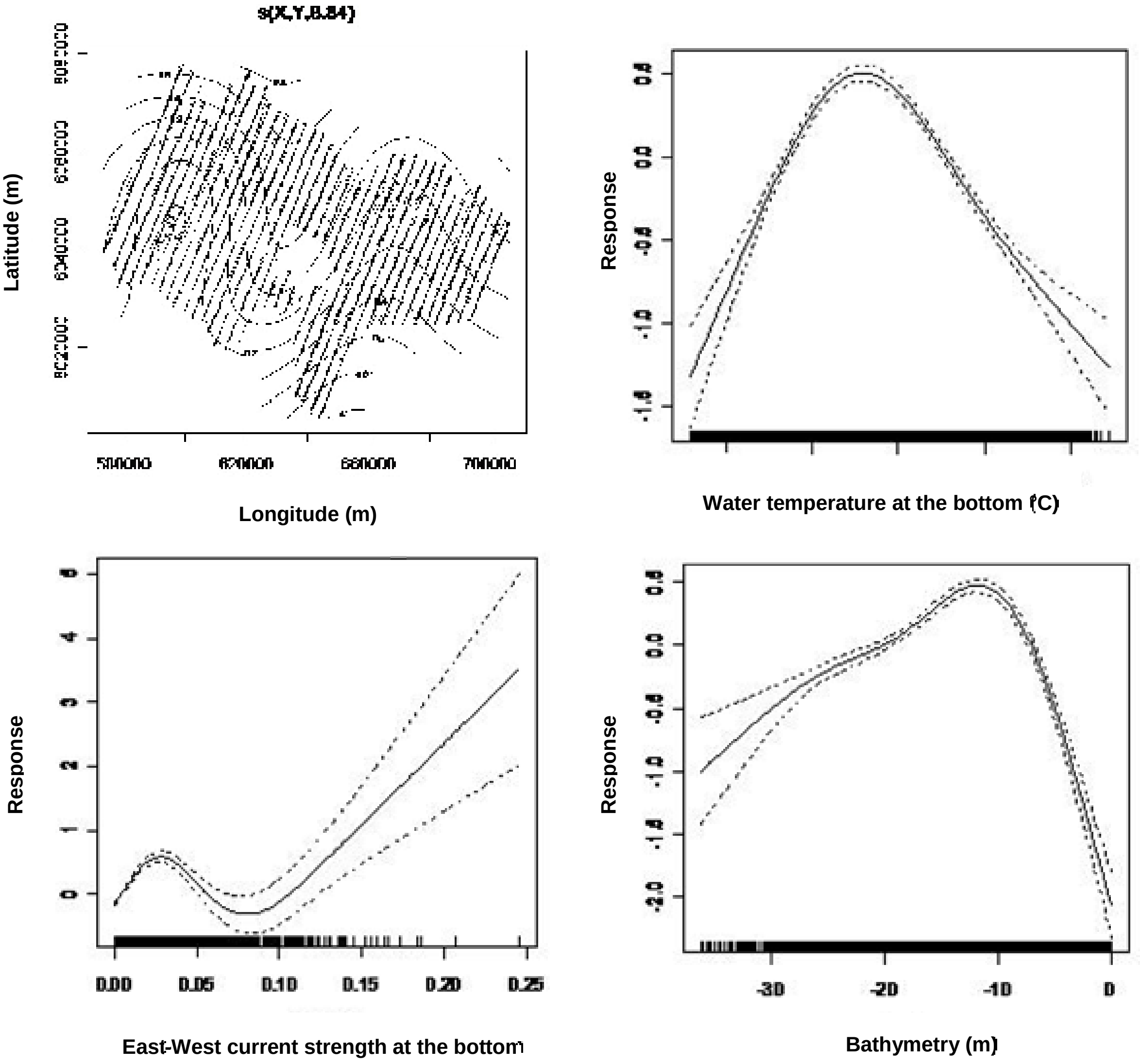

Figure 2.4-1 Plots of the response variable (log density) as a function of the predictor variables chosen in the GAM. The top left plot shows log density as a function of an interaction between latitude (Y) and longitude (X). The top right plot shows bottom water temperature. The bottom left plot shows east-west current strength at the bottom, and the bottom right plot shows depth as a function of log density with ±2 standard errors (dotted lines). The ticks along the x-axis and dots on the latitude longitude plot indicate the range and distribution of the predictor values in the data.

2.4.3.3. Prediction and variance estimation

The selected model was used to predict animal density over a series of prediction grids which contained the environmental covariates averaged over the time periods of interest (e.g. summer and winter in 2009 and 2010). Since the environmental covariates in the prediction grids are averages over the time periods of interest, the predicted density surfaces and abundances estimates also represent averages over the time periods.

The estimated density surfaces are given in Figure 2.4-2 - Figure 2.4-5. Harbour porpoise abundances for the seasons of interest were obtained by integrating under the surfaces shown in Figure 2.4-2 - Figure 2.4-5. The abundance estimates are given in Table 2.4-3.

The coefficients of variation (CV) and 95% ‘percentile’ confidence intervals were obtained from 1000 bootstrap samples. The uncertainty associated with the estimated density surfaces is expressed as a percentage CV and shown in Figure 2.4-6 to Figure 2.4-9.

Table 2.4-3 Abundance estimates of harbour porpoise for the spatial and temporal ranges of interest, percentage CVs and 95% ‘percentile’ confidence interval (CI)

Year	Season	Abundance	%CV	95% CI
2009	Summer	1456	19.0	782 – 1631
	Winter	921	31.1	436 – 1467
2010	Summer	2078	17.8	1414 – 2709
	Winter	931	31.9	521 - 1800

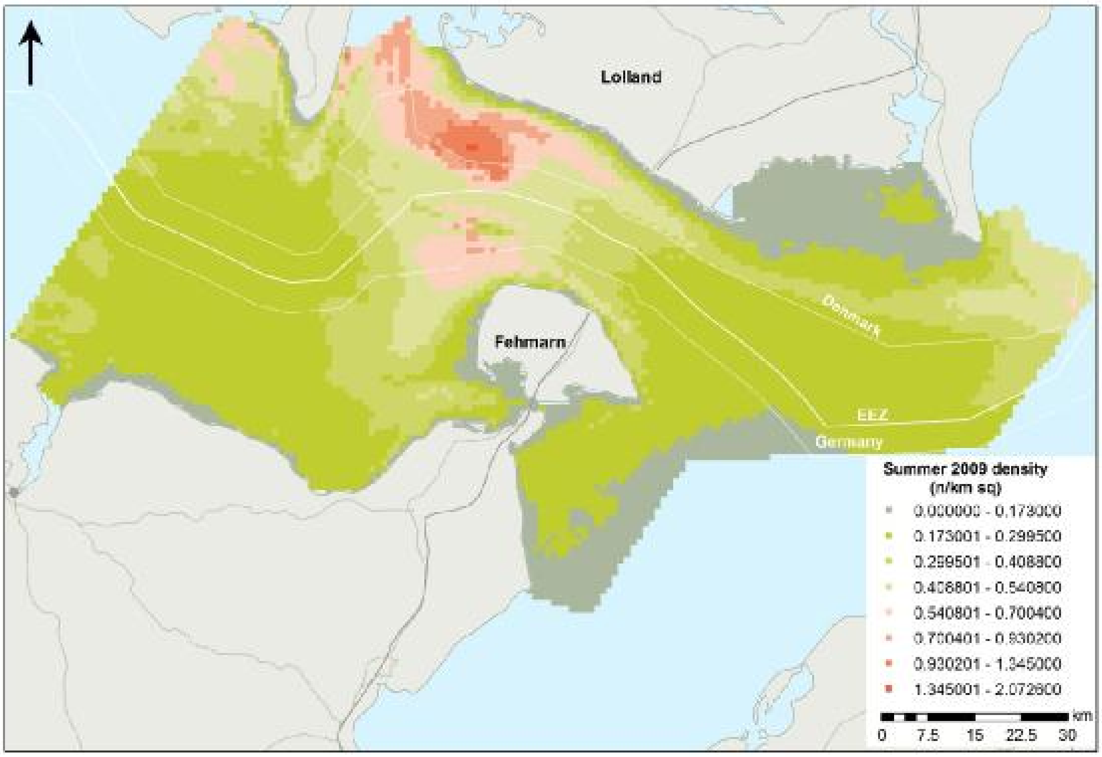

Figure 2.4-2 Estimated density of harbour porpoise (animals per km^2) for summer 2009.

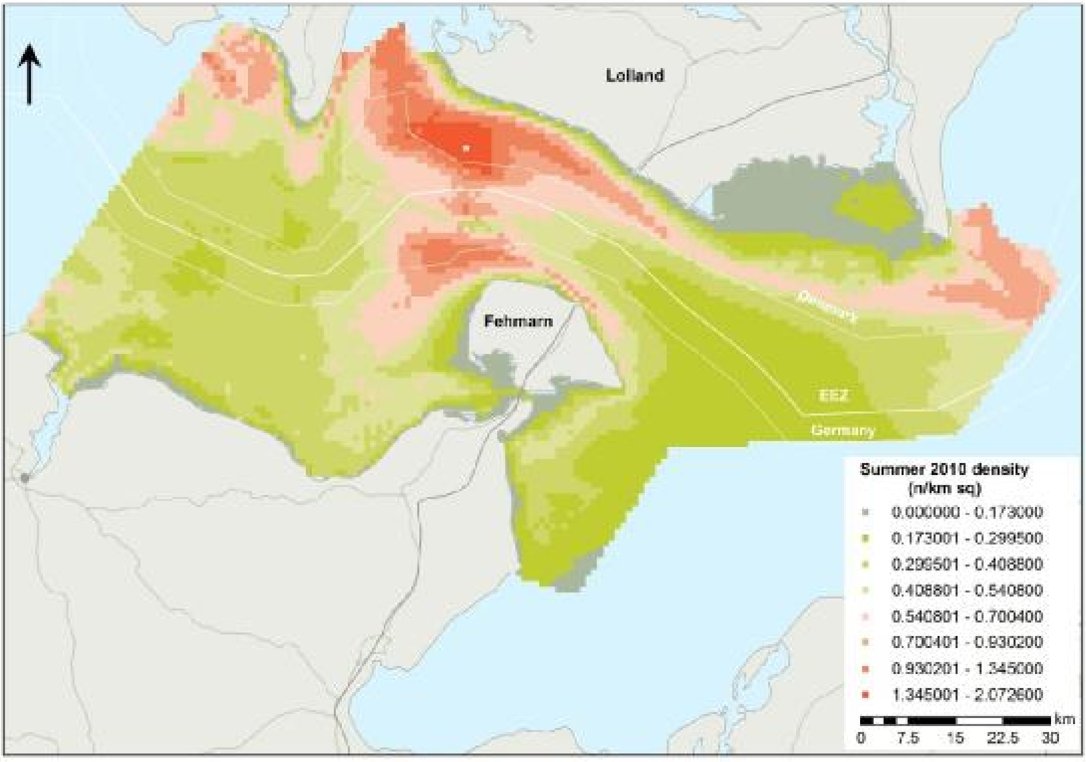

Figure 2.4-3 **Estimated density of harbour porpoise (animals per km^2) for summer 2010.**

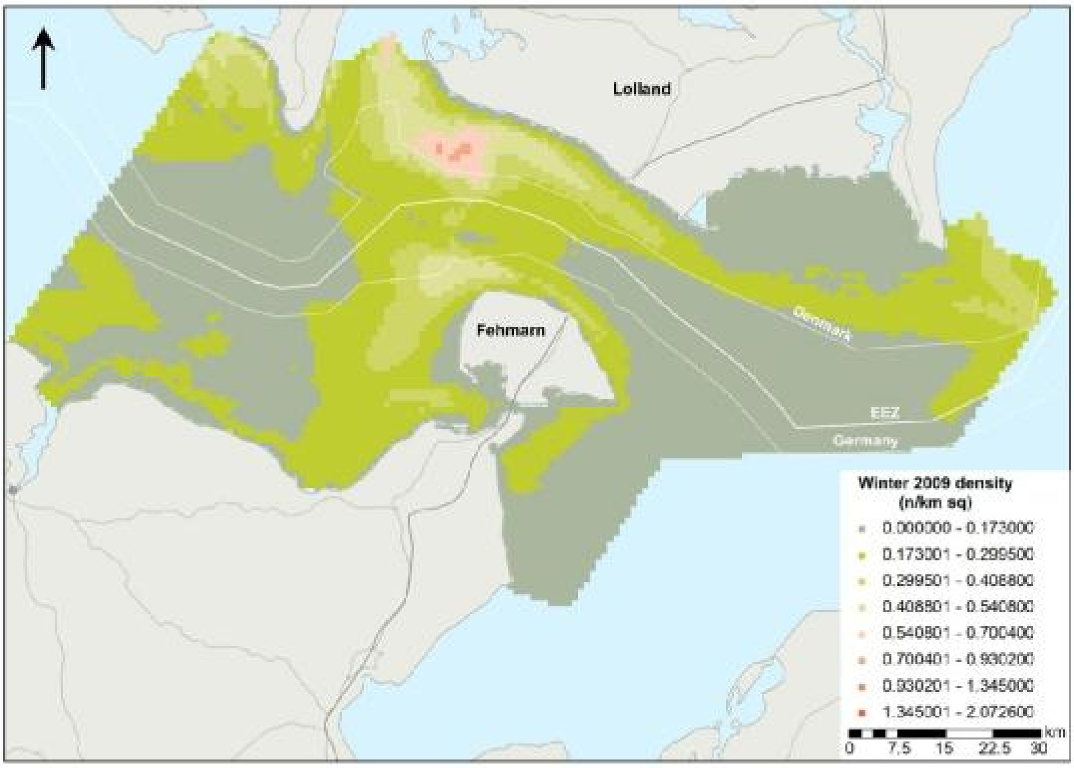

Figure 2.4-4 **Estimated density of harbour porpoise (animals per km^2) for winter 2009.**

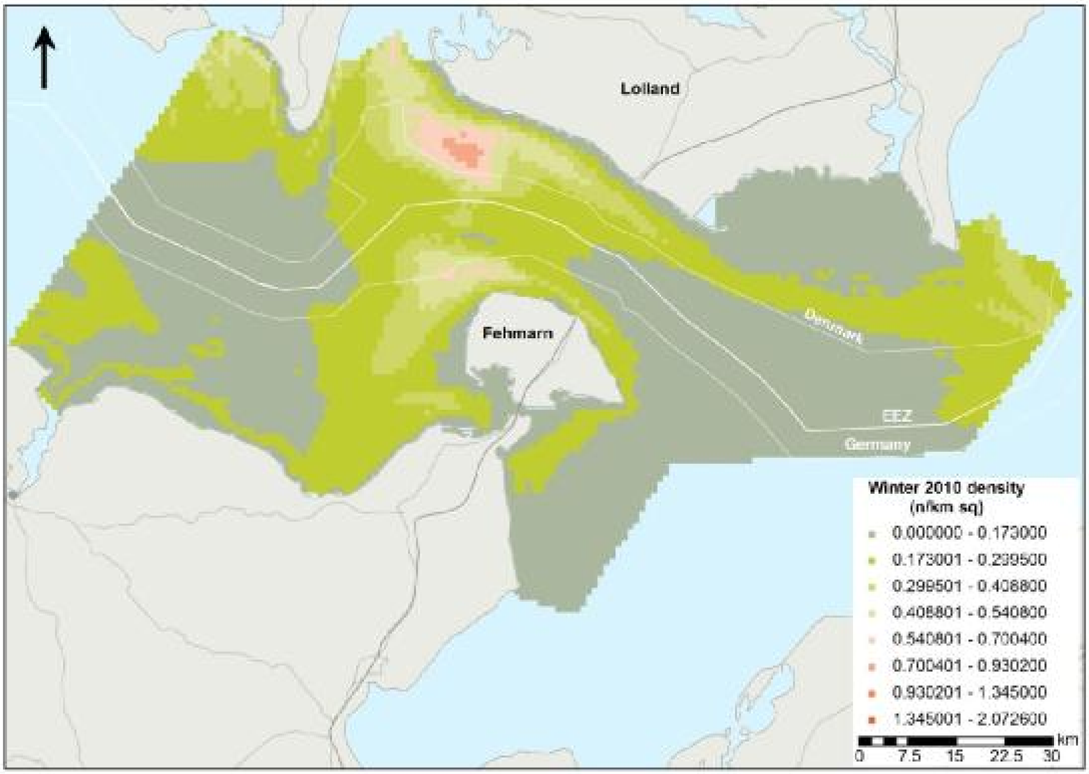

Figure 2.4-5 Estimated density of harbour porpoise (animals per km^2) for winter 2010.

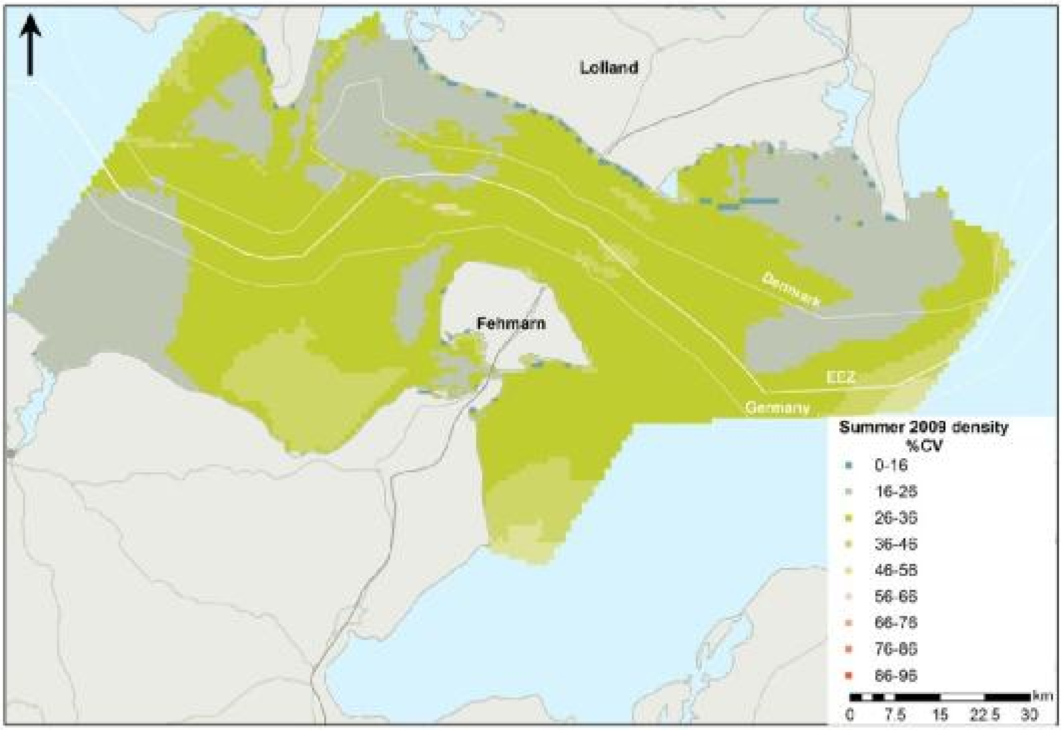

Figure 2.4-6 **Uncertainty surfaces for the estimated summer 2009 density surfaces. The scale is the percentage coefficient of variation (%CV).**

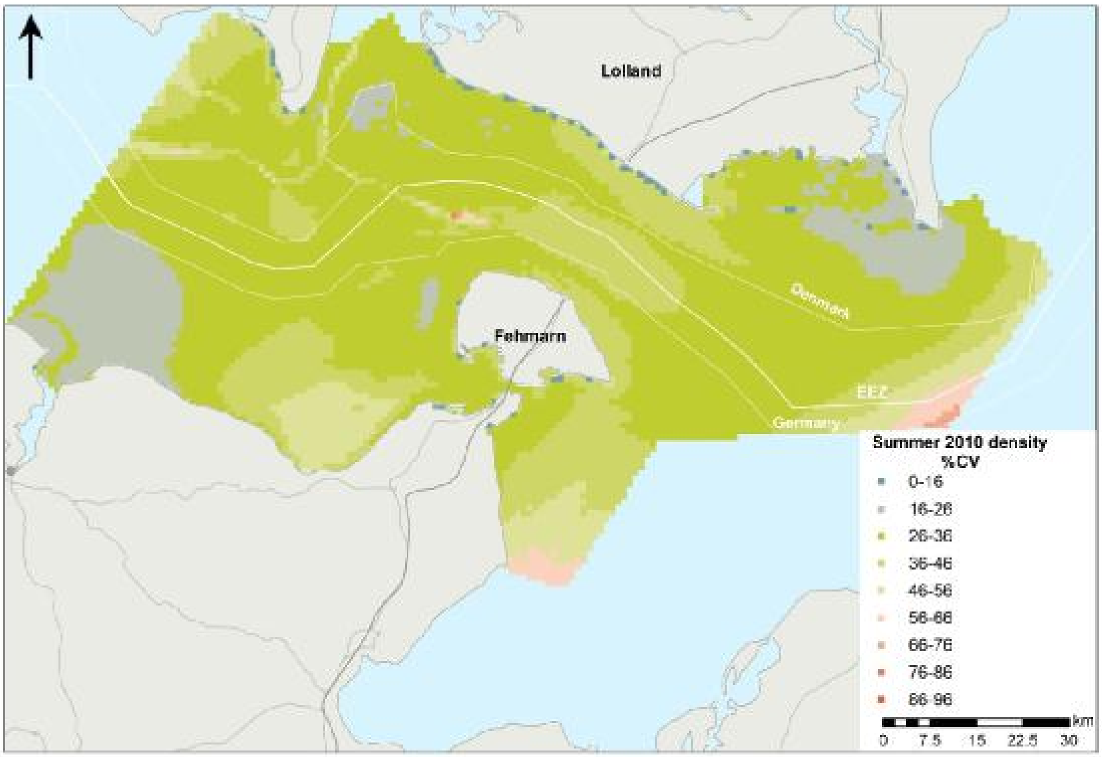

Figure 2.4-7 **Uncertainty surfaces for the estimated summer 2010 density surfaces. The scale is the percentage coefficient of variation (%CV).**

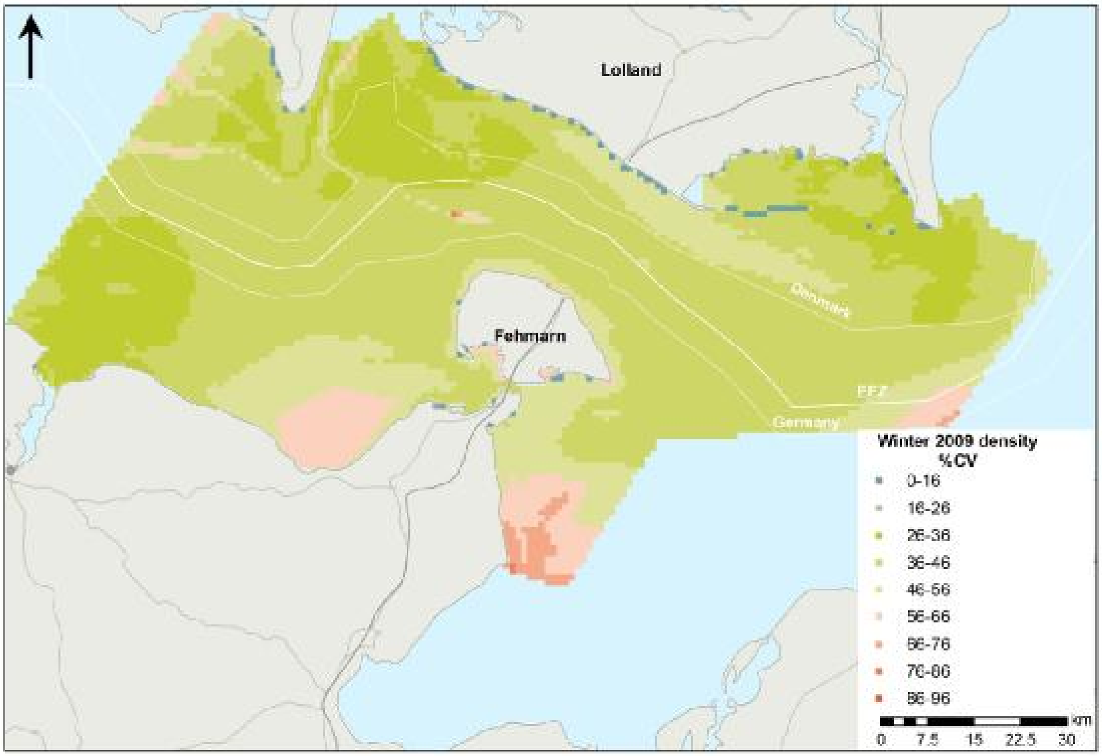

Figure 2.4-8 Uncertainty surfaces for the winter 2009 estimated density surface. The scale is the percentage coefficient of variation (%CV).

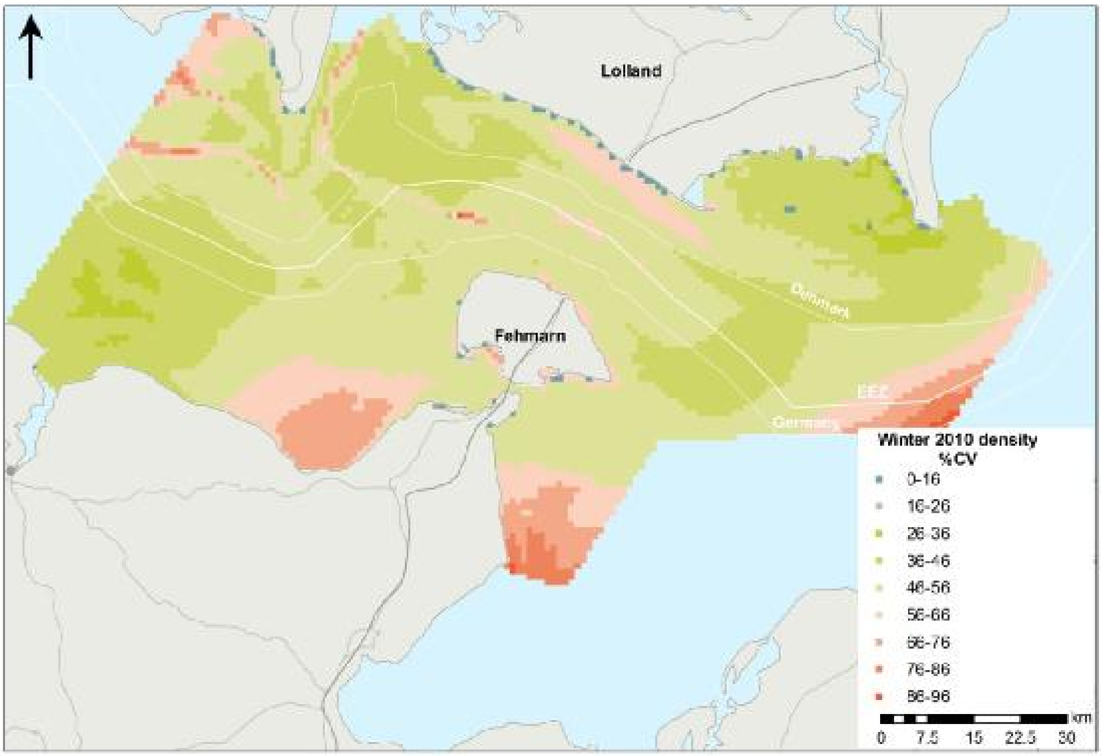

Figure 2.4-9 Uncertainty surfaces for the winter 2010 estimated density surface. The scale is the percentage coefficient of variation (%CV).

2.4.4. Discussion

The abundance estimates presented for harbour porpoises during the winter in 2009 and 2010 in Fehmarnbelt are statistically the same; 921 (%CV=31.1) and 931 (%CV=31.1), respectively. However, there is greater difference between the summer estimates, being 1,456 (%CV =19.0) in 2009 and 2,078 (%CV=17.7%) in 2010. The uncertainty associated with the abundance estimates is lower for the summer estimates than winter which is primarily related to the larger number of sightings during the former. Similarly, within seasons, areas with higher CVs are generally those where there were few harbour porpoise sightings or poor survey coverage.

There are areas within the survey area which consistently have higher densities of harbour porpoise in summer and winter and in both years. Higher densities of porpoises occurred in the north of the survey area off southwest Lolland but also around the northwest coast of Femern. Between the west and east of the survey area, there is a strip of relatively high density running along the southern coast of Lolland. Although densities were not as high to the east of the survey area as the west, there were still relatively high numbers of harbour porpoise compared to the more southerly regions of the survey area, such as the German Bay of Kiel.

The variables position, water depth, sea temperature at depth and the strength of the east-west current component at depth were the significant variables in predicting harbour porpoise abundance. However, the deviance explained by the best model was low

Relationships between the distribution of harbour porpoises and water depth are well documented (Hammond et al., 2002; MacLeod et al., 2003, 2007), all indicating a preference for shallower continental-shelf waters. In this study, higher densities were predicted in water depths of around 10-15 m. Density declines are predicted in deeper waters although harbour porpoises still occur in deeper waters. The variables sea *surface* temperature and sea *bottom* temperature were very highly correlated, but the bottom temperature covariate was retained in the model as it explained slightly more deviance. Porpoise density was highest when bottom temperature was between 5-10°; this likely reflects the higher densities that occur during the summer. Off the west coast of Scotland, MacLeod et al. (2007) found that sea-*surface* temperature was an important predictor of harbour porpoise distribution in water depths less than 60m. The east-west current strength was also an important predictor, with porpoises preferentially occurring in areas of weaker current. In our study, the upwelling/downwelling velocity variable (*W*) was not found to be a significant predictor of harbour porpoise density in the survey region. This contrasts with the study undertaken by Skov and Thomsen (2008) at the Horns Reef, eastern North Sea, where tidal-driven upwelling was found to be a motivating factor of harbour porpoise distribution as measured by acoustic activity. In the Bay of Fundy, Canada, regions of enhanced relative vorticity such as those around islands and headlands, represent important foraging habitat for harbour porpoise as they support aggregations of prey (Johnston et al., 2005).

The nature of the dynamic variables is that their values change depending on location and time e.g. water temperature; whereas static variables only change spatially e.g. water depth. The variability of the dynamic variables was captured in the segmentation process as preparation for the GAM; the spatial scale chosen was 1 km and the value of the dynamic variable was assigned to the exact second that the central point of the segment was surveyed. However, much of the varying temporal nature of the dynamic variables was lost in the prediction process because the sightings data were pooled over months to generate annual "seasonal" harbour porpoise density surfaces. However, the dominant variable in the model was depth, accounting for almost half of the explained deviance of the GAM. Therefore, the role of the dynamic hydrographic variables was limited. This conclusion compares well with the results of the modelling of the harbour porpoise telemetry data, where predicted distribution clearly mirrored bathymetry (see section 2.2).

There are a number of advantages of using a model-based approach for estimating animal density. The model-based approach often generates more precise abundance estimates (i.e. lower CVs) than design-based methods. Density surface models can produce estimates with higher precision because they use sightings data from all transect lines to model the relationship between the predictor environmental covariates and the response (abundance). Encounter rate variance (differences in encounter rates between transects) often dominates the estimates of precision in CDS analysis, and that source of variability is removed from DSM analyses. Furthermore, the method does not rely on a survey design with equal coverage probability and as such can, if needed, be applied to data collected opportunistically as long as the survey effort is representative of the area of the interest. This method will deal better with the exclusions from parts of the survey area imposed during these aerial surveys. Also, the density-surfaces generated from the model-based approach can be used to assess abundance in sub-regions of the survey area; however, this is only applicable if the GAM models on which the estimates are based are still considered applicable for the small area of interest. It is always advisable to test this assumption and if it does not hold, then new models should be fitted for the smaller area of interest.

The model-based estimates compare well with the design-based estimates. For example, applying the conventional distance sampling (CDS) approach to the mammal dataset and mammal-bird datasets collected during April – August 2009 (i.e. the definition of summer used in the model-based analyses), the mean of the combined estimates is 1,363 harbour porpoise. The DSM estimate for summer 2009 was 1,456 (%CV = 19) harbour porpoises. In 2010, the mean of the CDS summer estimates from the mammal dataset and mammal-bird dataset was 2,116 harbour porpoise. The DSM estimate for the same summer period was 2,078 (%CV=18). The estimates generated from the different approaches are not statistically different. It is to be expected that estimates from a CDS and DSM analysis will not be exactly the same because of inherent differences in how the abundance estimates are derived. The CDS abundance estimate is calculated from a mean density estimate for the entire survey area whereas the DSM estimate is a summation of the local density estimates (estimates generated per cell of the prediction grid) throughout the area and, therefore, reflects the variability in the area. The robustness of the CDS estimates is dependent on a sound survey design with even coverage of the survey area.

The ferry and aerial survey data show that harbour porpoises occurred year-round in the Fehmarnbelt area. The aerial data, in particular, provide good temporal and spatial coverage of the area, where previous surveys have only focused on the summer months (e.g. Heide-Jorgensen et al., 1993, MINOS/+). The ferry and aerial survey data show monthly variations in encounter rate and density, respectively, but both detected a peak in spring with continued higher densities throughout the summer months. The design based density estimates capture finer temporal variability than the model-based approach (i.e. monthly estimates rather than seasonal estimates); this is an important consideration when assessing likely impacts of the construction of the planned alignment.

2.5. Opportunistic ferry-boat surveys

2.5.1. Introduction

In 2009 Fehmarnbelt AS commissioned several contractors to investigate the use of the Fehmarnbelt area by harbour porpoises (*Phocoena phocoena*). These investigations will form the baseline for the Environmental Impact Assessment of the planned Fehmarnbelt Fixed Link. The presence of harbour porpoises is being documented by means of passive acoustic monitoring using C-PODs (see section 2.6). In addition to this, aerial line transect sampling provides a further dataset on density and distribution of harbour porpoises inhabiting the Fehmarnbelt (see section 2.4).

There are limited data describing the seasonal distribution of harbour porpoises in the Fehmarnbelt area. Satellite telemetry data show a year-round presence of harbour porpoises except for August and October, with peak occurrence in April, June and December (Teilmann et al., 2008). While there have been several other systematic sighting surveys carried out in the area (e.g. SCANS, SCANS-II, MINOS/+), most of these have been limited to summer months, and therefore are only comparable for part of the year. Additionally, surveys such as SCANS are focused on large-scale patterns in distribution and density, and are less useful at a small, more localised scale.

Additional information on changes in the occurrence of harbour porpoises can be collected by repeated surveys along a fixed transect – albeit at a spatial scale determined by the opportunistic platform. In this case, the ferries from Scandlines Vogelfluglinie provided a good opportunity to conduct regular surveys along the same transect, since they repeatedly travel along the same route close to the planned fixed link. Ships like the Scandlines ferries are considered “platforms of opportunity” and are already widely used for cost-effective data collection in offshore waters (Williams, 2003; Williams et al., 2006; Kiszka et al., 2007). The method is already applied by a research network called ARC (Atlantic Research Coalition) which combines several European countries conducting research on board commercial ferries[2]. It is also applied as a “REal time Plotting CETaceans programme” called REPCET (Mayol et al., 2007; Mayol, 2007). This programme runs within the Pelagos Sanctuary (Ligurian and Tyrrhenian Seas) in cooperation with ferry companies and using onboard observers to identify collision risk areas in near real-time.

Platforms of opportunity provide a practical and cost-effective method for data collection. They can provide large platforms with elevated observation decks, which are good vantage points for porpoise spotting.

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[2] Atlantic Research Coalition (ARC): http://www.iwdg.ie/ShipSurveys/?id=54

However, such platforms generally provide limited spatial coverage, especially if data are collected on a single passage/route. The Scandlines ferry only covers a small region of the Fehmarnbelt area. Despite their limited spatial coverage, the ferryboat counts supplement the data collected by passive acoustic monitoring and systematic visual surveys. The twice-monthly surveys enable year-round monitoring of harbour porpoises in close vicinity to the planned fixed link.

2.5.2. Methods

2.5.2.1. Data Collection

The plan was to conduct surveys twice a month from April 2009 to December 2010 on board the Scandlines ferries operating between Rødby, Denmark and Puttgarden, Germany. All trips started from Puttgarden. Weather conditions such as high Beaufort Sea state (see below for further details) led to occasional suspension of search effort.

Survey tracks were determined by the exact route chosen by the ferry company operating between the two harbours, Rødby and Puttgarden. Observation protocol followed the principle of distance sampling, which meant single observations were noted with estimated distance to the trackline. Line-transect theory assumes that sighting probability decreases with increasing distance from the trackline (Buckland et al., 2001). At the start of the study, the highest point accessible for data collection was the visitor deck, which had limited forward visibility (i.e. on the trackline). After five months, observers were permitted to record data from the bridge (Figure 2.5-1) which did allow observers to search on the transect line. However, there were too few sightings for the data collection period on the bridge and for this reason, the data have been analysed simply to look at encounter rates per month (rather than density estimates generated from distance sampling analysis).

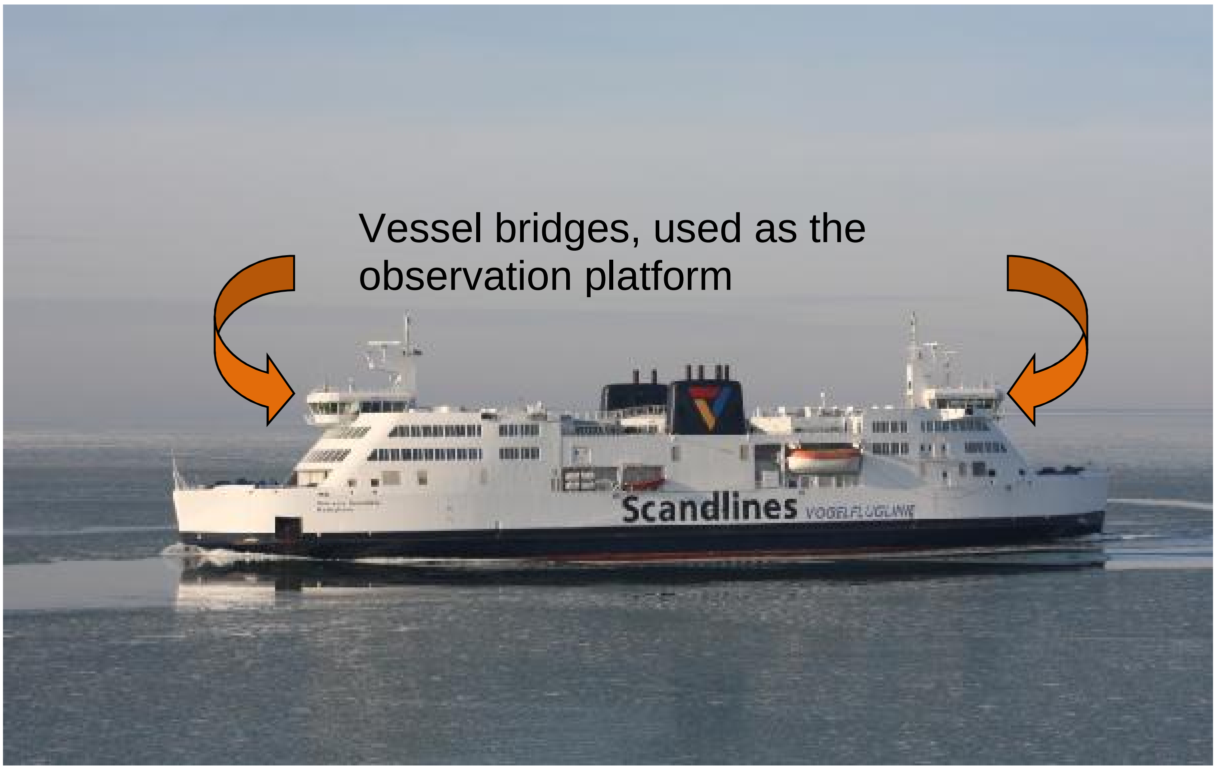

Figure 2.5-1 The platform of opportunity, the Danish ferry Princesse Benedicte.

Observations were carried out at heights ranging from 12 to 24 metres above sea level (locations were: visitor deck, upper visitor deck and bridge; the latter two were at the same height) depending on the type of ferry. The ferry travelled at an average speed of 14.6 knots (27.03 km/h). Surveys were only undertaken during daylight hours and with a sea state of not more than Beaufort Sea State 3. Higher sea states decrease the probability of observers detecting small cetacean species (Hammond et al., 2002.) Search effort was also limited to good (visibility> 10km, no glare, fog or mist) or moderate sighting conditions (visibility >5km; glare, fog or mist affected partly the area effectively searched) but did not prevent observations. Finally, surveys were not undertaken during winter months if ice cover was present.

Two experienced observers searched by naked eyes or binoculars, spanning from 90 degrees either side to approximately 20 degrees further than the effective trackline (the observers have a small overlapping area along the trackline). Observers made sure that no double-counting of animals occurred. A handheld GPS (Garmin GPS 60) was used to record effort by taking the location (longitude and latitude), ships course and speed every 30 seconds. Information on factors, mainly sea state, cloud cover, visibility (in nautical miles) and general sighting conditions (glare, fog) that may affect sighting probability, were recorded on a regular basis. When porpoises were observed, bearings to sightings (individual animal or groups of harbour porpoises) were measured using an angle board. Distances to the sightings were initially estimated by naked eye and, for a brief time, with a sliding calliper to provide a better estimate. Since March 2010, the methodology was improved by the use of reticle binoculars. Additional data, including the age-class of the harbour porpoise (i.e. adult or calf), direction of movement and behaviour were recorded. Based on previous studies (e.g. Goodwin, 2008) the behaviour of porpoises was divided into different categories (Table 2.5-1).

Table 2.5-1 Definitions of behavioural categories

Behaviour	Description
Resting	Porpoises rest on the surface with no obvious active behaviour
Porpoising	Fast swimming during which the porpoise dived in and out of the water showing almost the whole body above the water surface
Fast swimming	A constant fast movement into a specific direction
Slow swimming	A constant slow movement into a specific direction
Feeding	Porpoises repeatedly conducted deep dives more or less around one defined spot. Also the association with feeding seabirds was taken as a sign that porpoises were engaged in feeding behaviour
Milling	A slow and undirected movement within a given area. During "milling", porpoises were seen resting at the surface without particular active behaviour
Diving	Obvious movement where the full bended back of the porpoise can be seen before diving down

2.5.2.2. Data Analysis

All sightings were stored in a database with positions of the animals, together with the other relevant sighting information (as described above). The distribution of sightings along the alignment and in different water depths was analysed using ArcGIS (v. 9.3). Sightings per kilometre search effort were analysed per observer. Encounter rate of sightings defined as the number of sightings / km survey effort. Encounter rate of harbour porpoises is given as number of individuals / km survey effort.

Ivlev's selectivity index (Jacobs, 1974) was used to test whether a preference of harbour porpoises for certain water depths was apparent. The index relates the preference for a certain factor value against its availability. In this case, the proportion of sightings per depth class was related against the proportion of effort conducted per depth class. A positive value of the index indicates preference, a negative value indicates avoidance.

2.5.3. Results

2.5.3.1. Survey effort

Surveys were conducted on 34 survey days between April 2009 and December 2010 (169.4 hours of effort). Total search effort of both observers was 9,980 km (each one-way crossing was approximately 16.5 - 18km; up to eight crossings were undertaken per survey day). In November and December 2009, and January, October, November and December 2010 there was only one survey conducted due to poor weather conditions. No surveys were completed in September 2010. Sighting rate was highest during survey effort in Beaufort Sea State 1 and declined above this (Table 2.5-2). The mean sighting rates during 'good' and 'moderate' conditions fluctuated monthly (Table 2.5-3). Averaged over the study period, there was little difference in sighting rates between 'good' and 'moderate' conditions (Table 2.5-3).

Table 2.5-2 Harbour porpoises sighted during the different Beaufort sea states

Sea state	0	1	2	3
Total time spent searching [hours]	26.7	80.5	57.1	5.1
Number of sightings	54	174	50	4
Sightings/hour	2.02	2.16	0.88	0.78

Table 2.5-3 **Survey effort (km), sightings (n), mean sightings per km search effort (n/l) of the bi-monthly surveys during good and moderate sighting conditions (see text for description)**

	Effort (km, l)		Sightings (n)		Mean encounter rates	
Month	**Good**	**Moderate**	**Good**	**Moderate**	**n/l Good**	**n/l Moderate**
Apr'09	581	0	28	0	0.05	0
May	576	0	10	0	0.02	0
June	563	20	13	1	0.02	0.05
July	365	208	15	6	0.04	0.03
Aug	427	156	9	1	0.02	0.01
Sep	580	0	11	1	0.02	0
Oct	477	31	17	2	0.04	0.06
Nov	181	0	9	0	0.05	0
Dec	289	0	15	0	0.05	0
Jan'10	222	0	0	0	0.00	0
Feb'10	408	133	5	0	0.01	0
Mar'10	479	103	4	3	0.01	0.03
Apr'10	545	182	1	1	0.00	0.01
May'10	480	99	9	0	0.02	0
June'10	540	37	53	0	0.10	0
July’10	530	501	25	2	0.05	0
Aug’10	344	126	9	1	0.03	0.01
Oct’10	290	0	10	0	0.03	0
Nov’10	18	271	1	10	0.05	0.04
Dec’10	154	63	9	29	0.06	0.02
Total	**8049**	**1930**	**253**	**29**	**0.03**	**0.01**

As a consequence of the change in methodology the observations stopped from the visitor decks and relocated to the bridge from September 2009. The bridge proved to be a better search platform and improved overall data quality. This resulted in a higher proportion of sightings from the bridge than the other two positions; however this has not been corrected for effort (Table 2.5-4). Sightings were approximately evenly distributed for observer search direction and ferry direction (Table 2.5-5).

Table 2.5-4 Percentages of sightings from different observation platforms on the ferry

Observation position	Sightings (%)
Bridge	41.48
Upper visitor deck	22.36
visitor deck	36.15

Table 2.5-5 Ferry direction and spotting direction of observers for all sightings (each cell represents number of sightings expressed in %)

		Observer search direction	
		WNW	**ESE**
Ferry direction	**NNE**	25.27	25.63
	SSW	25.63	23.47

2.5.3.2. Sightings

A total of 282 sightings was recorded and group size ranged from 1-6 animals resulting in 428 harbour porpoises during the entire study period (see also Table 2.5-3). Figure 2.5-2 depicts the distribution of harbour porpoise sightings in the as observed from the ferry in Fehmarnbelt area. It shows that porpoises are present along the transect line as well as in the harbour entrance areas in Rødby and Puttgarden. Bigger groups (with four or more individuals) were spread throughout the survey area. There were a total of 14 calves sighted throughout the survey period. Calves were observed more often during the northern section of the ferry route in water depths ranging from 8 to 14 metres and in the centre of the Fehmarnbelt.

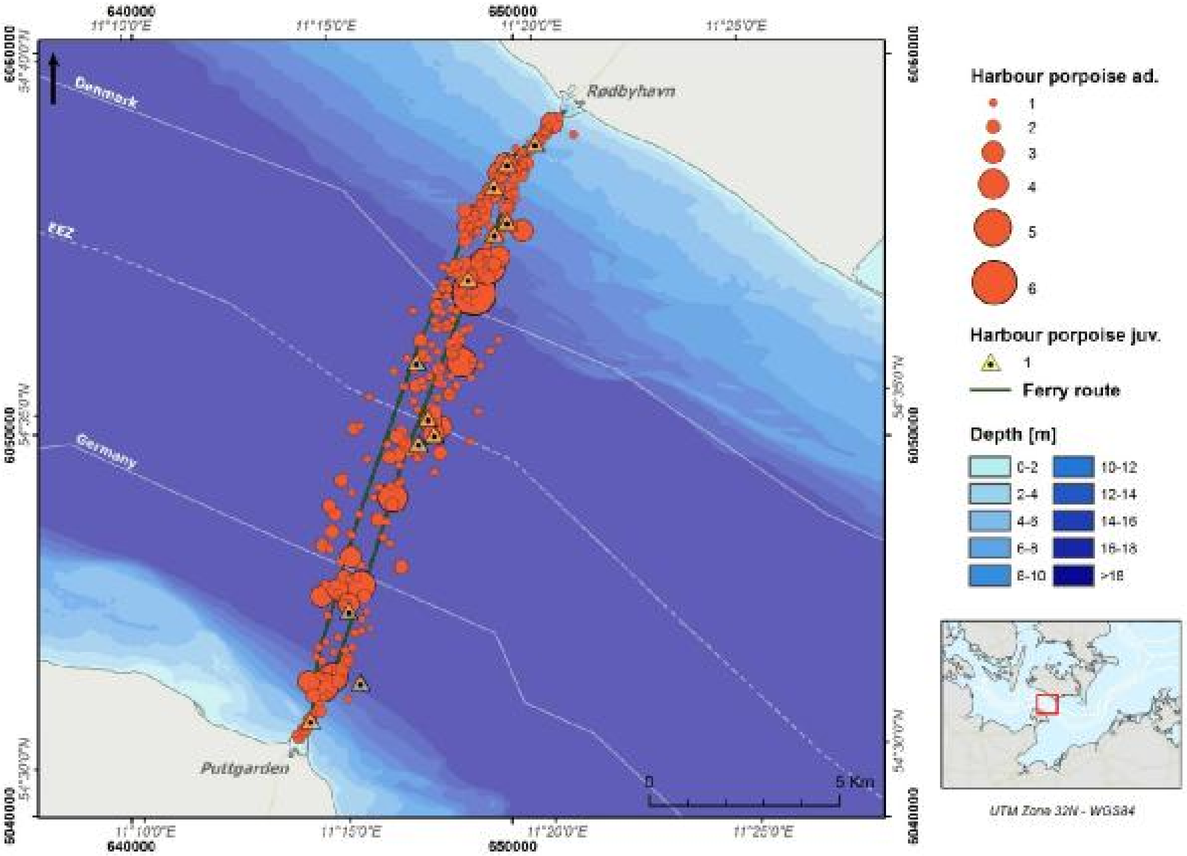

Figure 2.5-2 Map showing the locations of harbour porpoises recorded during the study period.

Group size ranged from 1 to 6 individuals, with an overall mean group size of 1.51 individuals (SE=0.05). 4.28% of groups were seen with a calf.

Figure 2.5-3 shows encounter rate of observations (either single animals or groups) expressed as sightings per kilometre of search effort. Sightings varied both within and between months. In April 2009, June 2010 and July 2010, the first survey of each month resulted in a higher encounter rate whereas during the second survey fewer animals were observed. These are also the surveys which represent peaks of encounter rates of porpoises. In Oct '09 the second survey resulted in much higher encounter rates than the first one. In January 2010 the single survey did not yield any sightings. In November and December 2009 and 2010 as well as in October 2010 only one survey was achieved. The first count in June shows the highest encounter rate of the whole period recorded.

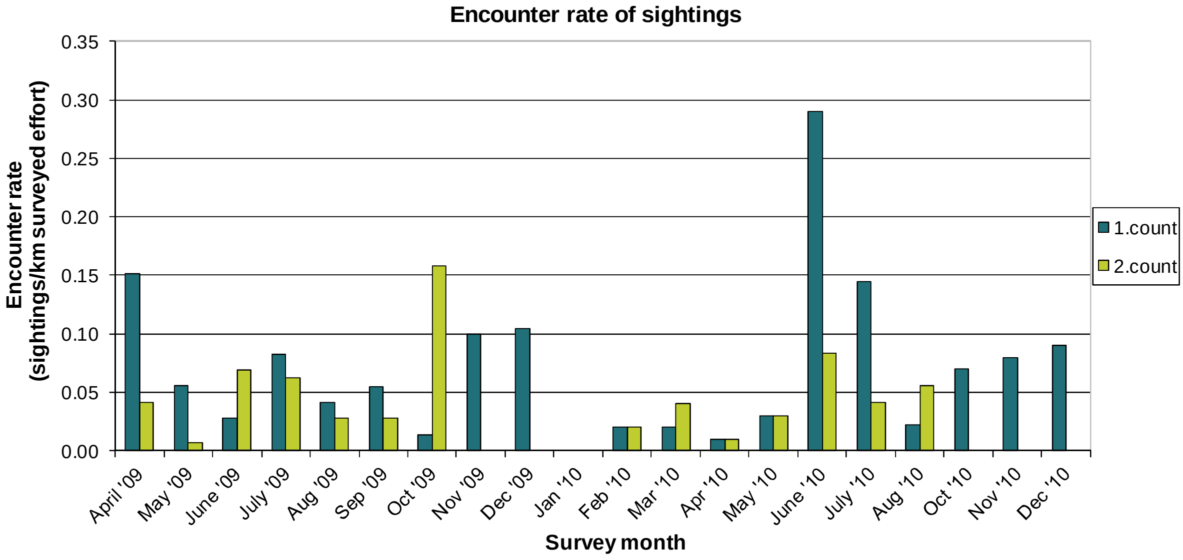

Figure 2.5-3 **Number of harbour porpoise sightings per kilometre by month showing the first count of the month in green and the second count in lime.**

Figure 2.5-4 shows encounter rate of individuals across the 21 month period, with notable variability apparent (though the pattern is approximately the same as in Figure 2.5-3). During the months when two surveys could be conducted there was obvious variation in sighting rates between counts. Remarkably, many of the lowest sighting rates (below 0.05 individuals per kilometre observed) occur in those months (May '09, '10, June '09, August '09, '10, September '09, October '09, in 2010 February, March, April). However despite this overall pattern, the highest sighting rate occurred in June 2010, followed by April, October, December 2009 and July 2010.

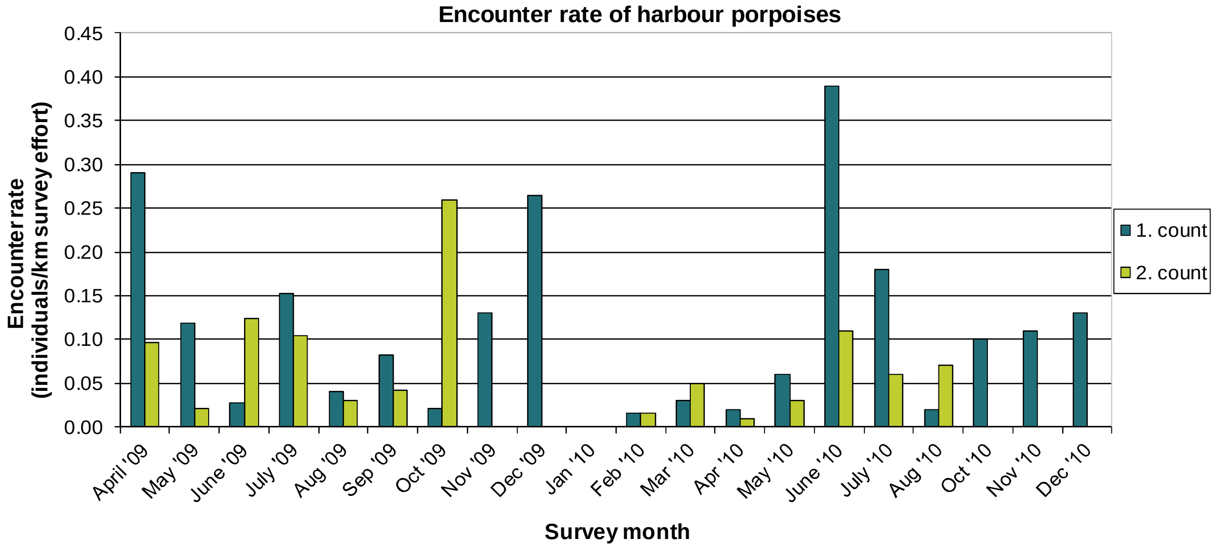

Figure 2.5-4 **The total number of individual harbour porpoises sighted per kilometre over the entire study period from April 2009 to June 2010 showing the first count of month in green as well as the second count in lime.**

Comparisons between the two years of the study show some differences in April, June and October. In April 2010, there were considerably less sightings than the year before. The encounter rate in June 2010 was six times that recorded in the previous year, whereas in 2009 encounter rates were somewhat higher during October-December. The marked peaks in April 2009 and June 2010 may reflect events of porpoises migrating through the area.

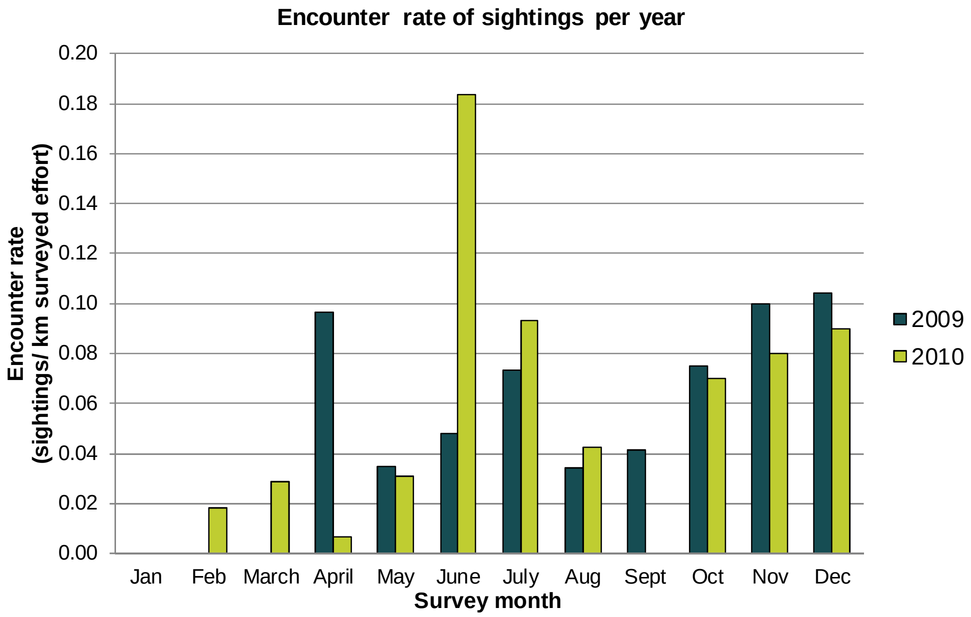

Figure 2.5-5 **Variation in encounter rates of sightings (corrected by effort) by month and year.**

The encounter rate of the harbour porpoise individuals show a similar pattern as depicted in Figure 2.5-5 with more individuals when more sightings occurred. While the second July count resulted in more sightings but fewer individuals compared to the previous year. In April, October and December more harbour porpoises were recorded in the first year; June is the only month where significantly more individuals were seen in 2010 than 2009.

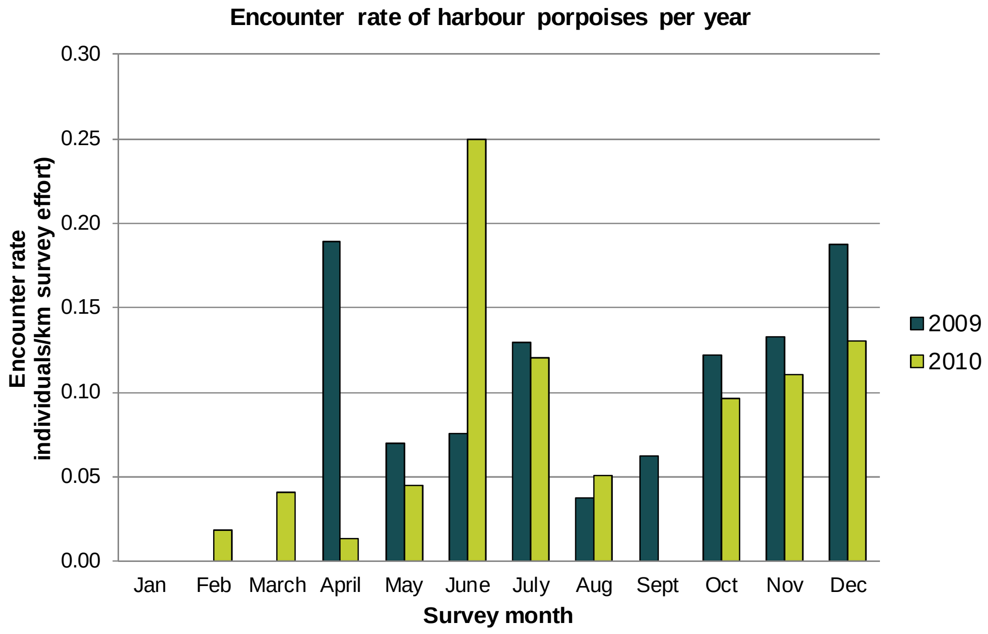

Figure 2.5-6 Variation in encounter rates of harbour porpoises (corrected by effort) by month and year.

Harbour porpoises were not uniformly distributed. Most sightings were made in the northern part of the Fehmarnbelt in water depths between 6 and 20 metres (Figure 2.5-7).

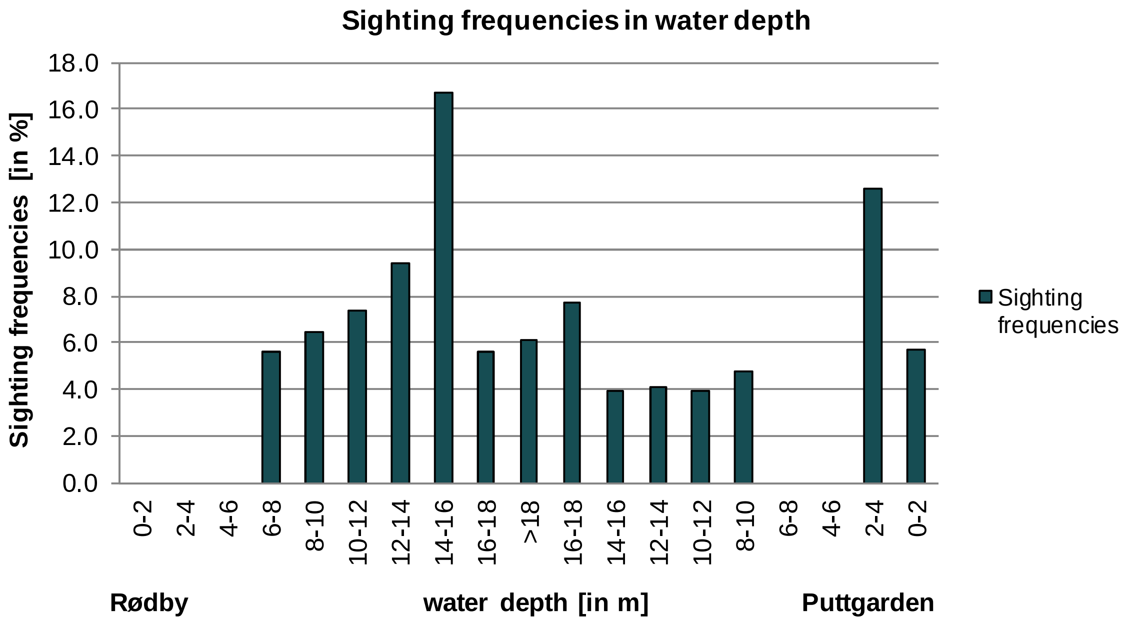

Figure 2.5-7 Sighting frequencies shown in percentage of the surveyed area (Rødby to Puttgarden) corrected by effort (km sailed/available water depth).

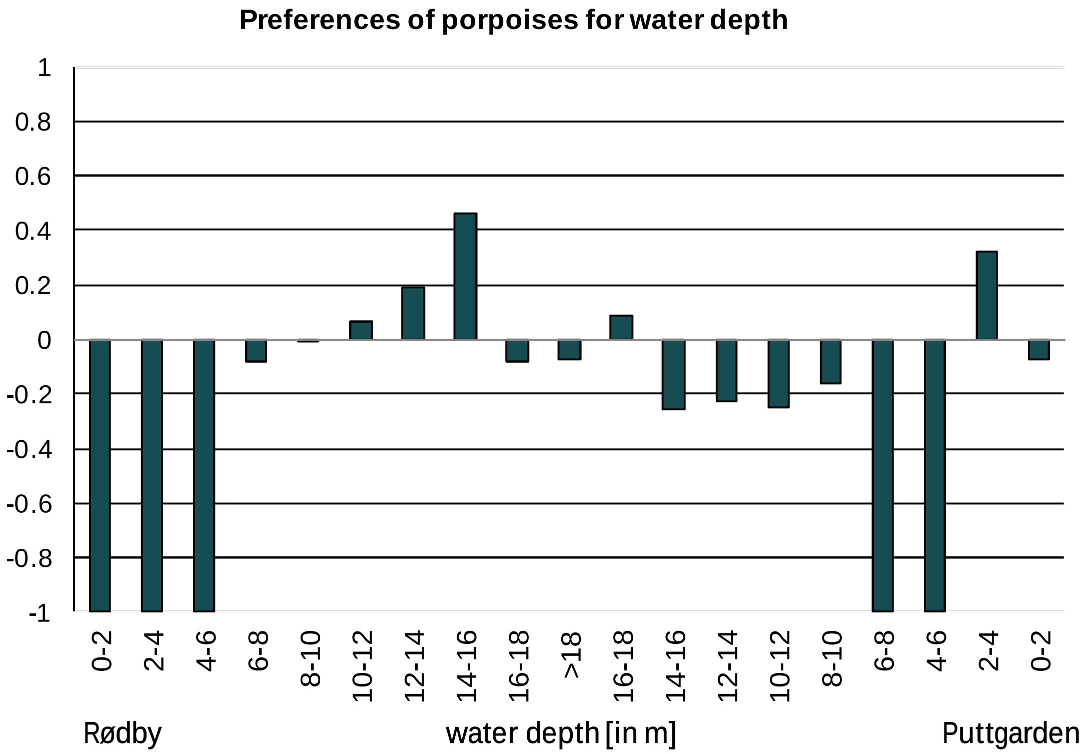

Figure 2.5-8 **Selection of water depth by harbour porpoises in the ferry route of Fehmarnbelt (Ivlev's selectivity index (Jacobs 1974)). Values indicate positive or negative selectivity for depth classes from Rødby (left) to Puttgarden (right).**

The analysis of preferences of porpoises for certain water depth after Ivle's selectivity index (Jacobs, 1974) is shown in Figure 2.5-8. It can be seen that porpoises at the ferry route between Rødby and Puttgarden avoid shallow waters below six metres but no clear pattern emerges for the remaining depth classes. On the Rødby side there was a preference for 12-16 metres but the opposite was true on the Puttgarden side. Waters deeper than 16 metres, representing 68% of the survey effort, represented 64% of the sightings and no marked preference could be detected.

2.5.3.3. Behaviour

Recorded behavioural categories are shown in Figure 2.5-9. Harbour porpoises were mainly observed when swimming (mixed age-groups: 74.7%; adults: 72.2% and juveniles: 50.0%). Mixed age-groups were seen on numerous occasions feeding. A total of 12.5% of the adults were feeding, while 5.2% were porpoising, milling (2.5%) and slow swimming (3.2%). Only a small number of harbour porpoises were recorded diving (0.5%).

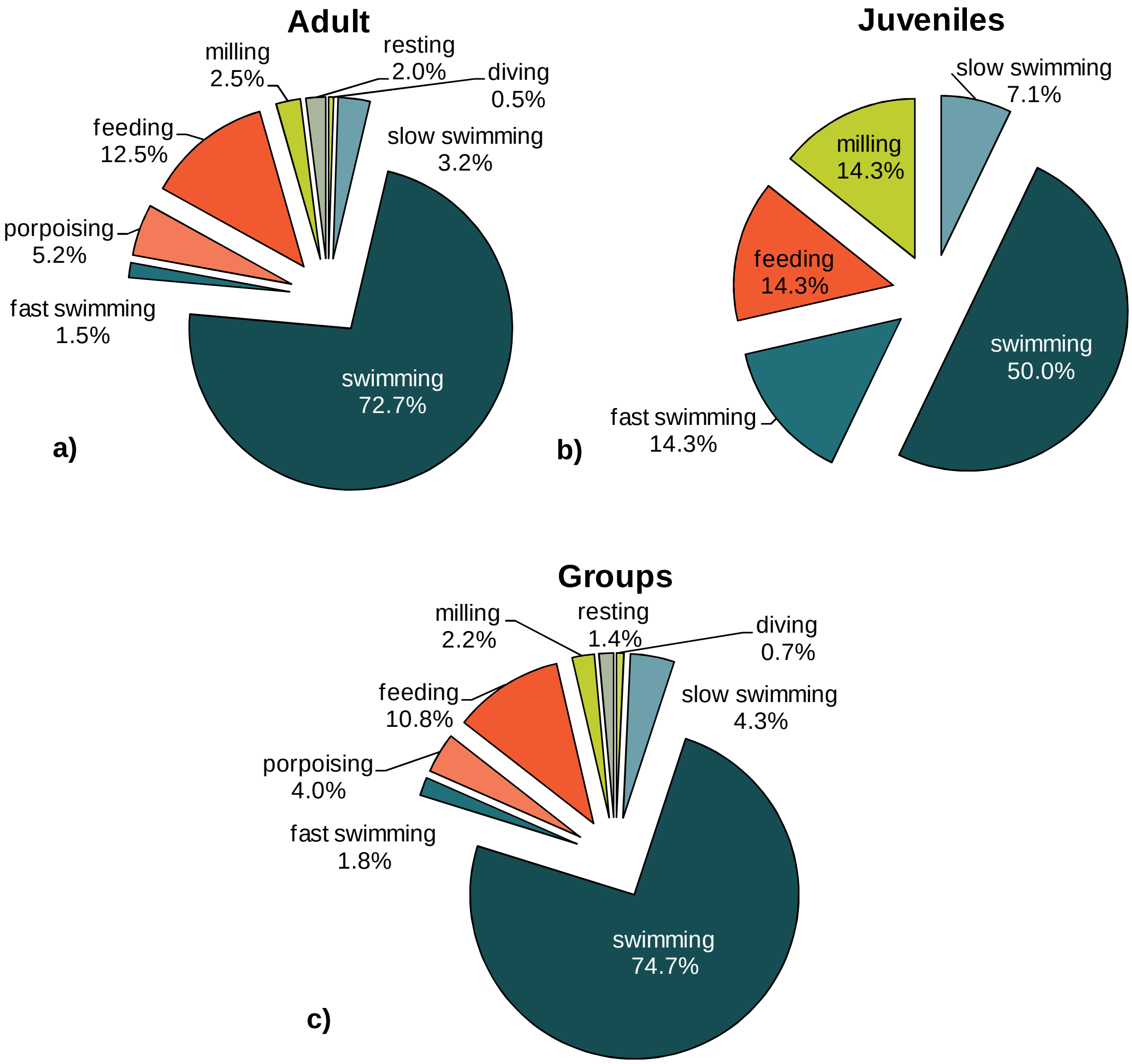

Figure 2.5-9 **Composition of observed behaviour of harbour porpoises divided by adults (a), juveniles (b) and groups (c).**

Juveniles, which represent only 4.28% of all porpoises encountered, were feeding, milling and fast swimming making up 14.3% in each of these categories. A further 7.1% was classified as slow swimming.

Figure 2.5-10 shows recorded swim directions. The direction of the arrows represents the swim directions, while the length of the arrows indicates the percentage of animals observed swimming in that direction. Percentages are shown by the concentric rings, and are given for each ferry direction (north-east [NE], south-west [SW]; equates to the true ferry line) and each observer direction (search area: spanning to north-west and south-east). Though no formal tests for differences have been carried out, a visual examination of the data indicated that for north-travelling ferries (top two diagrams in Figure 2.5-10) there were high numbers of porpoises observed moving away from the ferry. This pattern can also be seen for south-travelling ferries (bottom two diagrams) but to a lesser extent.

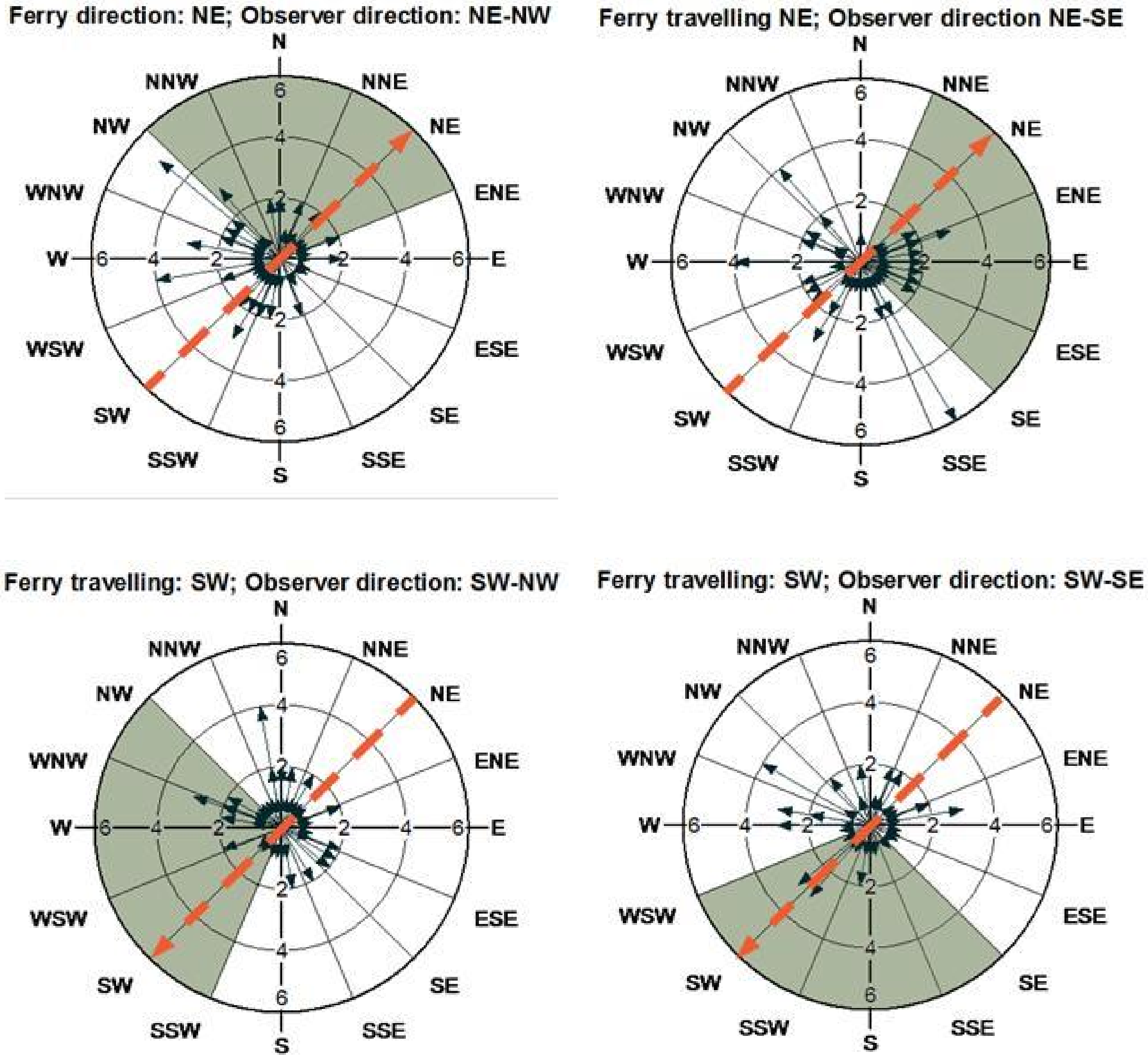

Figure 2.5-10 **Swim directions of all harbour porpoises sighted during different ferry directions and observation directions represented by the arrow length (see scales on concentric rings). The orange line represents the ferry route (north-east to south-west direction represents the true ferry route). The grey –green shaded area depicts the area covered by the observer.**

2.5.4. Discussion

Within the Fehmarnbelt Marine Mammal Studies the results presented from the ferry counts provide a very useful addition to the large scale aerial surveys and PAM work with regards to presence of porpoises directly in the alignment area. The data provide good temporal resolution which enables comparison of porpoise relative abundance along the planned Fehmarnbelt Fixed Link over time. However, spatial coverage is limited and therefore extrapolation of the results to the whole study area is very limited. However, as can be seen from the vast amount of data gathered in the two years, the ferry boat counts provide a very cost-effective and straightforward opportunity to collect valuable data on the occurrence of porpoises directly in the area of the proposed fixed link. In the following discussion we focus on the main conclusions. We also compare the results gathered here with the ones of the passive acoustic monitoring (PAM) at the stations in the alignment.

The main findings based on the ferry boat counts are:

1) Porpoises occur year round in the alignment area.

Except for one survey in January 2010, at least one sighting of a porpoise was recorded during every survey. This observation is completely in line with results of the PAM study. The C-PODs recorded porpoises on 91 % of all days at the six PODs close to the alignment. Based on satellite telemetry data Teilmann et al. (2008) identified an area west of the Fehmarnbelt as an important area for harbour porpoises where the animals are present all year round.

Even though shipping activity in the alignment area is quite high (see chapter porpoise baseline pressure in this report) our results and the ones from the PAM studies indicate that porpoises use the area regularly. From the distribution of sightings it cannot be concluded that any area along the ferry route is avoided by the animals. At least two other studies in the Great Belt (Svegaard et al., 2010), the other just recently undertaken in the Istanbul Strait (Dede et al., 2011) have confirmed porpoises to be common in high shipping areas.

2) Sighting rates between surveys, months and even years are very variable.

Even though a seasonal pattern with more sightings in spring and late autumn could be seen in both years, this trend was not completely consistent over both years. In 2009 the spring peak occurred in April whereas in 2010 most sightings were made two months later in early June. The autumn peak in 2009 continued from late October until December. In 2010 sighting rates from October to December were considerably higher than during the other months but not that pronounced compared to the previous year. A large variation in porpoise occurrence could also be inferred from the C-POD data. The overall seasonal pattern of porpoise click activity at the stations placed in the alignment is fairly similar to the ferry count results (Figure 2.5-11). In 2009 a clear peak in porpoise recordings also occurred in April-May which fits very well to the ferry boat counts. The lowest numbers of porpoise recordings were registered in June and September 2009, also in line with the ferry boat counts. Recordings in November and December again were slightly higher than, but not as pronounced, as shown by the ferry boat sighting rates.

In 2010, similarities between the two data sets were less pronounced; especially the marked peak from ferry counts in June was less visible in the POD data. This may reflect a short period of high abundance with a small influence on the monthly average. It thus may indicate animals migrating through the area. While POD data (shown in Figure 2.5-11) indicates mean values from all days during a month, the ferry boat counts represent snapshots from two single days per month.

The general trend of relatively high numbers of porpoises in spring and summer is very similar between both the visual methods (aerial line transects and ferry boat counts) and to a certain extent to the results of the acoustic study. However it is remarkable, that this investigation also found relatively high occurrences of porpoises in autumn and winter. Apart from a period with ice cover in early 2010, porpoises appeared to be constantly present in the area. Sighting rates increased in autumn in both years. After ice retreated in spring 2010 sighting rates gradually increased.

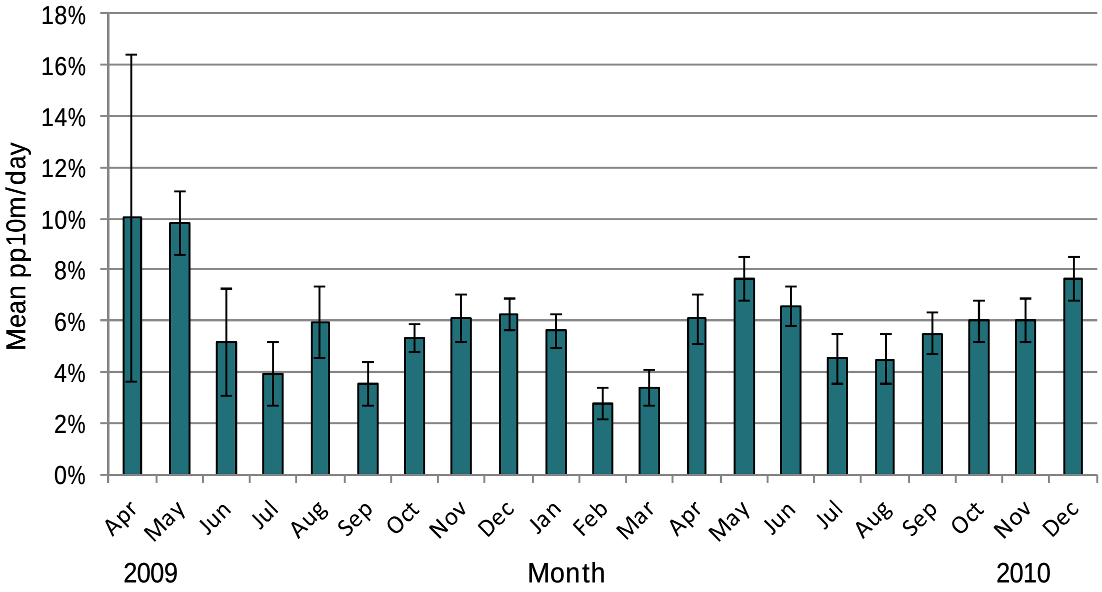

Figure 2.5-11 **Mean pp10m/day for data from six PODs deployed close to the planned alignment. Vertical bars indicate confidence intervals.**

3) Even though calves were seen only rarely, group sizes were rather high compared to other investigations

It has been suggested that the Fehmarnbelt may function as a corridor for migrating harbour porpoises between the Danish Belt Sea and the Baltic proper (Teilmann et al., 2008). Group sizes recorded during the ferry routes were fairly high and this may support the idea of individuals forming larger groups for travelling. Our data also suggest that harbour porpoise juveniles occur predominantly on the northern part (Danish side) of Fehmarnbelt, but are also dispersed in the deeper, central area of the Fehmarnbelt. Though the spatial coverage of these surveys is restricted to the ferry route, observations of calves in the northern part coincide with the results from the aerial line-transect surveys. However, it should be kept in mind that uncertainties in determination of calves appear in autumn time due to the difficulties distinguishing calves from adults (Galatius, 2005). The NERI tagging studies also suggest relatively high densities of females (which accompany their calves for the first months of life) in the western part of the Fehmarnbelt area.

4) The most commonly observed behaviour was swimming

This observation could be attributed to harbour porpoises being in the presence of ferry activity (along with the finding that porpoises swam away). It may reflect the behaviour of porpoises in a shipping lane with little time for feeding and possible avoidance reactions. Since all other behaviours only amounted to a small proportion of the overall behavioural budget, it could suggest that the area may not be a particular feeding ground for harbour porpoises. No further studies are known from the area dealing with behaviour of harbour porpoises.

2.6. Passive Acoustic Monitoring (PAM)

2.6.1. Introduction and scope of work

The objective of the baseline studies on harbour porpoises (*Phocoena phocoena*) in the Fehmarnbelt area is to provide robust information on the seasonal and spatial occurrence of the species within the area of the future Fixed Link and in areas surrounding this. It was also designed to investigate the environmental variables that govern the activity and movement of porpoises in the area to better inform the impact assessment. Previous studies have shown that harbour porpoises are the most common cetacean in the Baltic Sea and the only cetacean known to breed there. Porpoises have been observed in all parts of the Fehmarnbelt area; however, they are unevenly distributed within their range (Sveegaard et al., 2010) and a variety of methods can be used to investigate temporal and spatial trends as well as habitat usage.

In our baseline investigations on presence and distribution of harbour porpoises in the Fehmarnbelt area, we have used three approaches:

1. Visually using line transect surveys;
2. With data from satellite tagged animals (telemetry);
3. Passive acoustic monitoring (PAM).

Visual methods, which are effective at providing information about large-scale distribution and abundance, have limits when it comes to examining patterns at a finer temporal and spatial resolution. Also, harbour porpoises are very difficult to detect in sea states greater than Beaufort 2 (Teilmann, 2003), and they spend only a limited amount of time at the surface (Westgate et al., 1995). These factors, coupled with their small size and undemonstrative surface behaviour, make them among the most difficult cetacean species to detect visually. Using telemetry, only a subset of animals can be investigated in a given area. In order to provide the most comprehensive information on temporal and spatial trends of harbour porpoises in the Fehmarnbelt area and to analyse habitat use and relationships between activity and environmental factors, we have used PAM; an approach which has been shown to be very effective, especially for porpoises (e.g. Verfuß et al. 2007; Todd et al., 2009; Brandt et al. 2011). Nevertheless, indirect, relative measures of abundance are limited as it will only (at best) provide information on relative population size trajectories but not the absolute magnitude of the change. We thus build the whole Fehmarnbelt analysis of harbour porpoises on the combination of all three mentioned methods.

Harbour porpoises are highly vocal animals. They use echolocation for orientation (Verfuß et al., 2005; Koschinski et al., 2008) as well as for prey capture (Busnel and Dziedzic, 1967; Schevill et al., 1969; Verfuß and Schnitzler, 2002; Verfuß et al., 2009; DeRuiter et al., 2009) and for communication (Verboom and Kastelein, 1997; Koschinski et al., 2008; Clausen et al., 2010). Wild individuals have been shown to produce sonar-click trains on average every 12.30 s (Akamatsu et al., 2007). Harbour porpoise echolocation clicks are relatively short and tonal (Schevill et al., 1969), emitted in a narrow beam width (16° in the vertical and horizontal plane; Au, 1999) with dominant narrow-band, high-frequency click components within 110–150 kHz (Møhl and Andersen, 1973; Verboom and Kastelein, 1995, 1997; Au, 1999; Teilmann et al., 2002; Villadsgaard et al., 2007). Porpoise-click durations range from 61 to 300 ms (Verboom and Kastelein, 1997; Teilmann et al., 2002). Clicks can be emitted singularly or in series known as trains. The distinctive click structure allows detection automated systems (such as a porpoise detector (C-POD) to be implemented with a high degree of efficiency. Autonomous PAM devices have the advantage of gathering 24 h data during long-term deployment in weather or sea-state conditions during where visual observations would be impossible. Data collection is also independent of individual observer skills.

With its standardised and automated mode of data collection, autonomous PAM has emerged as a common tool for recording dolphin and porpoise presence and has become an important device, especially in waters with low density of target species (Verfuß et al., 2007; Jaramillo-Legorreta et al., 2008). One of the most common PAM devices, the so-called T-POD, was developed by Nick Tregenza (chelonia.uk) and has been used in different studies worldwide (bottlenose dolphins *Tursiops truncatus:* Philpott et al., 2007; Baily et al., 2010), hector's dolphins *Cephalorynchus hectori*: Rayment et al., 2009). However, the main species investigated by T-PODs is the harbour porpoise. Different T-POD studies have aimed to understand long-term trends in distribution and occurrence (Verfuß et al., 2007; Dähne et al., 2009; Gallus et al., 2010), behaviour (Carlström et al., 2005) and the effects of offshore installations on these animals (Diederichs et al., 2008; Todd et al., 2008; Tougaard et al., 2009; Brandt et al., 2011). However, the T-POD has now generally been replaced by the C-POD. C-PODs record sound within the frequency range of 20–150 kHz. In comparison to the T-POD it collects a much wider range of information to advance species identification. For each sound, fundamental frequency, duration, intensity, bandwidth and envelope of the frequency spectrum are logged. Test-tank measurements showed a slightly higher sensitivity of C-PODs compared to T-PODs (Verfuß et al., 2010) which should result in a larger detection range. C-PODs were used in the Fehmarnbelt area for the study described here.

From an ecological efficiency viewpoint, we would expect the distribution of harbour porpoises to be linked to the distribution and abundance of prey and perhaps to other variables such as water depth and latitude. The distribution of prey species is in turn believed to be linked to hydrographical parameters such as salinity, temperature, hydrographic fronts etc. (see Reid et al., 2003; Johnston et al., 2005; Camphuysen et al., 2006; Fontaine, et al., 2007; Skov and Thomsen, 2008; Edren et al., 2010). However, all of these either direct or indirect relationships between porpoise distribution and environmental parameters are not well understood. Yet, in order to assess the potential impact of the proposed fixed link through the Fehmarnbelt, likely impacts have to be considered relative to other factors that already govern the activity of porpoises in the area. Apart from documenting the temporal dynamics in the acoustic activity of porpoises for various parts of the Fehmarnbelt area, our objective in the PAM studies was to identify and quantify possible drivers of existing patterns of porpoise distribution in the area. Thus, the main focus of this study is to examine the distribution of harbour porpoises in the

Fehmarnbelt area and relate their (relative) occurrence to a number of components of the physical environment.

The baseline POD study aims to address the following question: What are the large-scale and small-scale environmental factors determining the current distribution of harbour porpoises in the Fehmarnbelt region?

To help to answer this question, C-POD data were used as the input for different models, which were applied to describe the dependency of porpoise acoustic activity on a number of environmental parameters (explanatory variables) including human infrastructures like existing offshore wind farms, static variables like water depth or distance to land, and a subset of hydrodynamic parameters describing the hydrographic characteristics in the Fehmarnbelt area.

2.6.2. Methods

For the passive acoustic monitoring, we used automated porpoise click detectors. From four different types of available monitoring devices we chose the C-POD (Chelonia Limited, UK). The production of the predecessor model, the ‘T-POD’ (Chelonia Limited, UK) stopped in 2008. Two other devices, A-Tag, (W20-AS, Little Leonardo, Tokyo, Japan) and Aquaclick100 Porpoise Click Logger (PCL, Aquatec group Ltd, UK) were also tested during this study but we were not able to gather useful data using these two passive acoustic monitoring instruments. The A-Tag is a very fragile device and not made for long durations of deployment, which would demand a time-intensive regular service due to short time of power supply and a small memory. Problems with the PCL included corroded saltwater switches and data logging that did not work very well due to unknown reasons.

C-PODs are fully automated, static dataloggers of ultrasonic sounds (Figure 2.6-1). Manufactured by N. Tregenza (UK, see www.chelonia.demon.co.uk), the C-POD consists of an 80 cm long plastic pipe (diameter 90 mm) containing a hydrophone with an electronic filter and an amplifier. The C-POD runs on eight (older version) or ten (newer version) 1.5 V batteries and contains electronics and a SD flash card for storing data. The batteries supply sufficient energy for at least 8 weeks of deployment. The SD flash card can save 4 GB of data. The hydrophone is omni-directional within the frequency range of 20–160 kHz and the detection range for the frequency around 130 kHz (porpoise click frequency) is estimated to be up to a few hundred metres (Verfuß et al., 2010), but detection probability will clearly decrease with increasing distance of the animal to the hydrophone (Tougaard, 2006; Kyhn, 2010). For the configuration of the PODs we used the manufacturer’s defaults with a limit of 4,096 clicks per minute and a switch angle of 110° in which the POD was active.

Through an algorithm, the C-POD software CPOD.exe (Chelonia Ltd., UK) automatically identifies click trains (clusters of clicks) in different classes according to their probability of coming from harbour porpoises, dolphins or boat sonar. For this study, data were downloaded and processed using CPOD.exe version 1.020 (5th Oct 2009).

The train filter developed as part of the software will improve species identification as more specific data produced by echolocating animals become available from users. All software improvements developed by the manufacturer are available free of charge and will be retrospectively applicable to all data sets. Thus, older data can be re-analysed together with the latest data sets.

Figure 2.6-1 C-PODs.

2.6.2.1. Study design

27 fixed C-POD stations were relatively evenly distributed over the Fehmarnbelt area spanning from west to east over a distance of approximately 90 km - with the site for the planned fixed link in the centre (Figure 2.6-2). All C-PODs were separated by a minimum distance of approximately 5 km and all stations had a different distance to the planned fixed link.

The study area was divided into three parts:

- Impact area (A) around the planned fixed link: Here 6 C-PODs were deployed with a maximum distance of approximately 3 km to the link;
- Western area (W): The area south of Langeland up to a minimum distance of 4 km west of the planned link;
- Eastern area (E): The area up to the south of Gedser (Kadet Trench) with a minimum distance of 4 km to the east of the planned link.

Data collection started in January 2009 and ended in January 2011. Initially four C-PODs were deployed at positions A1, A2, W8 and W9 on 29thJanuary 2009. On 27th March 2009 the next 6 C-PODs were deployed on the Danish side (A4, A6, W4, W5, W10 and W12). All positions have been occupied since June 2009. All C-POD positions are shown in Figure 2.6-2. Table 2.6-1 shows the locations together with the main static variables; numbers of available data points are also listed.

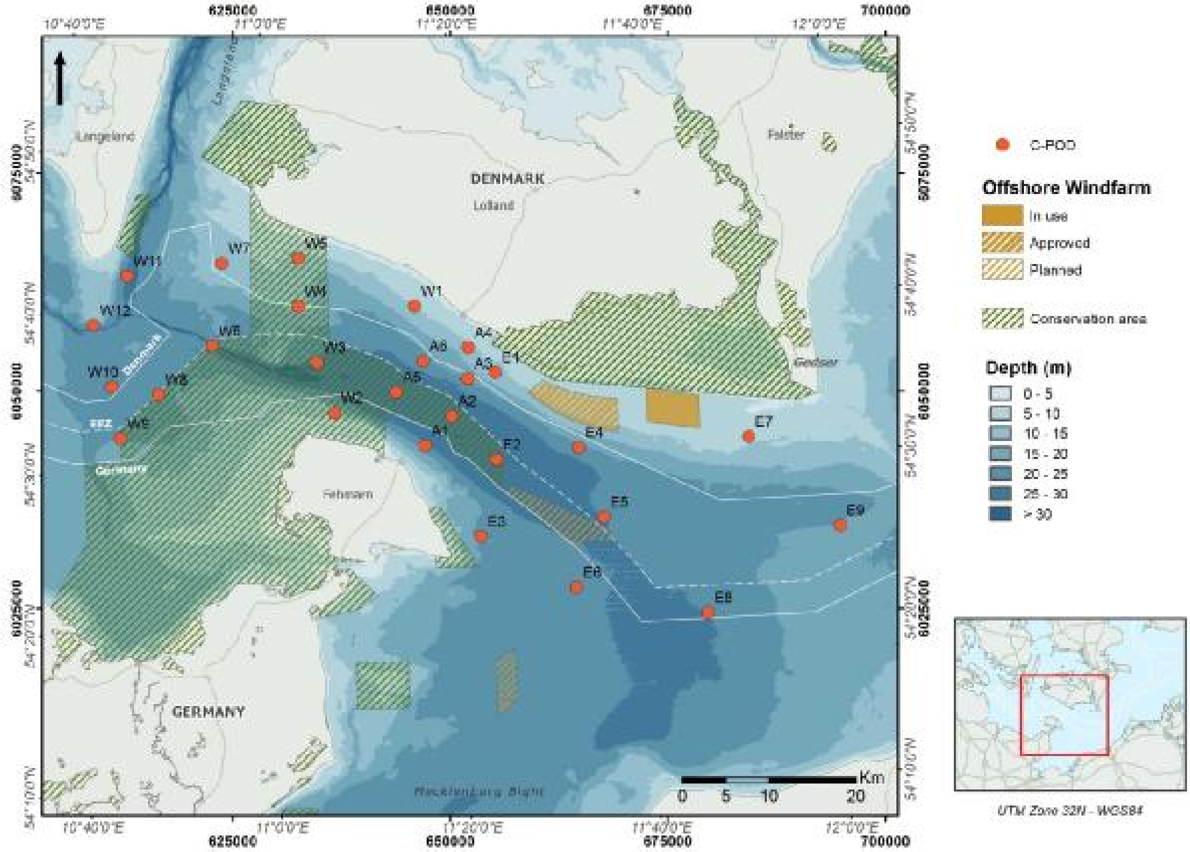

Figure 2.6-2 Positions of all C-PODs deployed in the Fehmarnbelt area.

Table 2.6-1 **Positions (°, min; WGS84) of all C-POD stations in the Fehmarnbelt area with information on some static variables like water depth (W), distance to coast (Dist2l), distance to main shipping lane (Dist2s) and substrate. The last column gives number of days the PODs collected data until 01.01.2011.**

Station	Latitude	Longitude	W [m]	Dist2l [m]	Dist2s [m]	Substrate	days
A1	54°31.14' N	11°16.33' E	23.5	2890	0	Mud	651
A2	54°32.97' N	11°19.34' E	28.2	7474	0	Mud	649
A3	54°35.24' N	11°21.17' E	19.7	6213	1093	Mud	512
A4	54°37.14' N	11°21.34' E	12.3	3084	530	Boulders	540
A5	54°34.55' N	11°13.50' E	28.8	7088	0	Mud	547
A6	54°36.41' N	11°16.40' E	22.3	6792	530	Boulders	563
E1	54°35.56' N	11°24.12' E	11.6	3721	750	Boulders	531
E2	54°30.14' N	11°23.93' E	28.0	9500	530	Mud	431
E3	54°25.39' N	11°22.02' E	21.0	3891	9406	Sand	495
E4	54°30.72' N	11°32.72' E	21.2	9356	0	Boulders	439
E5	54°26.35' N	11°35.11' E	25	17802	1677	Mud	519
E6	54°22.06' N	11°31.97' E	24.3	14785	10437	Mud	525
E7	54°31.00' N	11°50.83' E	6.6	7905	4508	Boulders	485
E8	54°20.21' N	11°45.8' E	24.8	20304	0	Mud	459
E9	54°25.25' N	12°00.16' E	19.2	15545	265	Sand	419
W1	54°39.86' N	11°15.71' E	10.2	3302	3942	Boulders	453
W2	54°33.37' N	11°06.82' E	11.3	3020	2121	Sand	532
W3	54°36.49' N	11°05.10' E	27.4	8144	0	Mud	460
W4	54°40.03' N	11°03.31' E	12.1	8563	3237	Boulders	621
W5	54°43.01' N	11°03.48' E	11.8	3166	7831	Sand	573
W6	54°37.73' N	10°53.98' E	22.5	14886	1326	Boulders	536
W7	54°42.84' N	10°55.26' E	12.2	7674	1428	Sand	499
W8	54°34.79' N	10°48.15' E	22.3	16614	0	Boulders	613
W9	54°32.12' N	10°43.97' E	21	18846	2386	Sand	626
W10	54°35.33' N	10°43.17' E	24.1	14779	0	Mud	503
W11	54°42.20' N	10°45.08' E	25.7	3438	265	Mud	545
W12	54°39.19' N	10°41.36' E	16.7	7553	5337	Boulders	611

For the deployment of the C-PODs, a safe but also easily operated anchor system was developed (Figure 2.6-3). A yellow warning buoy, marked with a flashing lantern with a power of up to 3 nm, marks the position of a heavy 600 kg concrete anchor block protecting the system against drifting by heavy currents or fishing gear. The anchor block is connected via a 60 m long taifun wire with a second smaller 90 kg anchor stone. This stone is connected to a yellow warning ball (60 cm in diameter) at the sea surface by a rope in which the C-POD is spliced in at a height of 5 m above sea bottom. For service procedures only, the small stone needed to be recovered and then the C-POD could be replaced. By changing the device during every service (approximately every 6 weeks), C-PODs were rotated randomly between different fixed locations during the project.

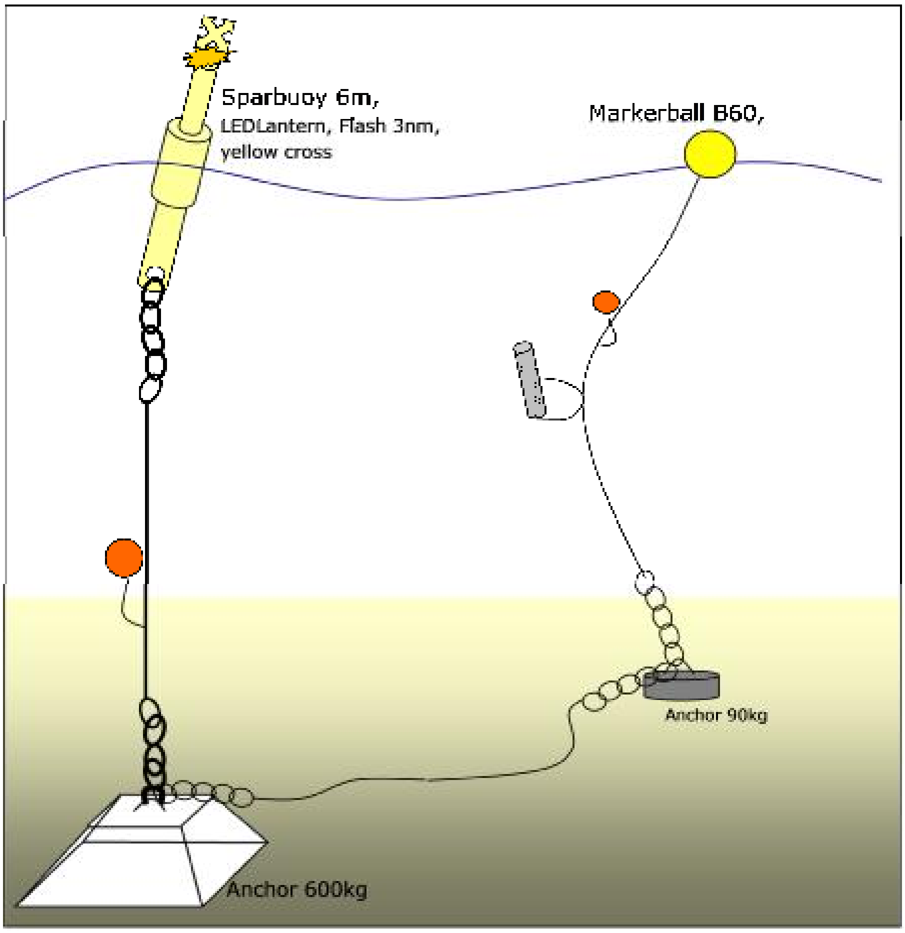

Figure 2.6-3 **Draft of the anchor system used in the Fehmarnbelt project.**

After changing each C- POD the SD flashcard was removed and the data were downloaded onto a Notebook on board the survey vessel. In the lab all data were transferred to a PC, where the raw data were processed using the CPOD.exe software (version 1.020). After running the algorithm all click train details were stored in an Access-database for further analysis.

2.6.2.2. C-POD data

Characteristics of harbour porpoise echolocation clicks
Figure 2.6-4 shows the waveform (above) and spectrum (below) of a porpoise echolocation click with the scale units being kHz. The click beam has a 3 dB width of 16 degrees (Au et al., 1999). The click spectrum does not change much at increasing angles from the centre of the beam (Au et al., 1999).

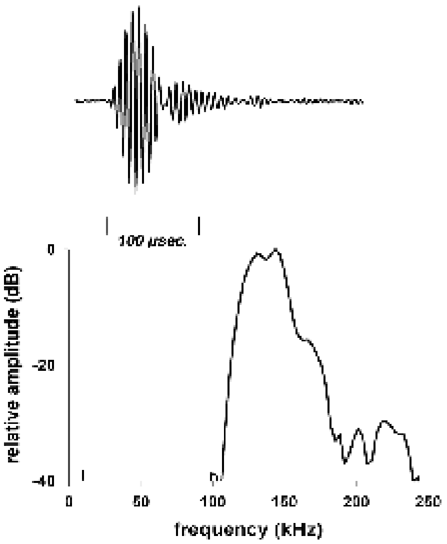

Figure 2.6-4 **Waveform (above) and frequency spectrum of a porpoise echo-location click (from Verfuß et al., 2004).**

The clicks are produced in rapid succession (click trains) of ten to 100 clicks per second. It is assumed that lower click frequencies indicate echolocation used for navigation, whereas trains with higher and accelerating values (‘fast trains’) are known to be used for prey capture (Busnel and Dziedzic, 1967; Amundin, 1991; Kastelein et al., 1997; Verfuß et al., 2005; Koschinski et al., 2008; DeRuiter et al., 2009; Verfuß et al., 2009). These click trains show rapid rises in the interclick interval, commonly resulting in a minimum interclick interval of less than 10 µs (Figure 2.6-4). High-repetition-rate click trains (termed buzzes) - are known to be used in the final stages of prey capture. The highest repetition-rate-click trains recorded were 640 clicks s^{-1} (1.6 ms ICI), produced from harbour porpoises during feeding bouts in experimental trials in Kerteminde in 2008 (DeRuiter et al., 2009).

Parameters of POD recordings

All clicks recorded by C-PODs are stored in real-time with a resolution up to one microsecond. To gain information on the recording differences of all sounds in the water we first exported all click data (raw data). The next step was to apply the algorithm to the raw data. When running the algorithm, the software searches for consecutive clicks, which form a click train. When these are found, the algorithm searches for particular features like frequency trends, centre frequency, duration, intensity, bandwidth, interclick intervals and envelope slope. These are logged for each click train and the software sorts them according to their probability of originating from different sound sources such as harbour porpoises, dolphins or boat sonars.

The software divides raw data into four different classes with decreasing probability of porpoise clicks:

1. Train filters quality high: very high probability of harbour porpoise origin.

2. Train filters quality moderate: less distinctive, but still with a high probability of porpoise origin.

3. Train filters quality low: trains, which in noisy environments are likely to have a non-cetacean origin.

4. Train filter quality doubtful: trains may have come from porpoises but cannot be reliably identified as having that origin. These trains have often been subject to multiple reflections and may contain multiple clicks in clusters.

For further analyses, only porpoise clicks which were classified in the first two classes were used to reduce the probability of including falsely classified porpoise clicks. On the basis of the processed data, different parameters were calculated. These are outlined below.

The parameter ‘porpoise positive time’ per time unit (days/hours/10minutes or minutes) is widely used to define porpoise presence and also used as a measure of relative porpoise density (e.g. Tougaard et al., 2006, Verfuß et al., 2007). ‘Porpoise positive time’ means the proportion of time units (days/hours/10minutes or minutes) with at least one porpoise click train compared with the total number of time units in which the C-POD (T-POD) was active (equation 1 below, x_t= number of porpoise clicks during time unit).

$$\text{(1) Porpoise positive time per time unit [\%]} = \frac{\text{Number of time units with porpoise clicks}}{\text{Total number of time units}} = \frac{\mathrm{N}_{\{xt>0\}}}{\mathrm{N}_{\text{total}}}$$

It can be argued that click activity might be dependent on behavioural state which could bias any POD results on relative abundance. However, the parameter we chose, “porpoise positive time unit”, takes this problem into account. Clausen et al. (2010) showed that porpoises use the same narrow band high frequency clicks in different contexts such as orientation, foraging or communication. The interval between two consecutive clicks seems to contain the key information (Verfuß et al., 2009; Clausen at al. 2010). Thus, analysing just the number of clicks would clearly lead to different results depending on the behavioural context in which the clicks were emitted. The parameter used here is more or less independent of the number of clicks. As shown in different studies (e.g. Akamatsu et al., 2007) porpoises use their echolocation system almost continuously. Furthermore, Kyhn et al. (2011) showed a clear relationship between absolute densities and PAM data, indicating that click data can be used in investigating pattern of occurrence as we have done. Porpoise positive time has been widely used to describe harbour porpoise presence in a certain area (Tougaard et al., 2006; Verfuß et al., 2007; Diederichs et al., 2008).

For the baseline study, we chose to use ‘porpoise positive 10 minutes per day’ (pp10m/day). This measure specifies how many of the 144 10-minutes-sections during a 24-hour-day have at least one porpoise recording. This parameter was used by Diederichs et al. (2008) to show the best compromise between high temporal resolution and an adequate scale to avoid huge blur caused by small sensitivity differences of different devices (see section 2.6.2.3).

2.6.2.3. C-POD data validation

For the Fehmarnbelt C-POD study, it is necessary to ensure that the analysis of POD data gained with different devices is not unduly affected by different sensitivities of individual PODs. But since C-PODs are relatively new devices there is a lack of experience with C-POD data in terms of sensitivity differences. A calibration study by Verfuß et al. (2010), focused on test tank calibration of C-PODs, showed that C-PODs are reasonably standardised at 130 kHz, but vary more at other frequencies. As 130 kHz corresponds to the main frequency range of harbour porpoises, it was assumed that the method was appropriate. However, so far, the effects of even small sensitivity differences on the amount of data collected in the field haven’t been investigated.

In order to obtain an insight into the reliability of the C-POD data collected during our study, particular calibration experiments were established (see Appendix 7.5). The objective of these experiments was to investigate the performance and comparability across C-PODs and between C-PODs and other available PAM devices. For this purpose we deployed, during five experimental trials, several C-PODs close to other PAM devices, so that each pair of devices could record the same clicks produced by free-ranging and captive harbour porpoises. For an additional validation of the individual hearing threshold of different PODs, C-PODs were measured in a test tank with standardised procedures under controlled conditions provided by the German Oceanographic Museum (for further details on experimental setup see Verfuß et al. 2010).

These comparisons confirmed that C-PODs are capable of reliably collecting relevant biosonar data of harbour porpoises. Detections, in terms of raw data clicks/hour from all C-PODs deployed close to a randomly chosen reference C-POD, were highly positive correlated. However, especially during noisy conditions, as often occurs in areas with strong currents and movable sediment, the number of recorded clicks as well as the number of identified porpoise clicks can vary extensively. This is particularly evident when only a few porpoise clicks were recorded. We could show that similarity of data from several C-PODs, deployed at the same spot for the same time period decreased with higher resolution of time units and type of parameter used. Highest deviation across PODs occurred for raw data per hour. This result is most probably caused by differences in sensitivity of particular C-PODs in frequency ranges below or above130 kHz. During very noisy periods, the algorithm has difficulty in distinguishing harbour porpoise clicks from the large amount of other clicks. These differences are then more pronounced during periods with only a few porpoises present in the vicinity of the hydrophones. But even in the porpoise pool at Kerteminde, which presents a quiet environment with porpoises always present close to the hydrophones, it was found that some C-PODs can deviate clearly from others in terms of porpoise detections per hour. The test tank measurements of 50% detection threshold at the main frequency of harbour porpoise clicks at 130 kHz showed a relatively homogenous receiving hearing threshold with a mean of 116 dB. As 35% of the tested PODs had a greater deviation than 2 dB (which is within the error of measurement),the test tank study also demonstrated some differences in sensitivity between different PODs. But only two (out of 40) C-PODs showed a difference of more than 4 dB.

The results of the calibration experiments led us to rotate the CPODs between monitoring positions in order to reduce any bias due to differing sensitivity of individual C-PODs. Additional individual C-POD-IDs were included in the modelling exercise (see below) to take account of these sensitivity differences.

In light of the results of the C-POD calibration experiments, we further examined the validity of the C-POD data from our study. We plotted the number of identified porpoise clicks per day against the number of all clicks the C-POD had recorded on that day for all 14,529 days the PODs collected data during the study (Figure 2.6-5). It can be seen that the more clicks the devices recorded, the lower the probability that these clicks came from harbour porpoises. This phenomenon can have different causes. It is possible that during very noisy days only a small portion of each minute could be sampled so that the memory of the C-POD was full before the end of the recording time. Yet, it is equally possible that porpoises leave the area with considerable noise exposure, especially as the noise occurs in their best range of hearing (see Kastelein et al., 2002). In order to check for the first (methodological) explanation we plotted the recorded number of all clicks and porpoise clicks against the time lost due to minutes with filled scan limit (Figure 2.6-6). It can be seen that on days when more than 4 Mio clicks were recorded, more than 30% time loss occurred due to reaching the scan limit. In order to find a trade-off between removing the bias caused by periods when the PODs could not detect beyond the scan limit and avoiding loss of too much information on the presence of porpoises within such noisy periods, we defined a threshold beyond which data were removed from analysis. This threshold was chosen based on the data presented in Figure 2.6-5 and Figure 2.6-6 and set at 4 Mio clicks/day (black line in both figures). It is important to consider that since we used a rather broad measure for relative porpoise abundance (pp10 min/day) the results are unlikely to be affected significantly by this phenomenon (see below).

78% of all days exhibited less than 1 Mio clicks/day (number of days indicated by the orange dots in Figure 2.6-5) which indicates that noisy time periods with several million clicks per day were not frequent. Thus, the removal of days with more than 4 Mio clicks resulted in deletion of only a small fraction (1.9%) of the whole data set. Data reduction due to noise was not equally distributed over all stations. Figure 2.6-7 shows that station E5 recorded an especially high amount of noise, so that a relatively high amount of days (100 from 527) had to be removed from this station for further analysis.

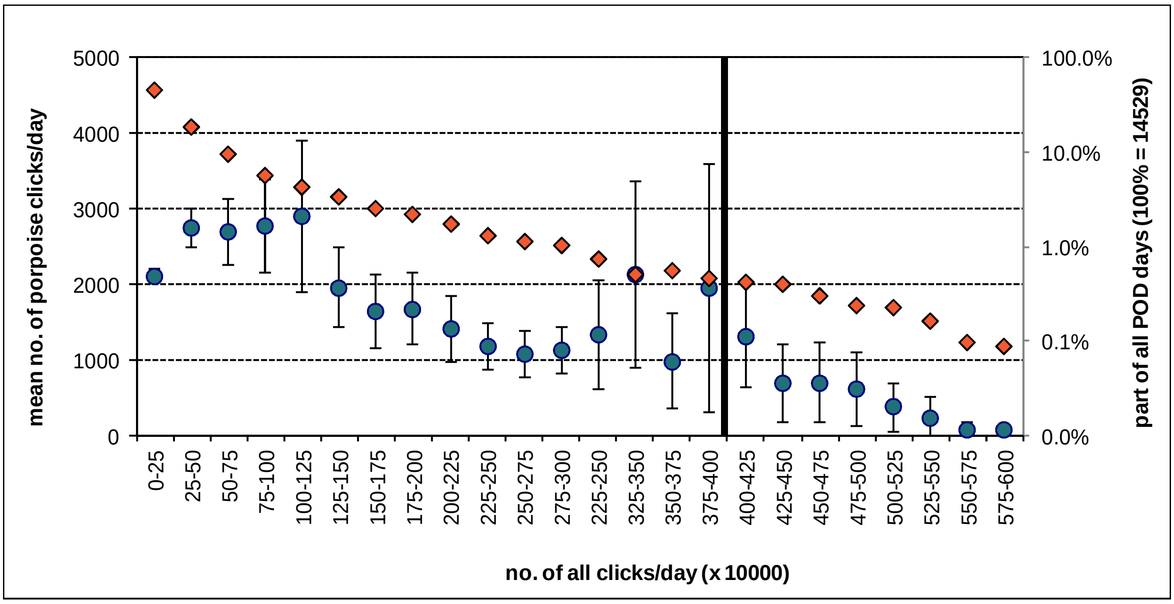

Figure 2.6-5 **Mean number of harbour porpoise clicks/day (±95% CI) identified by the software CPOD.exe (blue dots) and no. of days proportional to the number of all days (orange dots) plotted against the number of all recorded clicks/day. All data between January 2009 and January 2011 are pooled.**

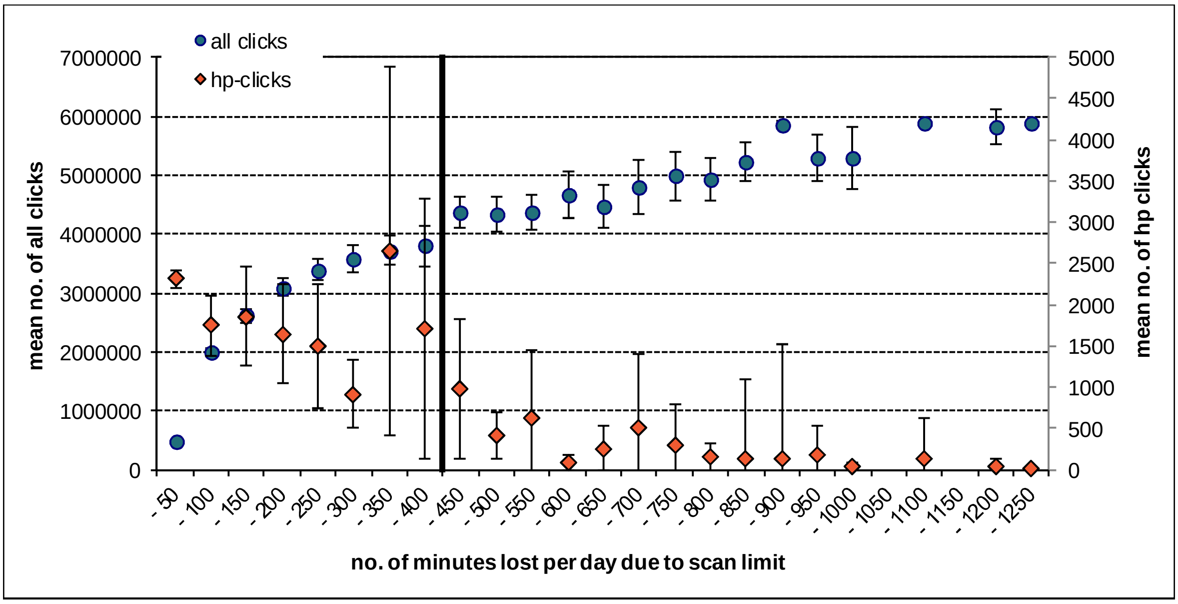

Figure 2.6-6 Mean number of all clicks/day (± CI, green dots; left y-axis) and mean number of harbour porpoise clicks/day (± CI, red dots; right y-axis) plotted against the time lost due to filled scan limit. All data between January 2009 and January 2011 are pooled. Black vertical line indicates the 4.Mio-threshold.

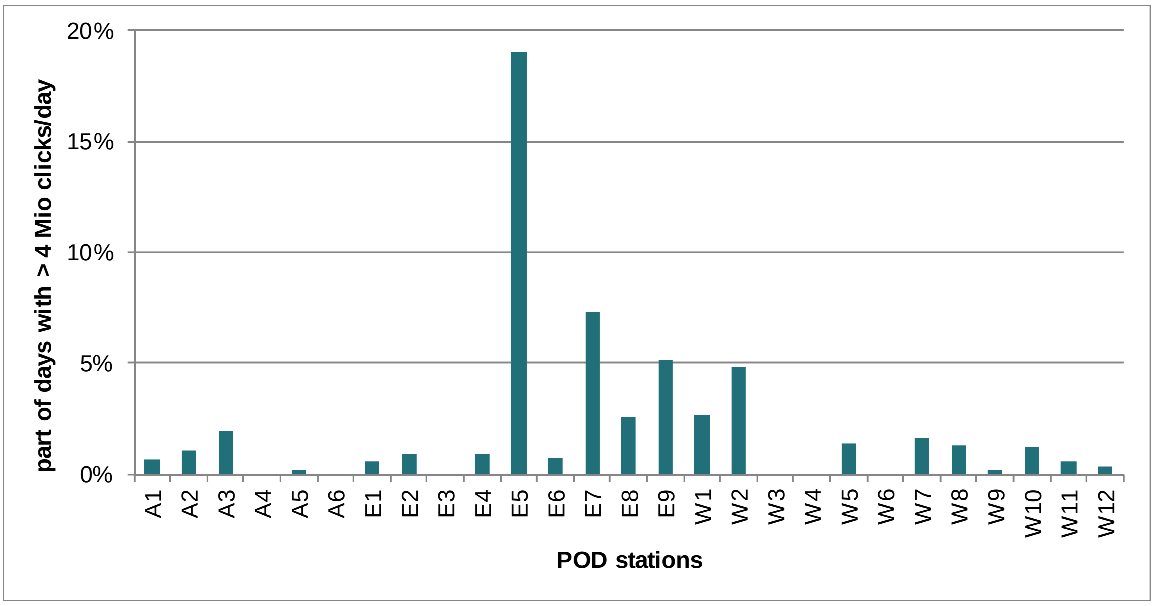

Figure 2.6-7 Percentage of days with more than 4 Mio clicks/day for all C-POD stations between January 2009 and January 2011 in the Fehmarnbelt.

Another approach to deal with the potential bias caused by noise was to apply different threshold limits for the number of clicks per day to the final model in order to determine whether it significantly impacted the explanatory power of any variables. We chose thresholds from 1 to 5 million for the number of raw data clicks per day

The final model was run five times with different amount of days included depending of the chosen limit. Results were compared with regard to a change of significance of chosen variables in the final model.

2.6.2.4. Description of model variables

Harbour porpoises are mainly fish-eaters (Benke et al., 1998). Therefore, in this study we primarily rely on variables which are important in relation to marine ecological processes which enhance the concentration and prediction of fish prey (Iverson et al., 1979; Schneider and Duffy, 1985, Schneider, 1990; Fauchald et al., 2010). The structures which display ubiquitous concentrations of cetaceans and other top predators are bathymetry and tidally steered structures. Concentrations of cetaceans have been reported for shallow sea fronts (Schoenherr and Wartzok, 1991; Reid et al., 2003; Doniol-Valcroze et al., 2007), plume fronts (Ainley and DeMaster, 1990), oceanic ridge fronts (Skov et al., 2008), bank fronts (Camphuysen et al., 2006), island fronts (Johnston et al., 2005), vertical fronts (Camphuysen et al., 2006), coastal upwelling zones (Bradstreet et al., 1987; Skov and Thomsen, 2008), eddies (Moore and Clarke, 1992) and shelf break fronts (Carwardine, 1995).

The general interpretation of these affinities has been the enhancement of the probability of prey encounter, which greatly maximises predators' foraging success (Schneider and Duffy, 1985; Fauchald et al., 2010). High concentrations in abundance of prey and predators have been documented at these structures, including harbour porpoises and seals (Weir and O'Brien, 2000, Reid et al., 2003; Johnston et al., 2005; Skov and Thomsen, 2008). In the oceanographic context of the Fehmarnbelt, possible structures which may govern the distribution of fish and thus also harbour porpoises are semi-stable frontal systems which can occur in a horizontal as well as in a vertical structure. Fronts can occur in fields of current velocity, salinity, temperature and density or in nearly all combinations of these. The most important fronts biologically are those which display a predictable oscillation pattern, and thus can be defined as conditionally stable over time (Longhurst, 1985, 1998). Apart from huge frontal systems (e.g. upwelling systems) along shelf edges displaying stability over long time periods and on a large scale and also more fine-scale marine phenomena such as weather induced (so-called "semi-stable") fronts can occur. These exhibit a regular periodicity with predictable variance patterns and thus should be judged conditionally stable in relation to a particular physiochemical environment. For the PAM study, variables have been selected which reflect such conditionally stable processes and structures in the Fehmarnbelt area such as horizontal and vertical fronts as well as eddies. Similarly, regular upwelling and downwelling events are known to result in markedly enhanced biological productivity (Andrews and Hutchings, 1980, Armstrong et al., 1987), and the variables reflecting these structures were also given high priority.

The Fehmarnbelt is affected by local and remote forcing: the local forcing is represented by winds which mix the surface water and drive the outflow transport in the upper layer and opposite recirculation below the upper layer; the remote forcing is due to the large scale pressure gradients which are built up by winds forming different wind set-up of the sea levels in the Kattegat and in the Arkona Sea. When the wind changes the barotropic pressure gradient is not balanced and forces strong currents (>30 cm/sec) through the Fehmarnbelt (Jacobsen et al., 1996).

At the same time, an estuarine circulation is observed in the Fehmarnbelt consisting of an outflow of brackish water in the surface layer and inflow of saline waters near the bottom. Both layers are separated by a thermocline and a halocline, which often coincide and form a strong pycnocline. The halocline is a permanent feature, due to high salinity of the near-bottom waters, which are, however, pushed back and forth and may vary significantly. The seasonal thermocline develops in spring and vanishes in autumn. However, different temperatures of in- and outflowing waters can establish a thermocline throughout the year. The typical depth of the pycnocline is 15 to 20 m.

High noise levels are of special concern for cetaceans, which depend on sound as the most important source of information about their environment (Richardson et al. 1995, Nowacek et al. 2007, Southall et al. 2007, Weilgart 2007, Tyack, 2008). While noise from shipping itself is not the loudest man-made underwater noise (pile driving, military sonar and ice breaking sounds, for example, can be much louder), it certainly is the one with the widest spread (NRC 2003). This is particularly relevant to the Baltic Sea, where shipping traffic is intense. Therefore, as an additional covariate, monthly mean noise levels were developed based on noise measurements conducted during the FEMM project. For further details on measurements and calculation of noise levels we refer to section 2.7.7.

Thus, in order to determine the key drivers which govern the distribution of harbour porpoises in the Fehmarnbelt area we collected information on 15 static explanatory variables and 13 dynamic hydrographic variables from which 8 variables are available from both sea floor and sea surface (e. g. 2.5 under sea surface). All variables are listed in Table 2.6-2.

All environmental variables except for position (latitude/longitude), month, year and background noise were either taken directly or developed through post-processing chains from static and dynamic data delivered by the FEHY and FEMA projects.

Post-processing chains, as well as a detailed description of and justification for the selection of the specific hydrodynamic variables, are described in detail in Appendix 7.4.

Because some substrate categories were not very frequent, substrate was divided into three categories, dependent on grain size:

1. Mud = mud / sandy mud / thin sandy mud;
2. Sand = sand / muddy sand;
3. Boulders = Coarse sediment/Boulders.

12 variables are constant for a particular station over the whole time period. Apart from the position variables, these static variables describe constant environmental parameters like water depth, distance to land or distance to the strait, which represents the shortest path between Fehmarn and Lolland. Every animal moving between the Baltic Proper and the Belt Sea has to cross this line, which represents the centre of a channel-like connection. Static variables also include some pressure variables such as distance to human infrastructures (wind farms) or distance to main shipping lines.

Table 2.6-2 **List of all selected predictor variables, which were included for the analysis of porpoise acoustic activity with their source of origin**

Variable name	Description	Parameter type	Data source

Variable name	Description	Parameter type	Data source
Station	Name of station: A1 to A6: stations close to the alignment; E1 to E9: stations east of the alignment; W1 to W12: stations west to the alignment	static	BC
Area	Three subareas: A = close to alignment; W = western Fehmarnbelt; E = eastern Fehmarnbelt	static	BC
POD-ID	Individual POD-No. (92 different PODs were used between 29.1.2009 and 10.1.2011)	static (data quality)	BC
Gain factor	Individual factor introduced by the manufacturer in order to synchronise PODs with different sensitivities	static (data quality)	BC
Month	Month	time-varying	BC
Year	Year	time-varying	BC
Longitude	Longitude (WGS84) [decimal degree]	static	BC
Latitude	Latitude (WGS84) [decimal degree]	static	BC
Water Depth	Water depth [m]	static	DHI
Substrate	Bottom structure, sorted by grain size from mud over sand to boulders	static	DHI
Background noise	Modelled noise level [dB]	monthly	ITAP
Distance to land	Distance to land [m]	static	DHI
Distance to strait	Distance to alignment (shortest distance between Puttgarden and Rødby) [m]	static	DHI
Distance to Rødsand Wind Farm	Wind Farm Rødsand under construction since 2009 [m]	static	DHI
Distance to Nysted Wind Farm	Wind Farm Nysted existing since 2003 [m]	static	DHI
Distance to shipping lane	Distance to main shipping lane [m]	static	Cefas
Salinity discharge	Daily mean discharge of salinity between Rødbyhavn and Puttgarden [kg/s]	time-varying	DHI

Variable name	Description	Parameter type	Data source
Pycnocline depth	Depth of stratified layer deduced by Brunt–Väisälä frequency values > 0.1 [m]	time-varying	DHI
Pycnocline strength	Strength of stratification measured by Brunt–Väisälä frequency [1/s]	time-varying	DHI
Density	Daily mean density at bottom / at surface[kg/m³]	time-varying	DHI
Salinity	Daily mean salinity at bottom / at surface[PSU]	time-varying	DHI
Temperature	Daily mean temperature at bottom / at surface [°C]	time-varying	DHI
U: E-W current velocity	Daily mean east-west current velocity at bottom / at surface[m/s]	time-varying	DHI
Vorticity	Daily mean vorticity(dV/dx - dU/dy) = eddy activity at bottom / at surface [1/s]	time-varying	DHI
V: N-S current velocity	Daily mean north-south current velocity at bottom / at surface [m/s]	time-varying	DHI
W: vertical current velocity	Daily mean vertical current velocity at 10 m depth (or bottom if water depth is less than 10m) [m/s] = upwelling/downwelling	time-varying	DHI
Current speed	current speed at bottom / at surface = sqrt(U*U+V*V) [m/s]	time-varying	DHI
Current gradient	Daily mean current gradient at bottom / at surface[1/s]	time-varying	DHI

To test the influence of the strength of current velocity independent from its direction, we transformed the variables ‘E-W current velocity’ N-S current velocity’ ‘vertical current velocity’ and ‘vorticity’ into absolute values by taking the modulus. These new variables were added to the list of variables, named with the addition of the word ‘absolute’.

2.6.2.5. Statistical Modelling approach

The following section details the methods used to formulate and obtain model results.

Modelling proportions: Generalized Additive Models (GAMs)

The observations comprise a number of 10 minute intervals in a day for each POD, where one or more porpoise calls can be recorded. Thus, the response used for the modelling is the proportion of 10 minute intervals where one or more porpoise clicks were recorded. Typically the number of listening intervals in a day was 144, but was as low as 18 on days when PODs were deployed or recovered.

The proportion of pp10m/day recordings were modelled against continuous and categorical covariates within Generalized Additive Models (Hastie and Tibshirani, 1990, Wood 2006) with a logit link and binomial errors. The smooth functions were implemented using cubic B-splines (Hastie, 1992) with one interior knot on the scale of the link function. However more (or less) flexible alternatives could also be considered inside this approach.

The GAM approach with a logit link generates coefficients which represent the log-odds of success versus failure and, when exponentiated, these coefficients convey the odds of observing a success (in this case a 10 minute interval where a recording is heard) relative to failure.

Variance inflation factors (VIFs, Fox and Monette, 1992) were used to identify sets of collinear variables. This is in contrast to Pearson's or Spearman's rank correlation coefficients which assume a particular relationship between the covariates (e.g. linear, or monotonic). VIFs greater than 5 motivated remedial action which meant that the predictor (of the collinear set) with the best fit to the data was retained and the other covariate(s) omitted. The 'best fit' is determined using an AIC-type criterion used by Hardin and Hilbe, (2002) to compare models with different correlation structures. It is called 'quasilikelihood under the independence model information criterion' (QICu).

Model inference: Generalized Estimating Equations (GEEs).

The data consist of repeated measures (proportions) at each POD location over time and thus the response data are likely to be auto-correlated in time and/or space. Further, this correlation is unlikely to be explained by the model in full and so is likely to be present in model residuals. Non-independence in model residuals must be accounted for in the modelling process if model standard errors and *p*-values are to be believed and realistic conclusions are to be drawn. Generalized Estimating Equation (GEE, Zeger and Liang, 1986; Liang and Zeger, 1986; Hardin and Hilbe, 2002) based methods are routinely used to model repeated measures binary data where a marginal model (rather than a conditional/mixed model) is desired. Additionally, using GEEs to model data in relation to physiographic and remote sensing variables has recently emerged in the cetacean literature (Panigada et al., 2008; Pearson, 2009; Tempera et al., in press).

The GEE approach requires `panels' to be chosen such that model residuals are permitted to be correlated within panels while independence is assumed between panels. This panel structure can be chosen using the data (assisted by empirical autocorrelation functions (Venables and Ripley, 2002 for example) or might naturally arise due to the sampling design (e.g. subjects). The GEE method requires a working correlation structure (within panels) to be chosen, but due to software limitations, only the independence and AR(1) error structures are able to be trialled. For this reason, robust (modified) sandwich estimates of variance (Pan, 2001) which are robust to misspecification of the working correlation structure were used to obtain model standard errors and associated *p*-values.

The GEE method estimates the coefficients for the mean model and the variance-covariance structure in a one-step procedure and the resulting robust standard errors ensure the conclusions obtained do not rely on a user-specified correlation structure, which in many cases is unlikely to hold in practice.

Model Selection

Model covariates were selected by an exhaustive procedure, selecting all possible subsets based on an objective score appropriate for GEEs. Specifically, QICu (Hardin and Hilbe, 2002) scores were used to govern the model selection process which considered all possible models based on the global (starting) model. Subsequent to this, GEE-based *p*-values were also used to assess the statistical significance of model predictors following selection of the covariates in the model, to ensure terms with large p-values were identified.

Candidate covariates were initially fitted separately to the response in order to ascertain the predictive power of each with respect to the modelled proportion. This was followed by the fitting of a global (full) model which was subjected to the model selection process.

2.6.3. Results

In Figure 2.6-8 an overview of the data collected during this study is given. Four C-PODs were lost completely due to fishery and/or high ship traffic in this region. However, other gaps in the data occurred because malfunctions occurred at times, which is common when a relatively new instrument such as the C-POD is introduced. Compared to other long term monitoring studies based on PAM (like MINOS/MINOSplus (e.g. Verfuß et al., 2004, 2008) or Horns Rev I (Tougaard et al. 2006)),the amount of collected data presented in this baseline study is very continuous and without any large gaps. Altogether 92% of the maximum possible amount of data-days was achieved. Apart from one station (W9), there were no data between the end of January and mid-March 2010 due to ice coverage. Figure 2.6-8 provides an overview of the data gained during this study at all stations.

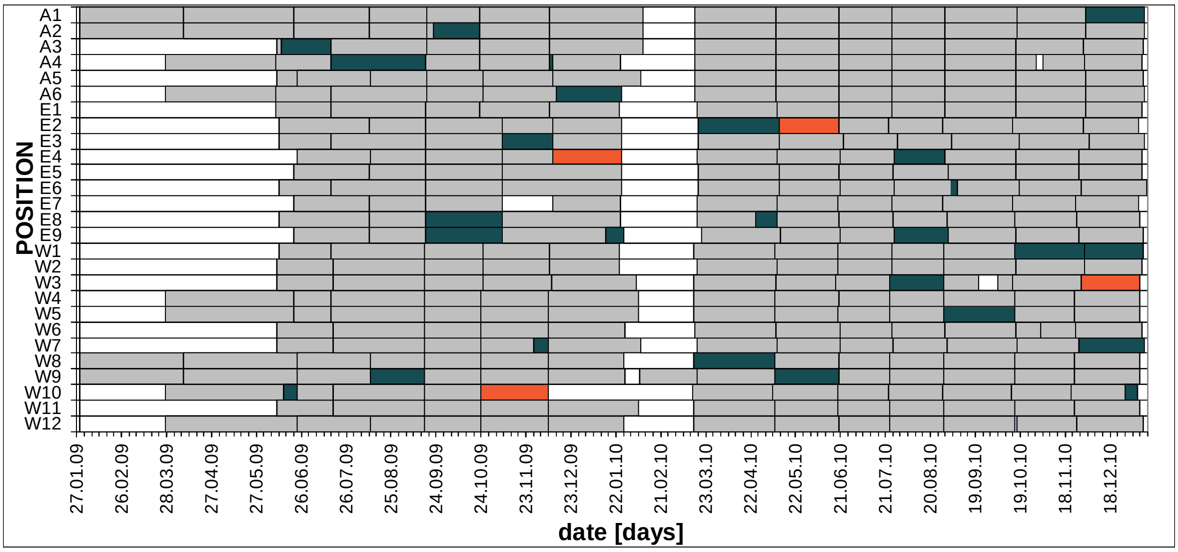

Figure 2.6-8 **POD deployment time in the Fehmarnbelt area in 2009 and 2010. Dark grey bars = good data; white bars = no POD in the water; dark green bars = PODs in the water but no data gained; red bars = POD lost.**

From the beginning of the study until January 10th 2011, C-PODs collected data on 14,530 days at 27 positions. As hydrographic variables were only available until January 1st 2011, data from only 14,337 days were used for the final model approach. Due to noisy periods (>4 mio clicks/day) 280 days were excluded from the analysis, so that in total 14,057 POD days were available for analysis. From these days, only 1,098 POD days (8%) were without any porpoise clicks. In other words, there were 92% "porpoise positive days". The 8% of days without porpoise recordings were distributed over all stations and over the whole study period. The only calendar days without any porpoise recordings at all were in February/March 2010 when only station W9 was occupied by a C-POD. This result indicates that harbour porpoises were present in the whole study area for nearly most of the year

2.6.3.1. Harbour porpoise presence in Fehmarnbelt measured by C-PODs

Spatial distribution

The mean numbers of recorded pp10m/day for each POD were not equally distributed over the different POD positions (Figure 2.6-9, Figure 2.6-10). Although these figures do not account for differences in number of days the PODs were deployed during each time period it gives an estimate of the mean presence of harbour porpoises throughout the study period in different quarters of the year. It shows some differences, with constantly more detections at some specific stations in the western part of the area throughout the year. Station W2 close to Fehmarn differs from all other stations; this station exhibited at least 10% pp10m/day across all quarters and greater than 30% pp10m/day in the second quarter - the highest of all stations. The four stations close to the entrance to the Great Belt (W5, W7, W11 and W12) also recorded more porpoise activity at most times of the year compared with the other stations close by. It was only in the first quarter of both years that numbers were rather similar for all stations (except for W2).

The stations in the eastern part of the area and for the majority of stations in the area around the planned link mean porpoise recordings per quarter remained below 10% pp10m/day which corresponds to a maximum presence of porpoises in 2.4 hours per day. The magnitude of measured porpoise activity is in line with previous studies from the Nysted wind farm area with 7% pp10m/day on average over a two year study period (Diederichs et al., 2008). For the Horns Rev area with a known high (absolute) abundance of porpoises (Skov et al., 2002) Diederichs et al. (2008) found pp10m/day values of nearly 30% on average over two years. As these studies were based on T-PODs, direct comparisons are somewhat limited but it is possible to put our results in a general context. Seasonal differences for those stations with lower porpoise activity were negligible compared with the differences across stations within a quarter. As the scale in all three figures was set by the data across stations it becomes clear that seasonality is a minor component when compared with spatial differences. For example, the three stations at the south-western edge of the study area (W8, W9 and W10) show mean porpoise recordings of less than 10% for each quarter of the year.

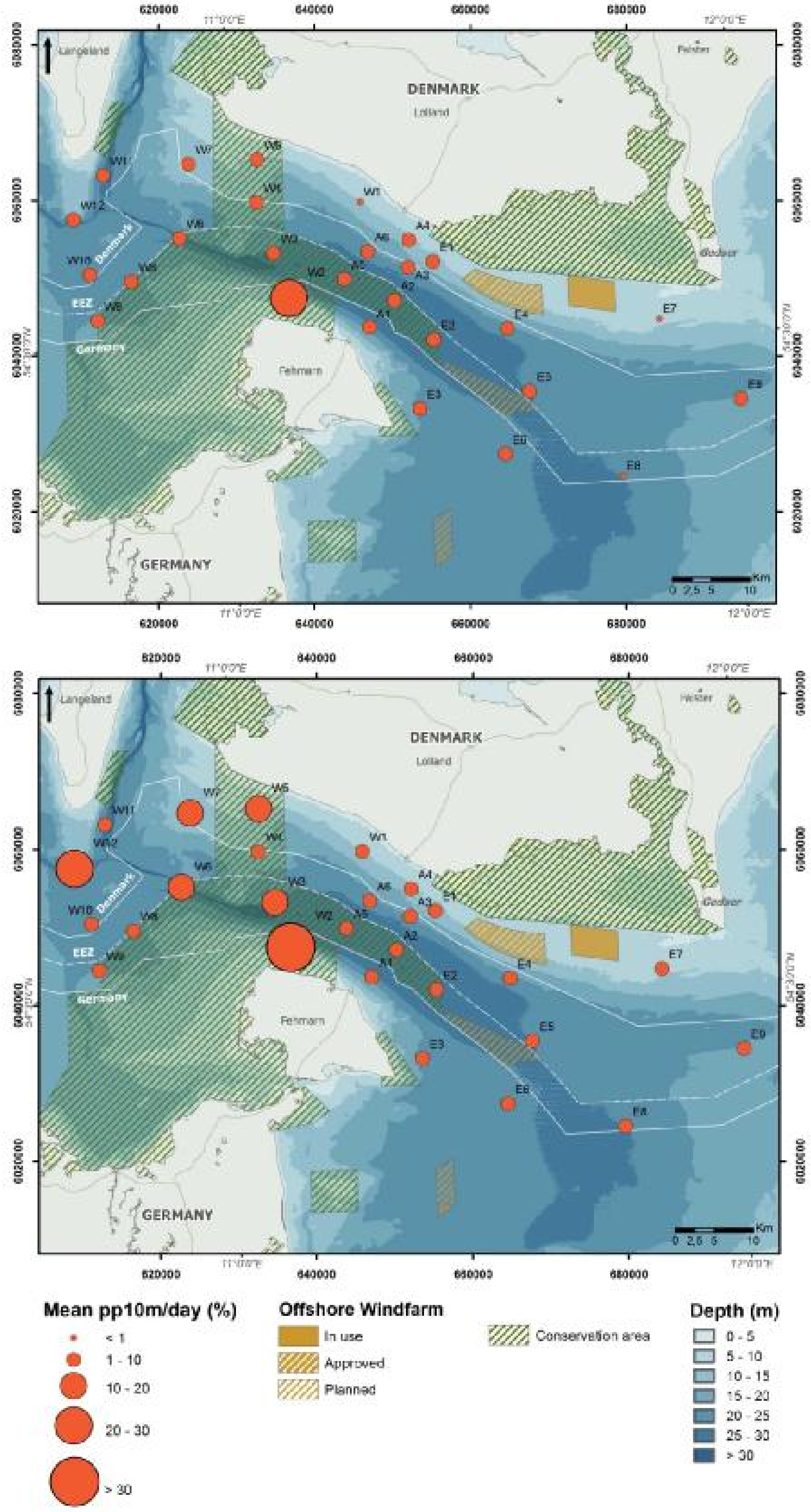

Figure 2.6-9 Mean number of recorded pp10m/day during first (above) and second (below) quarter of a year indicated by the diameter of circles around the position of PODs.

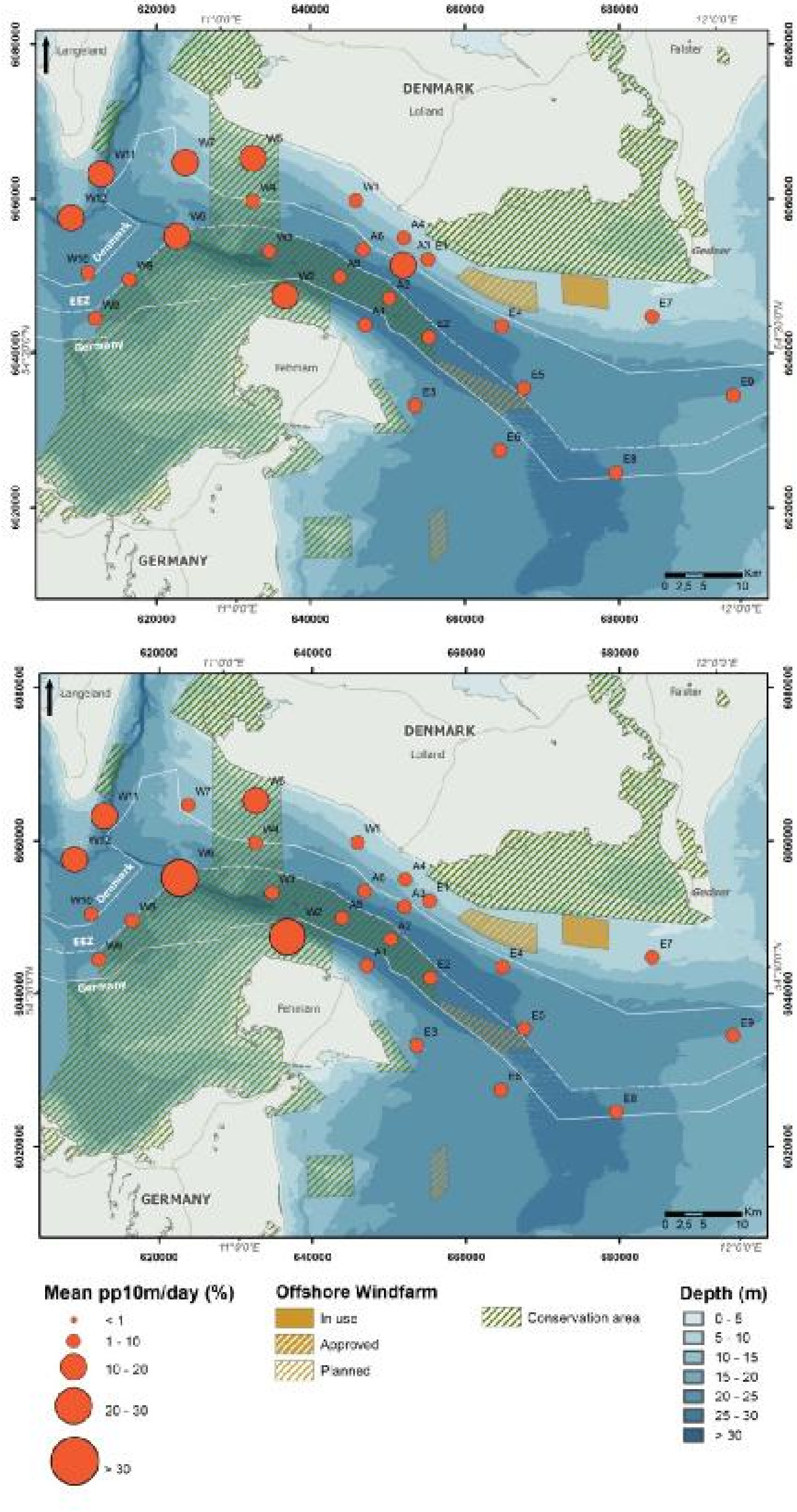

Figure 2.6-10 Mean number of recorded pp10m/day during third (above) and fourth (below) quarter of a year indicated by the diameter of circles around the position of PODs.

Seasonal occurrence

Pp10m/day values at all stations show a typically high oscillation having days with many porpoise detections often followed by days with very few detections. Due to the recovery of all PODs except for station W9 in winter 2010, all figures suffer from the bias that data are missing for the period from February to March 2010 (see appendix 7.5).

POD stations differed with regards to seasonal trends (see appendix 7.5). For example, two stations in area A close to the planned alignment (A1 and A2) show a similar pattern with one peak in April/May and a second one in December/January in both years (Figure 2.6-11). As both stations are only 5 km apart, a spatial autocorrelation should be assumed. In contrast to these two stations, Figure 2.6-13 shows a plot of pp10m/day for the stations W6 and W12, which were 14 km apart. At both stations no seasonality was evident but there was a clear opposite change in pp10m/day over time. By contrast, at W6 (located in the deep channel at the western entrance to the Fehmarnbelt), a constant increase in porpoise detections could be observed (especially in 2010), at W12 (south of Langeland), especially in 2009. Figure 2.6-12 shows an example of two stations on eastern part of Fehmarnbelt. Pp10m/day values are considerably lower and from these plots hardly little seasonality was observed, even though, at times, several consecutive days with more detections could be observed.

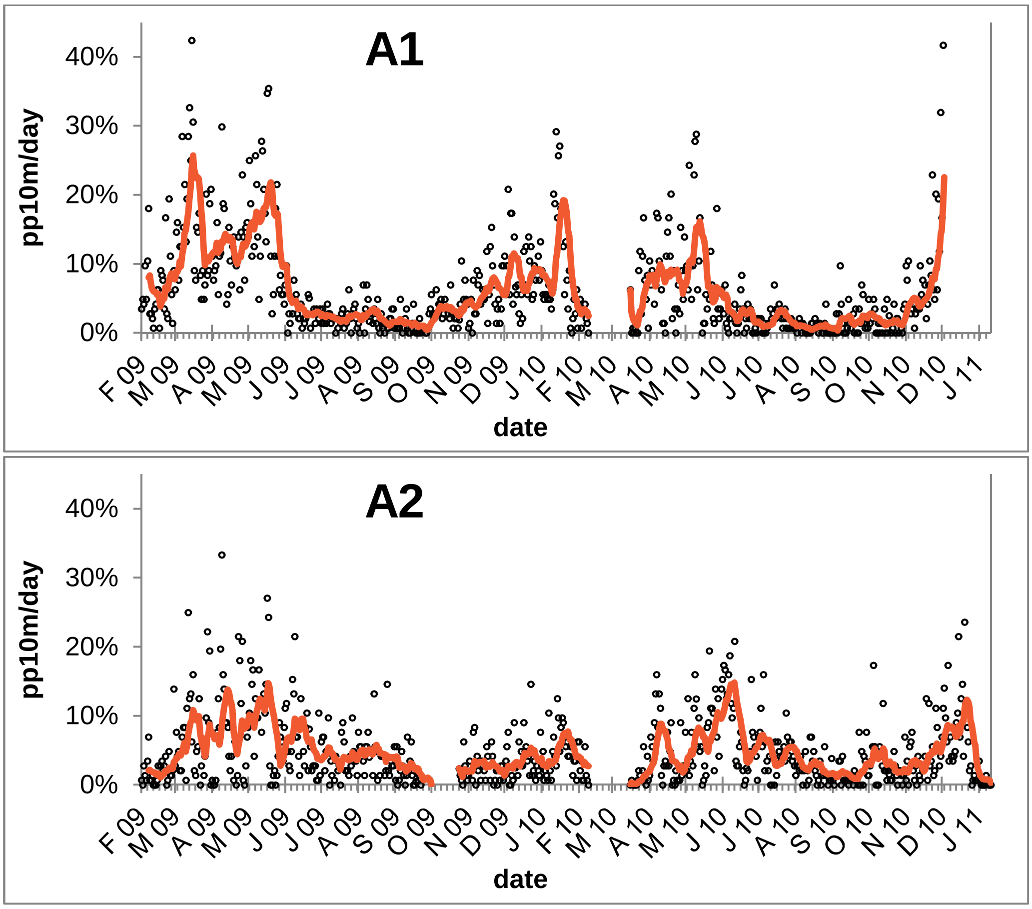

Figure 2.6-11 **Plot of pp10m/day against time for two single POD stations from area A. The red line shows the moving average for 10 days.**

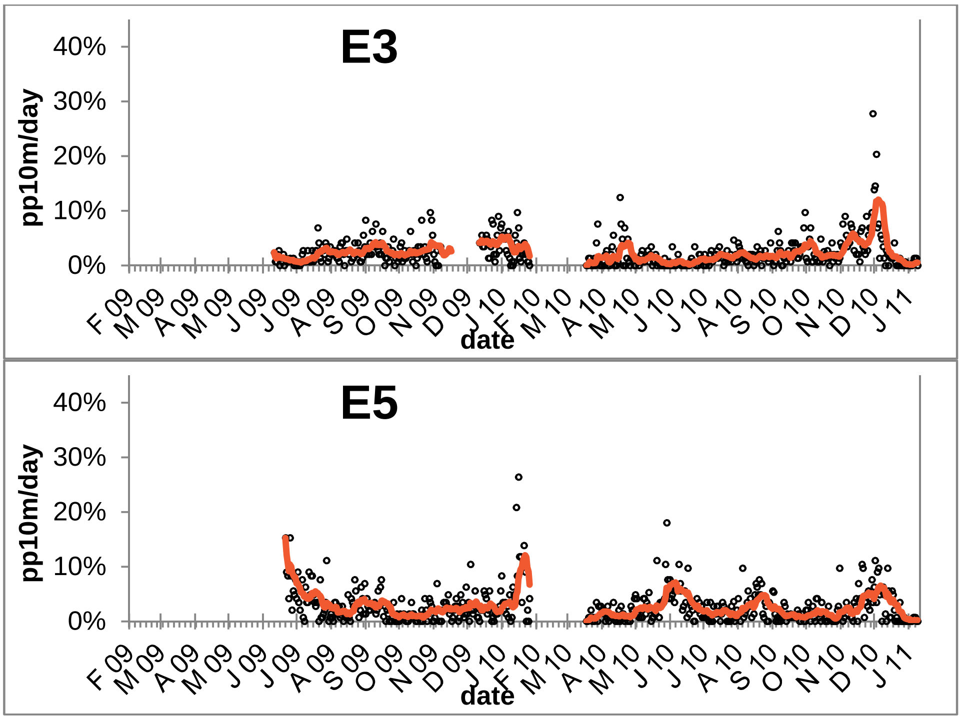

Figure 2.6-12 Plot of pp10m/day against time for two single POD stations from area E. The red line shows the moving average for 10 days.

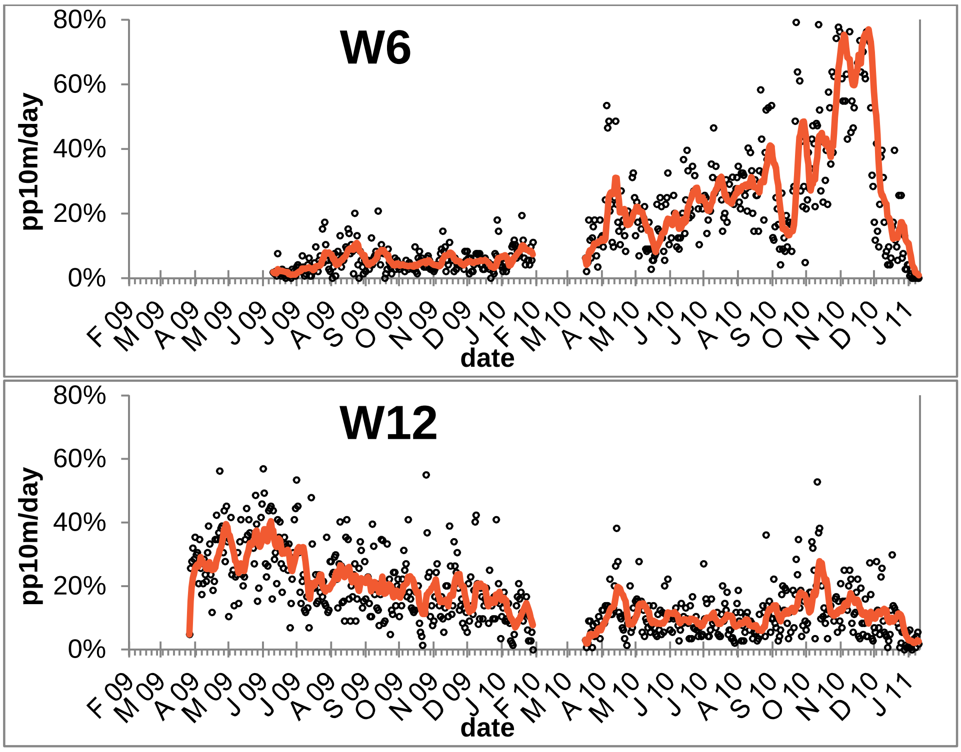

Figure 2.6-13 Plot of pp10m/day against time for two single POD stations from area W. The red line shows the moving average for 10 days.

2.6.3.2. Modelling of pp10m

Predictive power of the individual covariates

Based on the smallest QIC-U score the spatial location of the PODs appeared to be the best predictor of recording probabilities (Table 2.6-3). Station, longitude and latitude (fitted as factors) all returned the same fit to the data because each variable uniquely represents the spatial location of the 27 stations and thus these models produce station specific coefficients and model probabilities. The location of each station can also be represented using: Distance to wind farm (Rødsand or Nysted), Distance to land and Distance to the strait. However, in these models, variables were permitted to be less flexible than the factor variable implementations of Station, latitude and longitude (these variables were fitted as smooth functions with *df*=4) and so demonstrated a worse fit to the data than with Station alone. In practice, these distance-based variables could also be fitted as factors and therefore return an identical fit to ‘Station’ (Table 2.6-3). Indeed, one of these covariates could be fitted instead of Station in the global model and subjected to model selection.

POD-ID (fitted as a factor) also returned a relatively good fit to the data (Table 2.6-3) and since this generated a different baseline coefficient for each POD, 92 POD-specific (predicted) recording probabilities were obtained. The POD to POD variability (in the probability of recording porpoises) is likely to be due to multiple factors including the differences in sensitivity of the PODs at recording ultrasonic sound and a complex mix of information represented by the spatial location of each POD. For instance, PODs in certain locations will be more (or less) likely to record animals for several reasons and, while this (direct) information is missing from the model, POD-ID might be indirectly representing information of this type. The sensitivity of model results to including POD-ID is investigated on section 2.6.3.3. Additionally the substitution of gain information for each POD provided by the manufacturer is investigated. The gain factor is a non-dimensional factor given by the manufacturer in order to set PODs on an equal detection threshold at 130 kHz. The factor derives from the manufacturer’s calibration procedure (see www. chelonia.co.uk).

Table 2.6-3 **Changes in QIC-U scores for models with different covariates. The pseudo-R² was generated using the squared correlation between the observed and fitted probabilities. The hydrographic variables measured at the sea bottom are highlighted in bold and those measured at or near the surface are shown in italics**

Variable	ΔQIC-U	Pseudo-R²
Station*	0	0.325275
Longitude*	0	0.325275
Latitude*	0	0.325275
POD-ID*	32043.94	0.186766
s(Distance to Nysted Wind Farm)	33187.9	0.145013
Area*	35251.65	0.121714
s(Distance to Rødsand Wind Farm)	46895.51	0.08444
s(Distance to main shipping lane)	49810.13	0.074784
s(Water Depth)	51575.65	0.056231
s(Distance to land)	57627.28	0.034002
Substrate*	59095.84	0.029352
Month*	62160.33	0.019735
s(Temperature at surface)	*62661.5*	*0.01774*
s(Current gradient at surface)	*62699.36*	*0.016712*
s(Vorticity at surface)	*63038.44*	*0.016442*
s(Temperature at bottom)	**63063.64**	**0.014508**
s(Current gradient at bottom)	**63078.67**	**0.014058**
s(Vorticity at bottom)	**63195.26**	**0.013002**
s(Distance to strait)	64286.49	0.01259
Gain	62322.91	0.009979
s(Salinity at surface)	*64711.81*	*0.008797*
s(Density at surface)	*64798.33*	*0.008622*
s(Density at bottom)	**65503.34**	**0.008254**
s(U: e-w current velocity at surface)	*66059.87*	*0.007763*
s(Salinity at bottom)	**66291.93**	**0.007002**
Background noise	63227.36	0.006695
s(Absolute value of V: n-s current velocity at bottom)	**66303.06**	**0.006099**
s(V: n-s current velocity at surface)	*66429.15*	*0.00585*
s(Absolute value of W: Vertical current velocity)	66497.65	0.003653
s(Salinity Discharge)	66862.33	0.003468
s(V: n-s current velocity at bottom)	**66871.45**	**0.003211**
s(Current speed at bottom)	**66982.59**	**0.002835**
s(W: Vertical current velocity)	67031.63	0.002789
s(Absolute value of V: n-s current velocity at surface)	*67069.96*	*0.001401*
s(Current speed at surface)	*67091.82*	*0.001259*
s(Pycnocline Strength)	67247.72	0.001033
s(Absolute value of U: e-w current velocity at bottom)	**67281.71**	**0.00078**
s(U: e-w current velocity at bottom)	**67298.62**	**0.000595**
s(Absolute value of U: e-w current velocity at surface)	*67507.84*	*0.00034*
Year*	68391.24	0.000328

* Variables fitted as factors for maximum flexibility.

There appeared to be some month-to-month variability in recording probabilities (Table 2.6-3) but very low inter-annual variability (and low associated predictive power; Table 2.6-3).

Hydrographic variables at (or near) the sea surface or the bottom appear to be moderate-to-poor predictors of recording probabilities (Table 2.6-3). Good predictors are considered to have a pseudo R^2 with more than 1%, whereas moderate describes the upper half of the tested predictors up to 1%. A predictor with a pseudo R^2 of the lower half of the tested predictors are stated as poor. From 24 hydrographic variables only six have a pseudo R^2 of more than 1% (namely temperature, current gradient, vorticity, all measured at both the surface and the sea bottom). From 24 hydrographic variables only six have a pseudo R^2 of more than 1%. Of the hydrographic variables included, water temperature, current gradient and vorticity (all measured at the surface) demonstrated the highest predictive power. Notably, these variables at the surface exhibited more predictive power than the corresponding information from the sea bottom. On their own, gain and background noise appeared to be relatively poor predictors of porpoise recording probability (Table 2.6-3); however they became statistically significant at the 5% level when fitted with other covariates.

Assessing Collinearity

Salinity at surface and Density at surface were prohibitively collinear (VIFs> 7.96) and since “Density at surface” demonstrated a closer fit to the data, “Salinity at surface” was excluded from consideration in the full model. “Distance to Strait” and “Longitude” were also collinear (VIFs > 8.04) and since “Longitude” contained greater predictive power, “Distance to Strait” was also excluded from consideration in the model.

Many of the variables were only measured at the station level and to avoid “station” being for many of these variables (depth, substrate, latitude, longitude etc.) this was excluded from any models.

Assessing residual independence

Generalized Estimating Equations (GEE) were required for this analysis. There was statistically significant evidence for temporal autocorrelation in model residuals; the Pearsons residuals returned $p<0.001$ for the runs test (Mendenhall 1982). Additionally, visual inspection of the empirical autocorrelation function indicated that autocorrelation was present in model residuals up to 24 days apart (Figure 2.6-14). This information was used to specify `month’ as the panel variable to structure the autocorrelation, i.e. model residuals within months at each POD were considered to be correlated while values between months at each POD were considered independent.

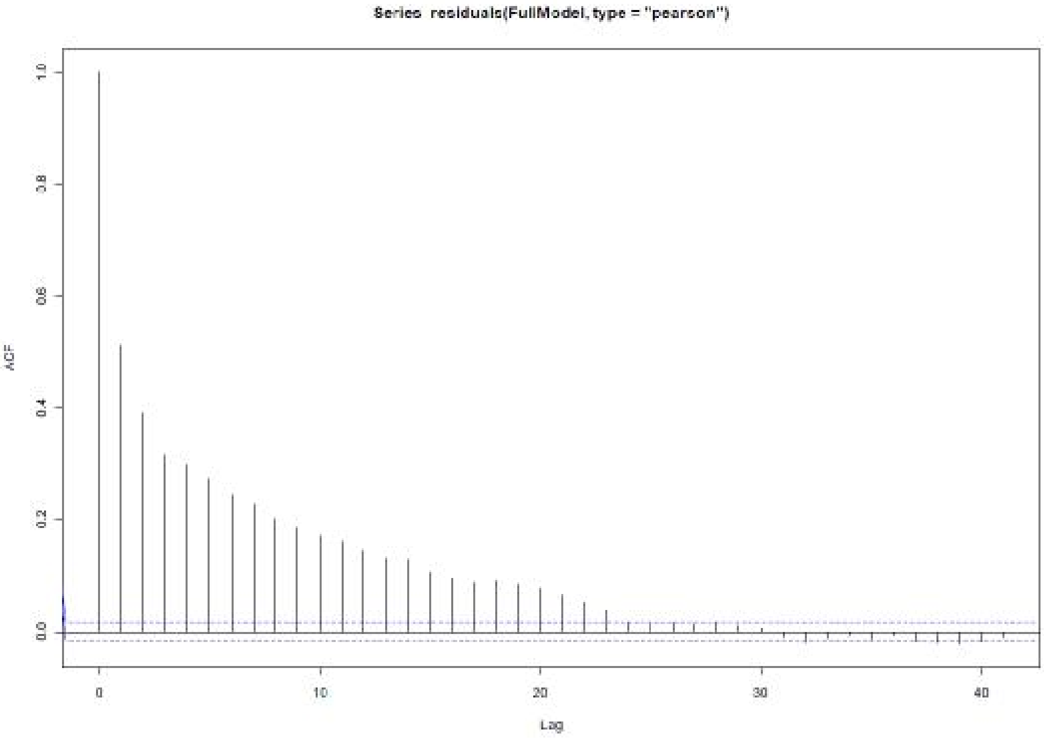

Figure 2.6-14 **Empirical autocorrelation function for the Pearson residuals from the global/full model. Residuals are ordered in time (days). For example, residuals which are one day apart have an estimated correlation coefficient of about 0.511.**

This GEE specification also assumes that residuals between spatial locations are independent. This assumption was found to be reasonable in practice; the correlation between model residuals across spatial locations was found to be negligible (based on a spline-based spatial correlogram) and within the bounds of independence with (Euclidean) distance between stations.

Model Selection

The following covariates were available to undergo model selection. For hydrographic variables, where both surface and bottom values were available, the covariate with the best predictive power was chosen to enter the selection process. The following were considered:

- POD-ID
- Longitude
- Latitude
- Background noise
- Water Depth
- Distance to shipping lane
- Substrate
- Month
- Year
- Temperature at the surface
- Current speed at bottom
- U: e-w current velocity at the surface

- V: n-s current velocity at the surface
- Density at surface
- Current gradient at surface
- Vorticity at bottom
- Salinity discharge
- Pycnocline strength
- Absolute value of W: vertical current velocity

The selected model retained all 19 candidate covariates (Table 2.6-4); however only 13 of these covariates were significant at the 5% level. This reflects the degree of uncertainty about some of the model terms. In line with results in Table 2.6-3, POD-ID exhibited the most predictive power; the full model had a pseudo R^2 of 65.6%.

The GAM/GEE method resulted in standard errors (and associated p-values) which were much larger than those returned assuming independence; GAM/GEE standard errors were between 6.8 times larger than the GAM standard errors assuming independence, on average. This justifies the use of the GAM/GEE approach

Table 2.6-4 Covariates with associated (Wald-test-based marginal testing) *p*-values based on robust estimates of precision from the GEE-based model. Bold represents statistical significance at the 5% level. Loss in pseudo R^2 represents the % loss in the pseudo R^2 when each variable was omitted.

Covariate Selected	p-value	Loss in pseudo-R^2 when omitted
POD-ID	**0.000000**	**31.60%**
Longitude	**0.000001**	**6.27%**
Distance to shipping lane	**0.000001**	**4.11%**
Background Noise	**0.000288**	**2.97%**
Temperature at surface	**0.000029**	**1.56%**
Year	**0.000056**	**1.43%**
Water depth	**0.000000**	**1.13%**
Substrate	**0.016409**	**1.09%**
Month	0.541447	1.00%
Latitude	**0.006394**	**0.90%**
Density at surface	0.291351	0.40%
Current gradient at surface	**0.000354**	**0.36%**
Current speed at bottom	**0.000381**	**0.35%**
V: n-s current velocity at surface	**0.000322**	**0.31%**
Pycnocline strength	0.085669	0.30%
U: e-w current velocity at surface	0.178366	0.23%
Absolute value of W: vertical current velocity	0.249295	0.21%
Vorticity at bottom	0.246022	0.19%
Salinity discharge	**0.002851**	**0.18%**

Fitted Relationships

There was a great deal of POD-to-POD variability in the prevalence of porpoise detections (Figure 2.6-15). For example, POD 8 detected approximately only a quarter of the number of pp10m/day as POD 6 (all other factors being equal), while POD 693 recorded around twice the number of pp10m/day as POD 6 (all other factors being equal).

While there was large variability across PODs, there was also substantial overlap in the confidence intervals for the POD-ID coefficients (Figure 2.6-15). For example, while POD 84 exhibited a much larger number of pp10m/day than POD 6 (about 1.7 times) this difference might be simply due to sampling variability alone and may not be due to a genuine difference in the underlying prevalence of porpoise recordings at these locations.

These substantial differences across PODs could be due to different sensitivities to sound across PODs or due to genuine differences in the number of porpoise clicks available to be detected.

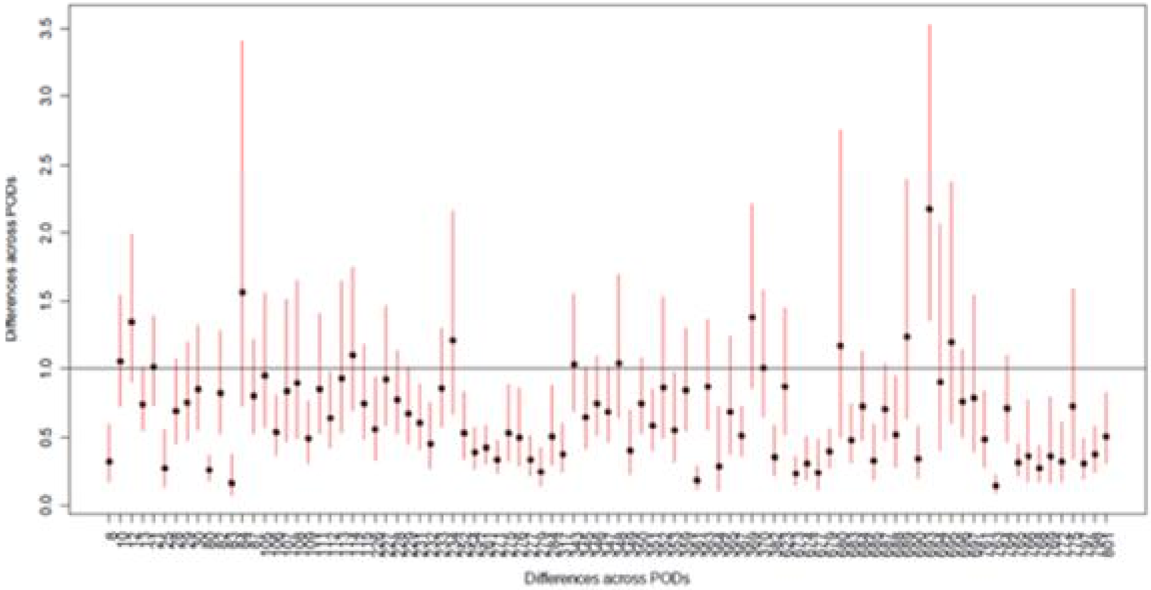

Figure 2.6-15 **Exponentiated POD-ID coefficients from the chosen model with exponentiated 95% confidence limits based on GAM/GEE standard errors. All coefficients are with reference to POD 6 which is represented by the horizontal line at 1. These coefficients represent the difference between each POD and POD 6 in terms of the odds of success versus failure to record porpoises.**

The prevalence of porpoise detections was very similar across calendar months (Figure 2.6-16). While some months exhibited approximately 1.5 times the number of pp10m/day than in January, there was a large amount of uncertainty about any month-to-month differences between all calendar months.

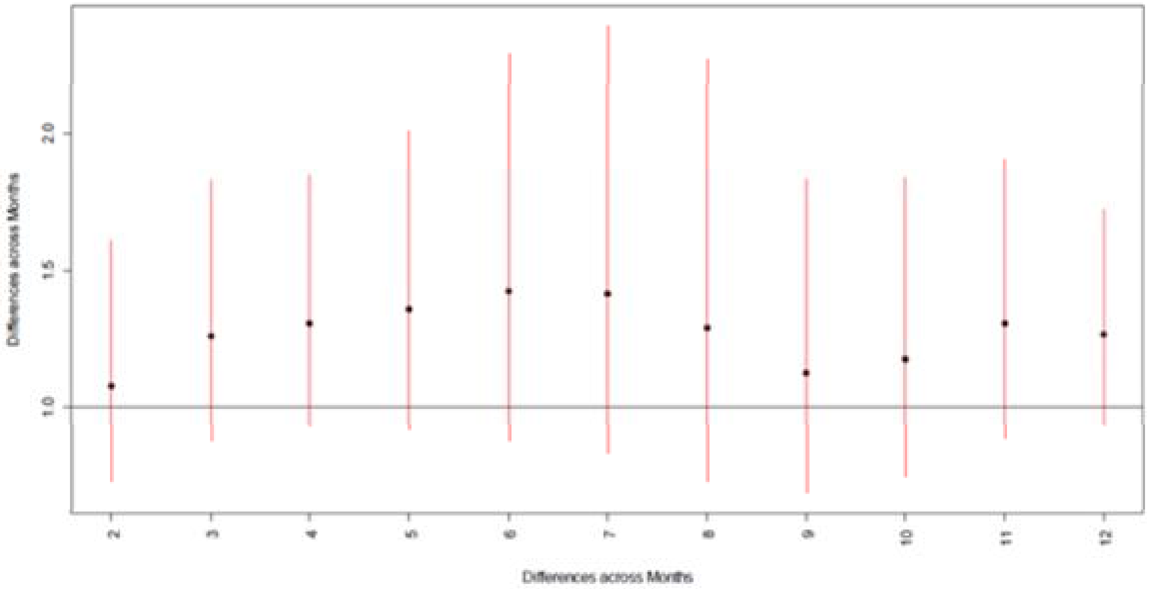

Figure 2.6-16 **Exponentiated Month-based coefficients from the chosen model with exponentiated 95% confidence intervals based on GEE standard errors. All coefficients are with reference to month 1 (January) which is represented by the horizontal line at one. These coefficients represent the difference between each month and January in terms of the odds of success versus failure to record porpoises.**

There appears to be a decrease in the number of porpoise recordings for moderate to high longitude values with an associated low at approximately 11.6° E (Figure 2.6-17). In contrast, the relationship appears cyclical with latitude and this appears to peak at approximately 54.55° N and at the extremes (Figure 2.6-17). There is substantial uncertainty in the depth relationship beyond 10 m but the prevalence of porpoise detections appears similar beyond this depth (Figure 2.6-17). Below 10 m, clearly, fewer detections were made.

The probability of recording a porpoise appears to steadily increase with increasing distance from the shipping lane up to approximately 8000 m, after which this probability falls to approximately 2000 m levels (Figure 2.6-17).

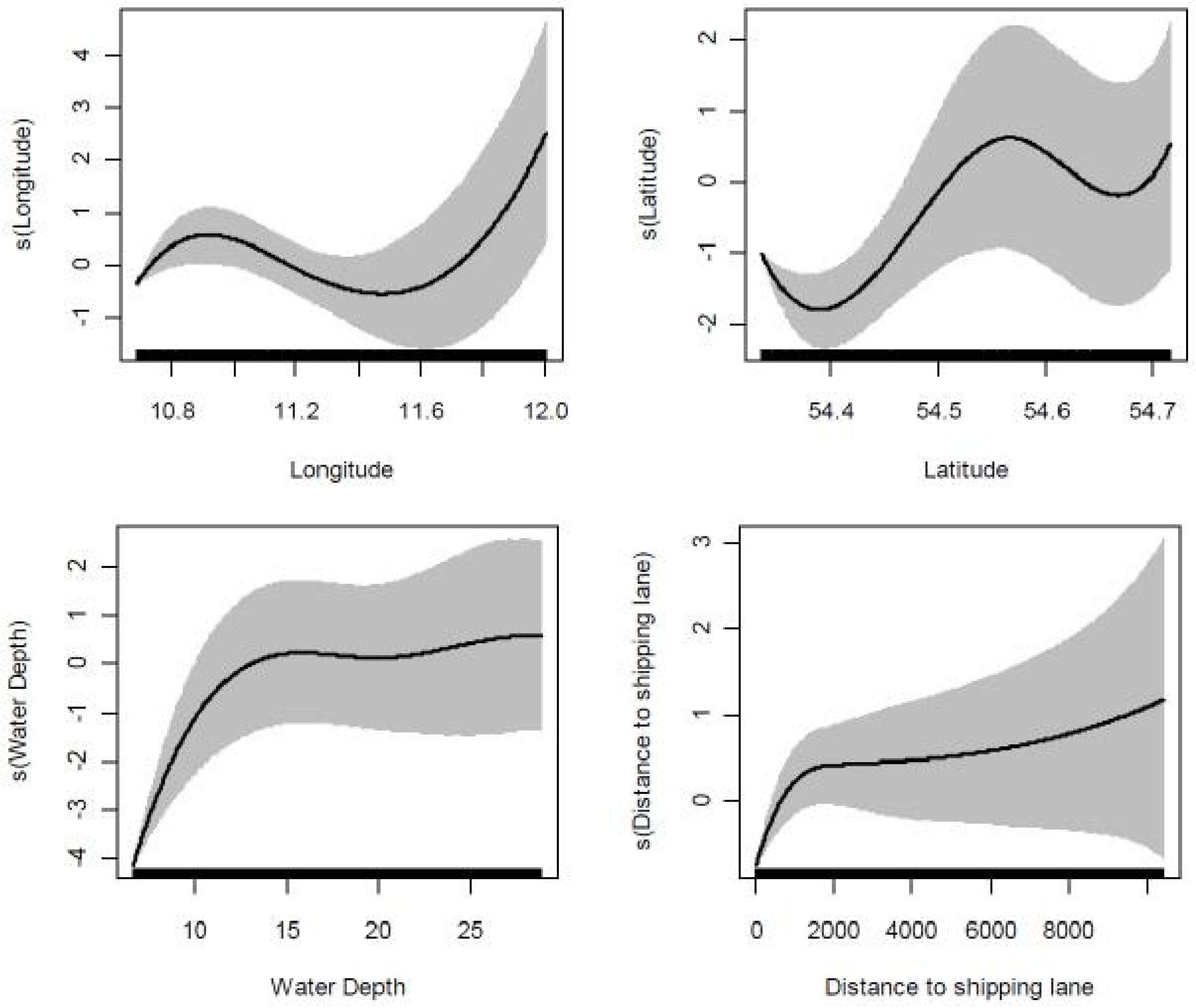

Figure 2.6-17 **Fitted relationships from the chosen model with (pointwise) 95% confidence envelopes based on GAM/GEE standard errors.**

The probability of detecting porpoises appears to be highest at surface temperatures of approximately 6°C and this steeply decreases at temperatures below 5°C. Highest porpoise recordings also seem to be most probable at current speeds (at the bottom) below 0.4 m/s (Figure 2.6-18). Beyond a current speed of about 0.4 m/s the chance of recording a porpoise falls sharply.

There is substantial uncertainty in the fitted relationships especially for U: (East-West current velocity at the surface) but also for V (North-South current velocity at the bottom, Figure 2.6-18). At North-South current velocity values below -0.7 m/s the probability of recording pp10m/day was highest. Beyond this value confidence intervals drift apart indicating high uncertainty until highest current velocity values.

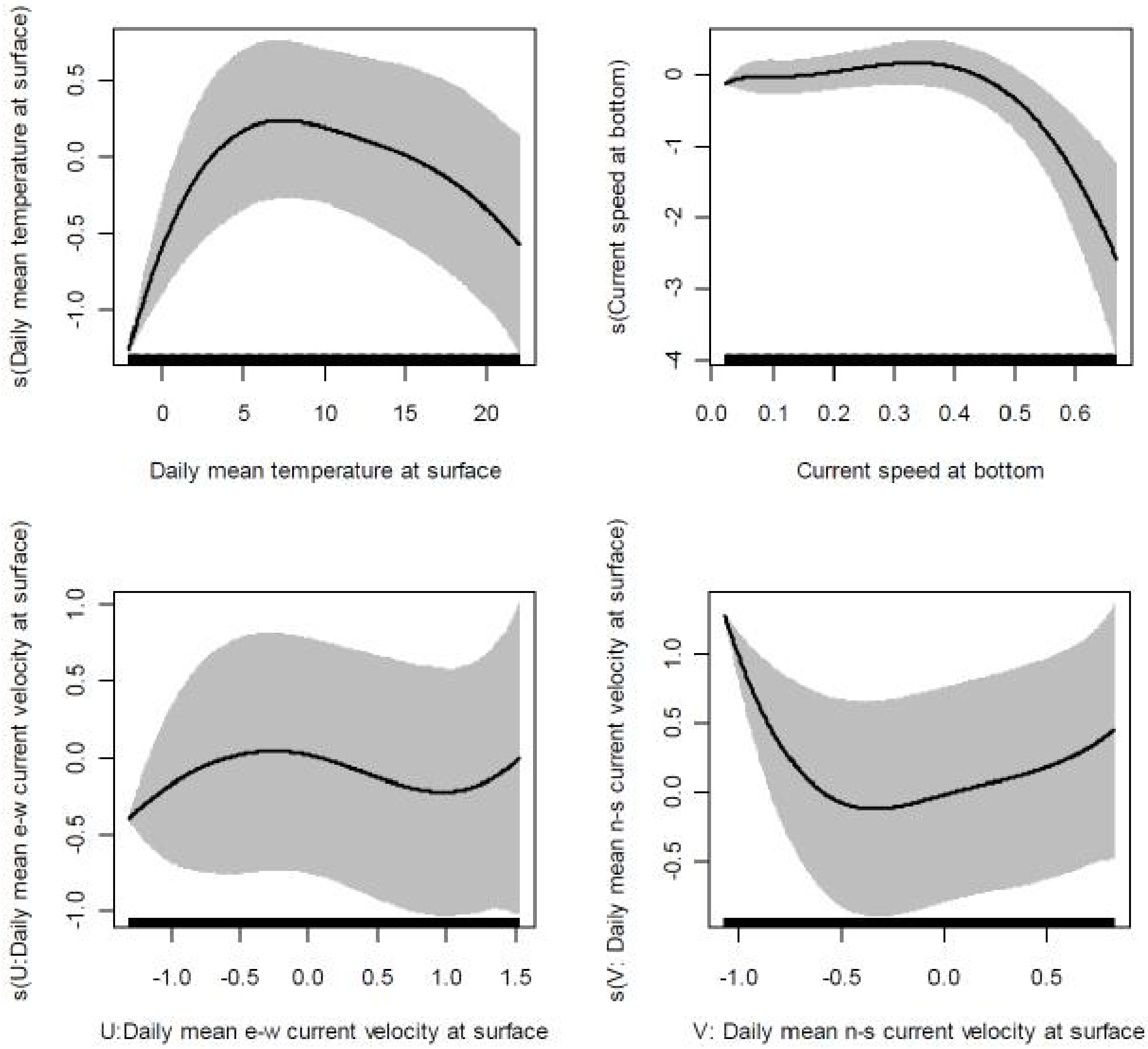

Figure 2.6-18 Fitted relationships from the chosen model with (pointwise) 95% confidence envelopes based on GEE standard errors.

The probability of detecting one or more porpoises appears to be lowest for extreme current gradient values (at the surface, Figure 2.6-19) and while there is great uncertainty about the relationships for mean density (at the surface), mean vorticity (at the bottom) and mean salinity discharge, there is some cyclical behaviour for mean density and salinity discharge (Figure 2.6-19).

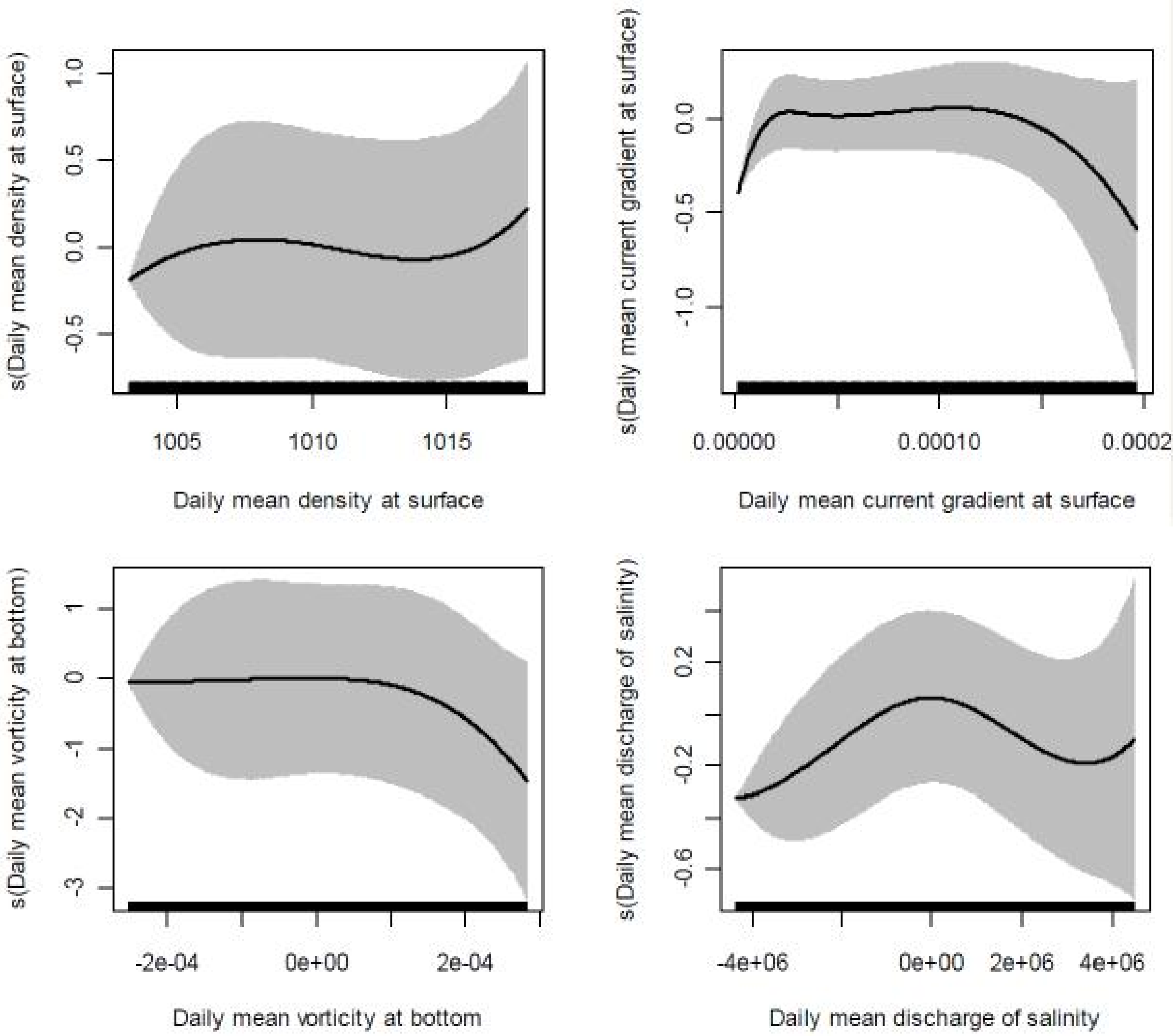

Figure 2.6-19 **Fitted relationships from the chosen model with (pointwise) 95% confidence envelopes based on GEE standard errors.**

The probability of porpoise detection increases steadily with increasing pycnocline strength while moderate values for mean vertical current velocity (upwelling/downwelling) were associated with a peak in the probability of porpoise recording at 0.0006 m/s. There was a high degree of uncertainty about these relationships for large values of these variables (Figure 2.6-20). The probability of detecting porpoises appears to increase with background noise up to a threshold of approximately 113 dB, after which it continuously declines until loudest values of 130 dB.

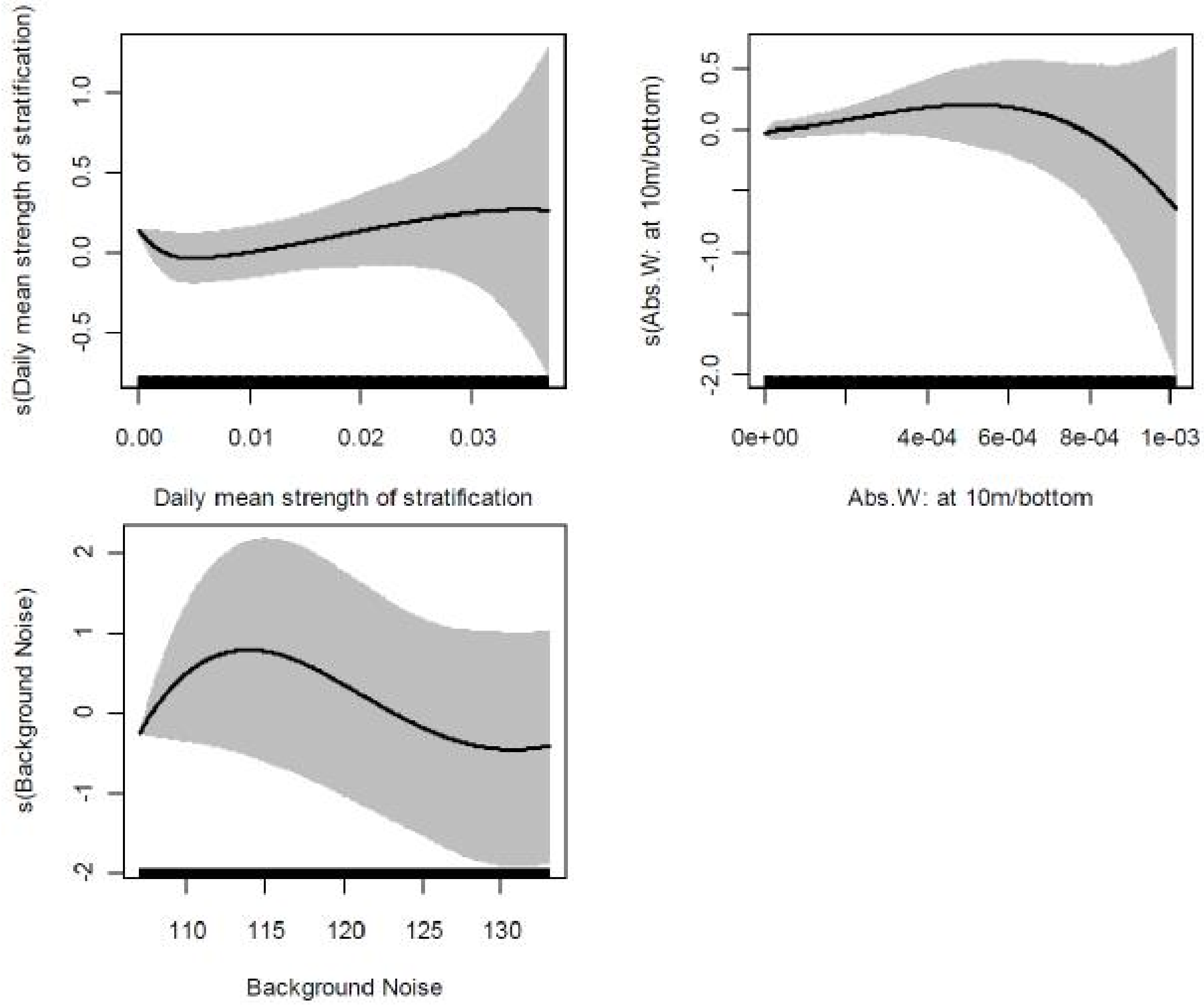

Figure 2.6-20 **Fitted relationships from the chosen model with (pointwise) 95% confidence envelopes based on GEE standard errors.**

2.6.3.3. Model Extensions

Interaction terms

The modelling approach will be extended to include biologically reasonable interaction terms. For instance, the way in which salinity discharge (Daily mean discharge of salinity (kg/s) between Rødbyhavn and Puttgarden) is related to the probability of recording one or more porpoise click trains might change with the Pycnocline strength (Daily mean strength of stratification [1/s]). These sorts of interaction terms should be considered to improve model performance and ensure the signal associated with these dynamic relationships is not attributed to other model predictors. Interaction terms will be incorporated in the model framework using tensor products of cubic *B*-splines (with two interior knots (for each margin), spaced equally) since these functions are appropriate for the marked differences in measurement scales for the input variables.

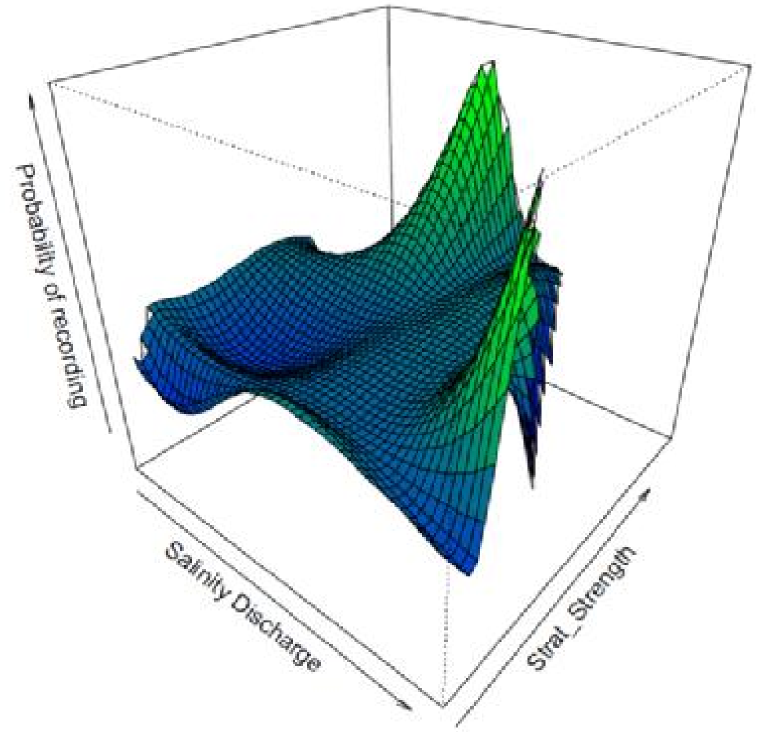

Figure 2.6-21 **Illustration of the use of a tensor product basis matrix to accommodate interaction terms in a model.**

Sensitivity of model results to the POD-ID covariate.

As POD-ID came out as the most important variable in the final model we investigated this issue in two steps:

1. Removing POD-ID from the final model in order to test for a possible masking effect by POD-ID;
2. Replacing POD-ID with a ‘gain’ factor, which is manufacturer information on the performance of the POD regarding its sensitivity at 130 kHz.

First, model results were investigated when POD-ID was removed from the model - to ensure that this variable was not confounding the effect of other model covariates.
This approach is based on the model comparisons without including background noise. However, the main finding can be transferred to the model where background noise was included.

Results showed that removing POD-ID from the model (and re-fitting the model with the remaining covariates) did not alter the statistical significance of 5 of the 6 model covariates, with relatively large p-values all above 5%. These variables were Month, Density (at surface), Pycnocline strength, U: e-w current velocity at the surface and Vorticity (at the bottom).

Removing POD-ID, however, altered the statistical significance of 1 of the 6 non-significant covariates which returned a *p*-value already close to the nominal (5%) level of significance (*p*=0.08). Removing POD-ID returned for the covariate Absolute value of W a p-value of 0.0135219.

The reduction in the size of the p-values is likely to be solely due to the power gained by excluding a variable with such a large number of coefficients; fitting POD-ID as a factor in the model incurred 91 coefficients. The change in significance for the absolute value of W is unlikely to be due to the correlation/overlap between POD-ID and W; there is a very weak relationship between the absolute value of W and POD-ID (Figure 2.6-22).

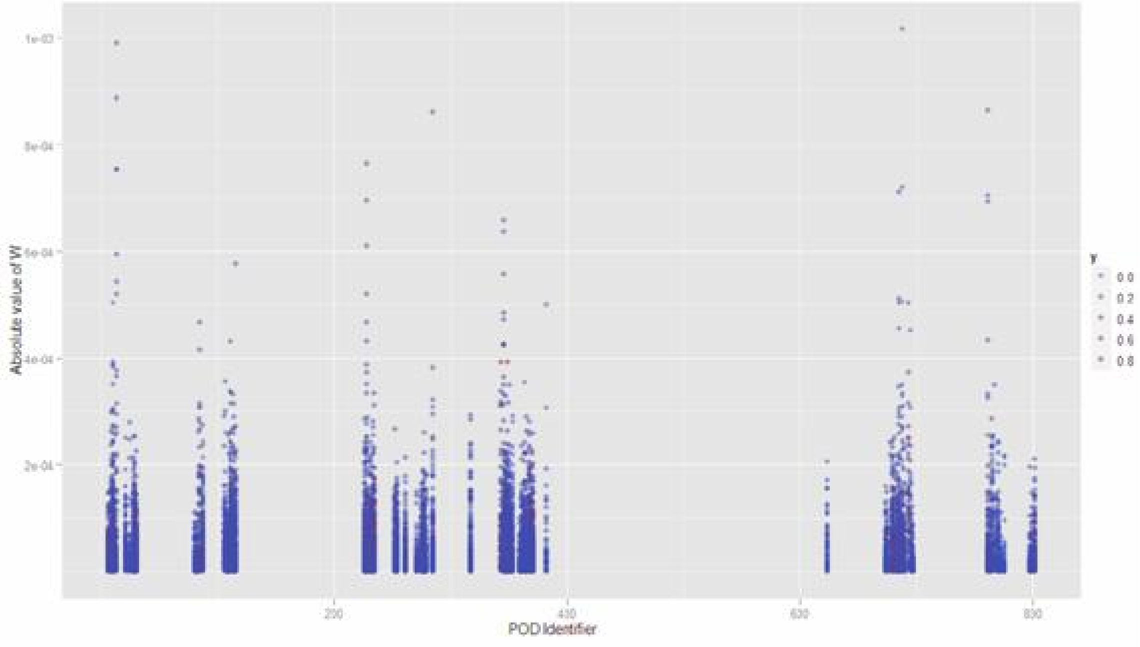

Figure 2.6-22 The relationship between the absolute value of W (at the bottom) and POD-ID. The response values are colour coded and have some transparency to help with the overplotting.

In a second step, we included the ‘gain’ information of each POD in place of the POD-ID variable to investigate if this could be used directly to explain POD-to-POD sensitivities. For this approach the gain covariate was substituted into the selected model and the marginal GEE-based p-values recalculated based on new results. On the whole, the conclusions were very similar, but with three exceptions: Substrate and Year are no longer significant when gain is substituted for POD-ID.; and

> absolute value of W covariate becomes significant at the 5% level when gain is substituted for POD-ID in the model.

As the power of the overall model decreased and most covariates had very similar effects on the number of porpoise detections, it seems very speculative that the gain covariate explains why porpoise recordings are more or less common in different substrates and/or years.

The significant effect of Absolute value of W could be explained by the POD covariate standing in for this covariate in some way; however further work would be needed to ascertain how this might occur. It is worth noting that this covariate also returns a small (and statistically significant) p-value when POD is excluded from the model, and statistical significance at the 5% level does not depend on including gain information in the model.

In conclusion, gain factor as a substitute for POD-ID does not seem to be a good covariate in terms of dealing with the effect of POD to POD variability. Therefore, we built our interpretation on the fact that the exclusion of POD-ID from the model does not change the explanatory power of most covariates as well as the actual relationship.

Sensitivity of conclusions to the threshold level applied for background noise.

The results shown thus far are based on removing days which have more than 4 million clicks recorded. When this threshold number of clicks is varied from 1 to 5 million clicks, however, the results are very consistent (Table 2.6-5).

There are two exceptions to this, namely:

- Latitude is marginally non-significant (p=0.059) for the smaller data set (threshold limit of 1 million clicks per day) but becomes statistically significant at the 5% level when threshold limits of at least 2 million clicks per day are applied.
- Daily mean strength of stratification is statistically significant as long as the threshold applied is less than 4 million clicks per day. Beyond this point the variable is no longer statistically significant at the 5% level.

Table 2.6-5 **Model covariates with associated (marginal testing) p-values based on applying different threshold limits for the number of clicks per day. These p-values are based on robust estimates of precision from the GEE-based model. Bold and framed with a black grid represent statistical significance at the 5% level.**

Threshold applied/ Covariate Selected	**1 Million**	**2 Million**	**3 Million**	**4 Million**	**5 Million**
POD	**0.0000000**	**0.0000000**	**0.0000000**	**0.0000000**	**0.0000000**
Background Noise	**0.0000560**	**0.0003112**	**0.0003536**	**0.0002880**	**0.0003335**
Longitude	**0.0000000**	**0.0000001**	**0.0000001**	**0.0000010**	**0.0000001**
Latitude	0.0597873	**0.0203409**	**0.0072224**	**0.0063940**	**0.0036241**
Water depth	**0.0000000**	**0.0000000**	**0.0000000**	**0.0000000**	**0.0000000**
Distance to shipping lane	**0.0000002**	**0.0000003**	**0.0000002**	**0.0000010**	**0.0000002**
Substrate	**0.0095794**	**0.0163698**	**0.0154501**	**0.0164090**	**0.0162223**
Month	0.5758599	0.5770249	0.5837355	0.5414470	0.5147285
Year	**0.0005256**	**0.0000935**	**0.0000742**	**0.0000560**	**0.0000411**
Temperature at surface	**0.0000001**	**0.0000000**	**0.0000000**	**0.0000000**	**0.0000000**
Current speed at bottom	**0.0191101**	**0.0105509**	**0.0008524**	**0.0003810**	**0.0021507**
U: e-w current velocity at surface	0.0692723	0.1954829	0.1731200	0.1783660	0.1416270
V: n-s current velocity at surface	**0.0134935**	**0.0027251**	**0.0002362**	**0.0003220**	**0.0002193**
Density at surface	0.2373674	0.3634322	0.3491861	0.2913510	0.2788761
Current gradient at surface	**0.0001230**	**0.0004037**	**0.0002299**	**0.0003540**	**0.0004202**
Vorticity at bottom	0.4510503	0.4655194	0.2830088	0.2460220	0.1918356
Salinity discharge	**0.0130935**	**0.0015316**	**0.0009506**	**0.0028510**	**0.0043167**
Pycnocline strength	**0.0233964**	**0.0297473**	**0.0319245**	0.0856690	0.0996935
Absolute value of W: vertical current velocity	0.3410157	0.2121735	0.1961969	0.2492950	0.1596713

2.6.4. Discussion

2.6.4.1. Seasonal and spatial trends in data

On the daily scale being investigated in this study, seasonal trends were apparently much weaker. However, the covariate ‘month’ as a proxy for seasonality still has a statistically significant effect on the detection of porpoises in the final model. In particular, in the eastern part and at least at some stations in the area around the planned link, a seasonal pattern with peaks in spring and late autumn/early winter can be seen. This pattern is very similar to the seasonal pattern of porpoise detections derived by PAM studies in the eastern part of the German Baltic (Verfuß et al., 2007; Dähne et al., 2009; Gallus et al., 2010). However, it is remarkable that the temporal oscillation in the POD data is much more inconsistent in the western area where many more porpoise signals were detected by the PODs. Also, this finding corresponds to the PAM studies of Verfuß et al. (2007), showing a much more pronounced seasonal trend for the stations east of Fehmarn. Generally, fewer detections at most of our POD stations during January and February is well in line with findings of the aerial surveys - indicating a seasonal emigration during times when the danger of ice coverage in such parts of the Baltic Sea exists.

Seasonal movements are often described for harbour porpoises in different areas over their distribution range (e. g. Neave and Wright, 1968; Thomsen et al., 2006; Weir et al., 2007; Gilles et al., 2009). Even for some parts of the Baltic Sea seasonal movements are known (Sound/Inner Danish Waters: Sveegard et al., 2011; Eastern German Baltic: Verfuß et al., 2007). It has been suggested that until the mid-20th century, harbour porpoises regularly migrated between the North and Baltic Seas (reviewed in Koschinski, 2002). Based largely on information from whale hunters, porpoises were thought to have followed movements of herring in spring, passing through Danish waters into the Baltic proper. It has also been proposed that porpoise migrate back out of the Baltic Sea in winter. Due to a small population size and no systematic monitoring programs, such migration patterns have not been be verified after hunting of porpoises stopped at the beginning of the 20th century (Schulze, 1999).

Despite these movements of large groups, or at least parts of populations, it is also known from tagged animals that seasonal movement patterns of individual harbour porpoises can be discrete and are not necessarily temporally coordinated migrations (Read and Westgate, 1995). Based on results from tagged animals in Danish Waters, Teilmann et al. (2008) and Sveegard et al. (2011) showed that porpoises use the Fehmarnbelt area year-round and they judge this area therefore as year-round important for harbour porpoises. From their studies we would not expect a very strong seasonal pattern in the Fehmarnbelt area. Following the assumption that the distribution of porpoises within the Fehmarnbelt is not strongly influenced by seasonal movements, it is more likely that the high temporal oscillation in the POD data is driven by patchy use within the area. Thus, our results showing some weak seasonal trends on a very broad scale and with stronger differences across subareas, and no consistent pattern at a finer scale (daily pattern and individual stations) are in line with previous results.

The high fluctuation of detected click activity at different times at different stations might indicate more pronounced individual movements of porpoises across the study area. Several recent studies have shown that individual migration plays an important role in the annual life cycle of the harbour porpoise in the Fehmarnbelt area (Teilmann et al., 2008; Sveegard et al., 2011).

2.6.4.2. Spatial and temporal resolution of data

With a total of 93% “porpoise positive days”, and the only calendar days with no detections at any station occurred when only one station was in operation, a continuous presence of the animals was demonstrated in the study area. This is in stark contrast to former studies by Verfuß et al. (2007), who used T-PODs to show a decline in porpoise presence to only 40% ppd/month in the first quarter of a year around Fehmarn. Our daily measurements exhibited a great deal of variability in porpoise recordings from one day to another, and since the dynamic parameters also showed periodic cycles of a few days we decided to choose pp10m/day as a daily value for further analysis.

2.6.4.3. Which variables are key factors for the presence of harbour porpoises?

Data quality

Before focussing on possible key drivers for the distribution of porpoises in the Fehmarnbelt area we have to critically consider the utility of C-PODs as tools to examine cetacean presence. It is important to note that C-PODs do not distinguish between one animal which is continuously present and several animals clicking when passing by. However, the parameter pp10m/day, we used here is broad and previous investigations have confirmed its usefulness in studies on occurrence of porpoises (see for example Verfuß et al., 2004; Kyhn et al., 2010).

A bias in the recorded data due to changes in sound propagation, caused by different levels of salinity, is unlikely as salinity differences are perhaps not great enough to cause any substantial propagation loss differences. Our model result shows salinity as a statistically significant covariate affecting porpoise detections. But instead of a gradient from fresh water to more saline water the effect follows a curve with a peak at 0 CPU. Thus, salinity seems rather to be a proxy for environmental preference than for differences in detection function of the C-POD.

With regard to comparable studies, the calibration experiments (Calibration Report appendix to be added once data analysis complete) show limitations of C-PODs in the form of individual variation in ultrasonic sound recording The exchange of POD-ID with the individual gain factor does not show a big change in the explanatory power of the considered covariates. Thus, it becomes clear that the variability is caused by two factors. Firstly, by the different sensitivities of the physical equipment to hear sound (resulting in different hearing thresholds) and secondly by unknown differences in the detection function of the algorithm of the C-POD software when exposed to slightly different raw data sets. For this reason, POD-specific differences are likely to be a complex mix of device specific and location specific covariate values.

However, different dataset gathered by C-PODs are still comparable by including POD-ID in the analysis as an explanatory variable as it stands in as a proxy for other variables (such as sensitivity but also location specific variables) not used explicitly in the model. Indeed, in order to reliably identify possible key drivers for porpoise recordings, we must investigate the signal with respect to the biologically meaningful variables *while* considering (and accounting for) the fact that PODs are different from each other. In order to provide reassurances that the signal from biologically irrelevant variables in the final model is not simply being replaced by POD-ID (since this might be somehow standing in for these), we removed POD-ID as a second step from the final model. In this way we demonstrated that all variables which were statistically significant when POD-ID was included remained statistically significant, and removing POD-ID did not result in other variables being substantially more important than before. In short, including POD-ID resulted in a model with substantially better predictive power without masking the information from the other meaningful covariates.

Another data quality issue relates to background noise, which clearly showed an effect on the number of detections in the way that with increasing background noise the number of detections decreased. Interestingly the appearance of background noise was not equally distributed across stations. At some stations like E5, exceptionally high noise levels resulting in data gaps per minute due to saturated memory. For this reason, we omitted days where the POD did not work continuously (and could therefore only record few porpoises) by setting a threshold at 4 Mio clicks/day. Despite this, we are aware that the potential to record porpoise clicks on days with slightly less than this threshold (4 Mio clicks/day) may be reduced. The analyses of the sensitivity to different threshold levels showed very consistent results, so that robust conclusions can be drawn by the model output based on the threshold of 4 Mio clicks/day without having a severe bias caused by background noise.

There are two exceptions to this, namely latitude and daily mean strength of stratification. As latitude only becomes statistically significant at the 5% level when threshold limits beyond 1 Mio clicks/day are applied, it can be assumed that this is solely due to increased statistical power as the data set size increases as higher thresholds are applied and the p-value is so close to 0.05 when a threshold of 1 million clicks is specified. Daily mean strength of stratification is statistically significant as long as the threshold applied is less than 4 Mio clicks/day. Beyond this point the variable is no longer statistically significant at the 5% level. Speculatively, this apparent loss of signal for this covariate in the larger datasets could be due to the extra noise exhibited in the datasets with very high numbers of clicks per day.

2.6.4.4. Model results

This study presents insights on the environmental preferences of harbour porpoises in the Fehmarnbelt area. Porpoise presence expressed by porpoise recordings in 10 minute blocks per day were modelled using GAMs and GEEs in order to select which covariates were driving their presence and use of environment in the area. So detection probability is considered as presence probability of harbour porpoise given certain values of the explanatory variables. Due to temporal autocorrelation of the dataset, the GEE approach is much more robust as it includes the temporal autocorrelation during the modelling process.

In our study, we used 28 static and periodic hydrographical covariates. The most important variables explaining porpoise distribution in the Fehmarnbelt area were related to the spatial location of the PODs (i.e. station, latitude and longitude) and since each of these variables uniquely represents the spatial location of the 27 stations, the model produces station-specific coefficients and model probabilities

To avoid station acting as a proxy for a mix of static variables like depth, latitude, longitude, etc. in the final model, we excluded it from selection in the model even though it gives the strongest signal from a statistical point of view. We also excluded measures of distance to the wind farm(s) and to the coast in order to avoid problems with model stability (due to collinearity).

The final model shows latitude and longitude are the most important variables (next to POD-ID). This clear effect of geo-coordinates on porpoise activity was expected; previous studies indicate that the distribution of harbour porpoises in the western Baltic Sea follows a gradient with the highest abundance in the western part (Scheidat et al., 2004; Siebert et al., 2006; Verfuß et al., 2007). From Figure 2.6-17 it is clear that there is both a West-East and Northwest-Southeast gradient in our study. Interestingly, the fitted relationship with Longitude in the model shows a clear increase in the probability of recording porpoises, again at the most eastern edge of the study area. This fits very well with observations from aerial surveys which show for both years, 2009 and 2010, an area with higher porpoise abundance south of Gedser around the 12th degree of longitude.

Geo-data based variables have previously been shown to be important for porpoise distribution (Johnston et al., 2005; Edren et al., 2010) and since we assume that the variables we are considering are intended to serve as proxies for prey distribution, it remains unclear how to bring these geo-coordinate variables into an ecological context. For several fish species, seasonal movements from coastal areas in summer to more offshore areas in winter are known (e.g. cod: Bergstad and Hoines, 1998; whiting: Zheng et al., 2001) and for this reason, a closer look at possible prey species in the Fehmarnbelt area and the correlation of fish distribution with these environmental factors is needed. The other two static variables, Water depth and Distance to shipping lane, have also shown statistically significant relationships in explaining the probability of recording porpoises. As shown in Figure 2.6-17 the probability of detecting porpoises is clearly reduced in water depth below 10 m, which means porpoises seem to avoid shallow areas close to the coast line like the Rødsand lagoon. The effect of the ‘Distance to main shipping lane’ covariate indicates that porpoises avoid the main shipping lanes up to distances of approximately 1 km, although other methods applied in this study do not also demonstrate this trend (see chapter 2.5). Akamatsu et al. (2007) showed that porpoises used their echolocation system nearly continuously so that we might assume that fewer porpoise detections are connected with lower porpoise abundance. However, harbour porpoises depend on their acoustic sense, thus these animals are highly sensitive to noise. Even though the Fehmarnbelt area has one of the highest ship traffic intensities in the world, to-date, little information on the effect of shipping traffic on harbour porpoises exists although individual porpoises have been reported to avoid ships at certain distances (Palka and Hammond, 2001). As a shipping lane can act as a proxy for noise emission, this finding gives us some indication for environment exclusion being caused by anthropogenic noise. This hypothesis is also supported by the (statistically significant) effect of background noise in our study. Even though noise from ships is by far the most pronounced sound source under water in the Baltic Sea (see noise chapter), the background at specific positions is not only related to the distance to shipping lanes but also dependent on water depth and especially substrate. Thus, the continuous decrease in porpoise detections with increasing noise levels indicates lesser presence of animals closer to the presence of high noise levels.

However, despite the effect being statistically significant in the final model its explanatory power remains low. As porpoise detections regularly occurred even close to the existing ferry route the effect of noise is clearly no exclusion effect but more a very slight replacement effect.

We included further hydrodynamic variables in the model assuming that they serve as indicators for prey distribution, which are in turn linked to a complex hydrodynamic environment. When looking at the relationship of porpoise detection probability with (surface) temperature it is striking that porpoise detection rate decreases abruptly below 4°C and is a maximum at 6°C and shows a constant decrease with increasing temperature (Figure 2.6-18). This suggests that water temperature may drive seasonal patterns in porpoise abundance within the Fehmarnbelt, most possibly due to the fact that porpoises will avoid ice cover and are therefore likely to retreat from areas with ice (indicated by water temperatures below 4°C). However, porpoises might also leave the area for other reasons during winter and the effect of temperature may be secondary. In the absence of information on other parameters like prey abundance this cannot be resolved. For several fish species a clear connection of seasonal movements with water temperature was shown (Carscadden et al., 1997; Ware and Tanasichuk, 1989; Sims et al., 2005). For example, Sims et al. (2005) have shown that flounder migration off south-west England appears to be driven to a large extent by short-term, climate-induced changes in the thermal resources of their overwintering habitat. Whether temperature governs the probability of recording porpoises directly (avoiding the risk of ice coverage in winter situations) or indirectly by governing the distribution of prey cannot be answered. Most probably it is a mix of both mechanisms.

One hypothesis is that porpoise distribution is related to inflow-outflow dynamics, which characterise the Fehmarnbelt ecosystem. Indeed, both porpoise detection rates and hydrographical dynamics often show very periodic patterns. Consequently, ‘Current speed’ at the bottom, ‘North-South current velocity’ at the surface, Current speed at the bottom and ‘Salinity discharge’ came out as statistically significant in the final model (Figure 2.6-18, Figure 2.6-19). The explanatory power of these variables, however, is limited; excluding these four dynamic variables from the full model resulted in a very small loss (1.4%) in explanatory power. This means that when measured on the daily scale these dynamic variables contribute relatively little information to the models. Considering that the position of hydrographical fronts can shift considerably in terms of hours, a daily resolution is, maybe, adding too little information. Accordingly, the fine-scale hydrodynamic features, which are closely connected to inflow/outflow dynamics do not act as key factors governing the general presence of harbour porpoises in the Fehmarnbelt area, at least not in an uniform way in the whole Fehmarnbelt.

Clearly, this notion does not mean that porpoise presence is generally not related to hydrographical variables. Several studies proved statistically significant effects of hydrodynamic features on porpoise relative abundance. For example, Skov and Thomsen, (2008) found a relationship between acoustic detection rates of porpoises and vertical current which might indicate the importance of local upwelling events (see also Tougaard and Wisz, 2010 for a critical discussion of the study). Embling et al. (2010) showed that maximum tidal current was the most important environmental variable explaining the relative abundance of harbour porpoises in all three years of their study on the west coast of Scotland. Johnston et al. (2005) found that satellite tagged porpoises targeted specific regions of enhanced relative vorticity, such as wakes created downstream at small islands and headland wakes, at foraging sites during the summer months in the Bay of Fundy. But they also stated that not all porpoises chose the same focal regions, indicating that some level of individual specialisation in foraging strategy and thus habitat use may exist. However, three out of the six tagged animals chose regions that exhibit predictable, tidally-induced, fine-scale oceanographic features clearly detectable with remote sensing techniques. Edren et al. (2010) modelled spatial patterns from harbour porpoise satellite telemetry data. Their results showed that average bottom salinity, distance to coast and bathymetry exhibited considerable importance in the full models, at least for one season. But the authors still called for stronger ecological hypotheses that illustrate a more direct causal link between environmental variables and porpoise occurrence.

Porpoises require a constant high energy input due to their small size, limited body fats and high energy expenditure (Kastelein et al. 1997; Koopmann 1998). Thus it can be assumed that their distribution follows the distribution of the most abundant prey species. A review by Nabe-Nielsen et al. (2010) on prey caught by porpoises in the Danish Belt Sea described herring, gobies, cod and whiting as the most important prey species. For none of these species, clear connections of occurrence with any hydrodynamic variables could be shown. In contrast, for herring, Corten (2002) proposed that migration routes are regulated by habits developed in the juvenile stage rather than by environmental factors.

Further research is required to assess whether individual harbour porpoises specialise within specific environments, as occurs in other marine mammals (Estes et al. 2003). These oceanographic features are likely to enhance foraging efficiency for porpoises by aggregating prey in a predictable manner in localised areas. Integration of C-POD data with data from satellite telemetry, line transect surveys, ferry boat counts and a well-founded selection of oceanographic features would be a useful way of developing objective criteria for the investigation of environment requirements by harbour porpoises in the Fehmarnbelt area and elsewhere.

With this baseline report we have shown that a modelling approach for identifying environmental key drivers based on a species needs is an effective and practical method for studying harbour porpoise in the Fehmarnbelt area. Even though we could only that some periodic hydrodynamic features representative for the inflow-outflow regime in the Belt are weakly correlated with porpoise acoustic detection probability (and hence porpoise presence). The identification of latitude, longitude, distance to shipping lanes and water temperature as robust predictors of harbour porpoise relative density shows that the approach is very promising in understanding the processes that influence distribution and habitat use of harbour porpoises. With the knowledge gained from this baseline report we will go into further analysis by building a spatial model of the Fehmarnbelt area which will provide a map of the probability of recording porpoises, based on the geo-coordinates and all other covariates which seem to govern the presence of animals in that area.

2.6.5. Summary

Between January 2009 and January 2011 C-POD data were collected at 27 positions within the Fehmarnbelt area. POD anchor system, service of POD stations and C-POD data collection all worked well, so that a reliable database could be achieved. An almost constant presence of harbour porpoises in the Fehmarnbelt area year-round at all positions was detected. A general west-east gradient was found, with more recordings in the northwest and fewest recordings in the southeast. This is in line with previous studies on the distribution of harbour porpoises in the western Baltic Sea. In particular, in the eastern part and at some stations in the area around the planned link, a seasonal pattern with peaks in spring and late autumn/early winter could be seen. This pattern is very similar to the seasonal pattern of porpoise detections derived by PAM studies in the eastern part of the German Baltic. At most stations in the western part of the study area, no such seasonal trend was recognisable in the POD data, at least at the daily scale being investigated in this study. Next to a high temporal oscillation in the POD data, a pronounced spatial variation with high variability between single stations could also be detected. The high fluctuation of detected click activity at different times at different stations might indicate more pronounced individual movements of porpoises across the study area. Several recent studies have shown that individual migration plays an important role in the annual life cycle of the harbour porpoise in the Fehmarnbelt area (Teilmann et al., 2008; Sveegard et al., 2011). From both the high temporal and high spatial variability it can be assumed that localised movements in response to small scaled ecological drivers may play an important role in the annual life cycle of the harbour porpoise in the study region.

The modelling of C-POD data suggested a weak to moderate effect of fine-scale hydrodynamic covariates, which are closely connected to inflow/outflow dynamics. Compared to static covariates describing the geo-location of the specific POD-station, the effects of hydrodynamic covariates were rather small which, in turn, suggests that they do not act as key factors governing the detection possibility of harbour porpoises in the Fehmarnbelt area. However, the strongest hydrographic variable was water temperature, which is not or only weakly affected by the flow regime in the Belt area. Porpoise acoustic activity decreases abruptly when temperature drops below 4°C. This can be explained by the fact that porpoises will avoid ice cover and are therefore likely to retreat from areas before ice coverage starts.

Further static variables, which were important in the final model, were: latitude, longitude, distance to main shipping lane, substrate, water depth and background noise. The importance of these variables, all describing station specific features, indicates that the distribution of harbour porpoises in the Fehmarnbelt is influenced, either primarily or secondarily, by location specific environmental conditions.

As it can be assumed that porpoise distribution at least partly follows the distribution of the most available prey species, a more detailed analysis of the distribution of prey and its relationship to the environment would be useful.

2.7. Pressure analysis

2.7.1. Introduction and scope

Describing a baseline with regard to the abundance of the target species and the pressures acting on the species prior to the planned activity is a prerequisite for any EIA. The baseline pressure analysis attempts to assess the impacts of the planned project in the context of existing pressures.

The aim of this chapter is to outline major activities that could lead to impacts and to discuss some of the documented effects of those activities. This should lead us to assess whether the existing pressure from human activities on porpoises in the Fehmarnbelt are low, medium or even high.

2.7.2. By-catch

By-catch – the incidental catch and subsequent death of porpoises during fishing operations - has been postulated to be the main threat to the harbour porpoise in the ASCOBANS area, which includes the Baltic (Berggren et al., 2002; Koschinski and Pfander, 2009). Harbour porpoise are taken as by-catch in a variety of fisheries (review by Berggren et al., 2002). Static gears are causing concern in the Baltic and surrounding seas. For example, Berggren (1994) estimated that gillnet fisheries were responsible for more than 80% of harbour porpoise by-catch in Swedish waters. Bottom set nets for cod and drift nets for salmon each also account for half of this percentage (Berggren et al., 2002). Therefore, we will focus our review on these fisheries and the resulting by-catch estimates.

2.7.2.1. Distribution of fisheries relevant to by-catch

In Swedish waters, gillnets are set for spiny dogfish in the Skagerrak (Berggren, 1994), bottom set gillnets are set for cod and pollock in the Kattegat (Berggren, 1994; Berggren et al., 2002) and driftnets are used for salmon (Berggren, 1994; Berggren et al., 2002).

Denmark has the largest gillnet fleet in the EU (although this figure does include the North Sea fleet) with gillnets being predominantly set for cod, turbot and plaice between five and 60 m in depth (Benke, 1994; Kock andBenke, 1996). There are also lumpfish, hake and common dab set net fisheries in the Kattegat and Belt Seas (Kinze, 1994; Vinther, 1999). Small boats in inner Danish waters also operate trammel set nets, which can result in multi-species landings. Pound nets are also used in Denmark, however, porpoise may be released alive from these nets (Koschinski, 2002). Pound nets are indeed the main source of live animals tagged by NERI.

Danish and Swedish fishermen also fish in German waters of the Baltic Seas and, together with German vessels, land predominantly herring, cod and sprat (Pedersen et al., 2009). Cod is again targeted using gillnets (although also with otter trawls), while the majority of herring and all sprat are caught using trawling gears.

In the Baltic Sea proper (defined as east of the Darss and Limhamn Ridge), in addition to the set net fisheries for cod, salmon is an important fishery, caught using surface drift nets (Vinther, 1999; Kuklik andSkóra, 2003). The European Commission imposed a ban on drift nets over 2.5 km long in 1992, extending this to a total ban in 2002. However, an exemption from the EU Regulations was given to the Baltic Sea, and in 2002, there were still approximately 300 vessels setting drift nets for salmon in the Baltic, with boats allowed to carry up to 21 km of nets (IFAW, 2002; Skóra, 1991 in Koschinski, 2002). During a Polish study by Kuklik and Skóra, (2003), 40% of dead porpoise (18 animals) caught in nets were found in salmon drift nets, while a further 33.3% (15 animals) died in cod nets.

2.7.2.2. By-catch estimates

The International Whaling Commission / ASCOBANS working group on harbour porpoise advised a maximum annual anthropogenic removal (including by-catch) of 1.7% of the population per year if the population is to be non-declining.

The majority of data concerning porpoise by-catch are likely to be gained from collection programmes (e.g. from strandings), reporting schemes (e.g. from fishermen), interview surveys or other anecdotal information (Berggren et al., 2002). Using independent observers to collect by-catch information is therefore very important as it provides consistent unbiased data.

Siebert et al*.* (2006) estimated mean abundances of harbour porpoises in the German Baltic Sea, divided into two blocks ,B (including the waters of Fehmarn) and C (the Baltic Sea proper), of 980 and 601 respectively in 1995 and of 1830 and 0 respectively in 1996. Between 1990 and 2001, 229 harbour porpoises were found stranded along the German Baltic Sea coast and 105 animals were incidentally taken in fisheries, totalling 334 animals and averaging 27.8 porpoises annually. From 2005 to 2007, annual by-catch estimates were 2.7% (51 animals) in 2005, 4.3% (82 animals) in 2006 and 7.8% (150 animals) in 2007, calculated from the median abundance estimates from 10 surveys in the region between 2003 and 2006. However, given the uncertainties governing the separation and movements of populations / management units of porpoise in the Baltic, by-catch estimates in other areas are also of relevance to the Fehmarnbelt region. In 1996 and 1997, surveys were undertaken in the Swedish Kattegat, which calculated by-catch levels of 1.2% and 2.4% of the porpoise population in the set net fishery for cod and pollock (ASCOBANS, 2010). Given that the set net fishery for cod and pollock in Sweden only accounts for approximately half of the by-catch caused by gillnets (Berggren et al*.*, 2002), this number could potentially be doubled to account for the salmon drift net fishery. Polish estimates of by-catch (Kuklik andSkóra, 2003) were calculated using dead harbour porpoise, both caught in nets and stranded ashore. In the period from 1990 to 1999, there were 45 verified reports of porpoise by-catch and seven reports of stranded individuals. However, given there are no reliable abundance estimates from the Baltic proper, it was impossible to calculate the percentage of by-catch of the population. No information on by-catch levels have been found from Norway or Finland, although it is likely that by-catch occurs in the Norwegian Skagerrak in both the cod bottom set gillnet fishery and in the mackerel driftnet fishery. In the Finnish Baltic Sea, sporadic by-catches have been reported by Mattsson (1995).

Other studies undertaken in the region (for example, see Benke, 1994; Rubsch and Kock, 2004; Scheidat et al*.*, 2008) yielded different estimates of both abundance and by-catch compared to the recent 2009 paper for ASCOBANS and the other studies mentioned above.

2.7.2.3. Conclusions on by-catch

All studies have indicated that by-catch estimates have exceeded the 1.7% criteria proposed by the International Whaling Commission and ASCOBANS in 2000. This clearly shows that the level of by-catch experienced by the harbour porpoise in the Baltic and surrounding seas is above the criteria required to maintain the population, and thus, is a threat to porpoises in the Baltic and adjacent waters.

2.7.3. Contaminants

Marine pollutants are probably associated with a number of physiological effects in marine mammals. However, there is limited scientific evidence for the establishment of clear cause-effect relationships. Causal links are difficult to establish due to likely cumulative impacts, and combinatory effects with other factors. There is also limited knowledge about pathology and the occurrence of disease in marine mammals (Reijnders and Aguilar, 2002), although, historically, reduced fertility in seals throughout the Baltic has been linked with high levels of PCB contamination (Helle et al., 1976).

Pollutants accumulate up the food chain which explains why levels in toothed whales are higher than those in baleen whales as they feed at higher trophic levels. Variations in levels of contamination between animals within the same population can be related to differences in diet, since prey species contain different levels of contaminants due to different levels of uptake. Lipophilic pollutants accumulate in fatty tissue (about 70 to 95% ends up in the blubber). Mercury, cadmium, zinc and other heavy metals accumulate mostly in liver and kidney, while lead accumulates mostly in bone tissue (Reijnders and Aguilar, 2002). Some metals, such as copper and zinc, are essential to the animals' health and are homeostatically controlled.

Organohalogen compounds are highly lipophilic and are transferred from the mother into her foetus and, especially via milk, from mother to offspring, leading to decreased levels in pregnant or lactating females (Reijnders and Aguilar, 2002). This can involve the transfer of as much as 80-90% of the mother's body burden to her offspring.

Pollutants can affect reproduction and cause direct or indirect mortality. Jepson et al. (2005) reported that harbour porpoises with elevated PCB levels were more likely to die of infectious disease than due to physical trauma. In another study, it was shown that this effect becomes apparent above an established toxicological threshold of 17 mg/kg total PCB in blubber (for each additional 1 mg/kg increase in concentration, the average increase in risk of infectious disease mortality was 2%: Hall et al., 2006). This is consistent with, but does not prove, PCB-mediated immunosuppression. In turn, diseases can affect the resilience to pollutants. While it is difficult to relate pollutants to diseases in organisms, in-vitro studies showed a correlation between reduced immune responses and high levels of PCBs and DDT (Reijnders and Aguilar, 2002). Some pollutants (such as DDT and PCBs) can interfere with the synthesis, secretion, transport, binding, action, or elimination of endogenous natural hormones (Murphy, 2009).

There are very few direct studies of the effects of contaminants on harbour porpoises within the Baltic region and even fewer concerning the Fehmarnbelt area. The following describes the contaminants found within the Baltic region. Whether, and to what degree porpoises within the Fehmarnbelt area are affected in the manners described is uncertain.

The Baltic Sea has been exposed to extensive use of chemicals since the beginning of industrialization and has a small water exchange rate (about 30 years for a full exchange; HELCOM, 2010a). For example, Berggrena et al. (1999) observed higher levels of contaminants in blubber tissue samples of male harbour porpoises in the Swedish Baltic Sea compared with the Kattegat-Skagerrak Seas and the west coast of Norway. Siebert et al. (1999) found higher levels of mercury in harbour porpoises of the Baltic Sea compared to Greenland waters.

Hazardous substances emitted or discharged by households, traffic, industries and agriculture are transported to the sea via water courses and the air (HELCOM, 2010a). The contaminant levels recorded in the Baltic Sea could have management implications for the status of the harbour porpoise in this area (Berggrena et al., 1999).

About 300,000 synthetic organic chemicals and their metabolites are known, but only a very small number are monitored on a regular basis (Reijnders and Aguilar, 2002). Groups considered as "priority compounds" that should be monitored closely due to the level of production and release into the environment, bioaccumulation potential and toxicity include organochlorine pesticides and PCBs, brominated flame retardants, polychlorinated dibenzo-*p*-dioxins and dibenzofurans, and heavy metals (Reijnders and Aguilar, 2002).

Approximately one quarter of the area of the Baltic Sea could be affected by chemical weapons from WW II dumped after the war (Society for the Conservation of Marine Mammals, 2007a). Due to erosion of munitions containers, poisonous substances (such as Tabun, Phosgene, Cyclon B and Adamite) are leaking into the Baltic Sea and have entered the food chain. The position of dumping grounds are often poorly known, and the munitions may be spreading due to fishermen pulling them up in fishing nets and throwing them back overboard in different areas (Society for the Conservation of Marine Mammals, 2007a).

Additional pollutants are oil (polycyclic aromatic compounds), litter, sewage-related pathogens, fertilizer, biotoxins and radionuclides (Reijnders and Aguilar, 2002). Data on these are sparse; however, these pollutants are not considered to be a significant problem in the Fehmarnbelt area (HELCOM, 2007; European Environment Agency, 2010). Polycyclic aromatic hydrocarbons, which arise from both petrogenic and pyrogenic sources, are unlikely to pose a significant threat to harbour porpoises as they are rapidly metabolised and eliminated in fish.

Most of the Baltic Sea is classified as “disturbed by hazardous substances” with the Kiel and Mecklenburg Bight (adjacent to the Fehmarnbelt area) having a comparatively poor status (HELCOM, 2010a). Pollutants that have been found at high concentrations in biota (mainly fish, mussels, birds) compared to their target levels in the area are:

- Caesium-137
- Hexachlorocyclohexane (HCHs)
- Lead
- PAH-metabolites
- PCBs

A recent study of trace elements in the livers of 22 harbour porpoises stranded in the River Elbe, the eastern North Sea and the Western Baltic Sea yielded median values as follows – units mg/kg wet weight: Ag, 1.3; As 0.32; Cd 0.05; Cu 9.2; Fe 274; Pb 0.003; Se 2.9; Zn 38 (Fahrenholz et al., 2009). Hg was not determined. One animal came from the Fehmarnbelt area. Concentrations of As were higher in porpoises from the North Sea, and of Sn in the Baltic Sea. No other significant regional differences were found.

Cadmium levels in the Fehmarnbelt area are relatively high compared to those in the central Baltic Sea, which might be related to a 1960s dumping area, highly contaminated with trace metals, in the Bay of Lübeck (Pohl and Hennings, 2009). Cadmium is known to affect the renal function in marine mammals (Fujise et al., 1988). Increasing shipping contributes significantly to air and sea pollution mostly with NOx, SOx and CO_2 in the Baltic Sea contributing to both eutrophication and acidification (Anonymous, 2007). Although the use of TBT in ships’ antifouling paints has been banned on large vessels since 2003 following a ban instituted by the International Maritime Organisation and levels are decreasing, those in the Baltic Sea are still high enough to pose a risk, especially to organisms at lower trophic levels (HELCOM, 2009c).

FEMA has carried out a sediment chemistry study along the proposed line of the fixed link (FEMA, 2013). In November 2009, sediment core samples to a depth of 3 metres were taken at 12 sites. Overall FEMA found that heavy metals and persistent organic pollutants within surface sediments were low compared to sediment quality guidelines. These included HCB, DDTs, PCBs, PAHs and TBTs.

2.7.3.1. Disposal of dredged material

Essential maintenance dredging and some capital dredging takes place around the Baltic Sea. In 2007 Denmark and Germany disposed of nearly two million tonnes of material in the Baltic Sea (IMO, 2010). Of this, Germany disposes of 300,000 tonnes of dredged material in the Baltic Sea. The main disposal sites being the Flensborg Fjord and the Mecklenburg Bight (IMO, 2010). Denmark disposes of over 1.6 million tonnes in the Baltic, however the disposal sites were not known at the time of writing.

There is no evidence to suggest that disposal of dredged material has a direct impact on harbour porpoises. There may be some indirect impacts, such as the releasing of anti-foulants such as TBT from dredged sediments (HELCOM, 2009c). However, as the impacts of TBT on harbour porpoises are unclear, conclusions cannot be made. There may also be indirect impacts from smothering of benthic communities and changes to prey availability but this can only be speculated upon.

2.7.3.2. Conclusions on contaminants

Although many contaminant levels have been decreasing in recent years, the present levels of some contaminants in the Baltic Sea is viewed as a pressure and could have management implications for the harbour porpoise in this area (Berggrena et al., 1999).

2.7.4. Eutrophication

Eutrophication is known to be a major issue in the Baltic and surrounding seas (reviews in Håkanson and Bryhn, 2008; HELCOM, 2009a, 2009b). The Baltic is particularly sensitive to eutrophication due to its nearly enclosed system, vertical stratification of the waters and limited and slow seawater exchange. These physical properties combined with a heavily populated catchment area of 1,700,000 km² and associated human activities, results in a large input of nutrients, predominantly nitrogen and phosphorus entering the marine environment, with little renewal of oxygen (HELCOM, 2009a; HELCOM, 2009b). HELCOM (2009a, 2009b) also assessed the eutrophication status of the Baltic Sea. The Fehmarn region (consisting of the Kiel and Mecklenburg Bight) had a “poor” to “bad” status, meaning they were affected by eutrophication. Oxygen depletion is a serious issue in the region, with incidents of depletion (and even anoxia) in bottom waters observed almost annually since 1981, with overall oxygen concentrations declining since the 1970’s (Lundberg, 2005). Work is being undertaken to combat the high levels of nutrients entering the system, aided by environmental legislation (Conley et al., 2000; Andersen et al., 2004).

Eutrophication can cause increased production of fish biomass, but also changes in fish community structure and function (HELCOM, 2006). The Belt Sea region (including Fehmarnbelt) is an important fishery for flatfish, eel, herring and cod. Cod is the most vulnerable species to eutrophication, with spawning success dependant on specific environmental conditions, although other species do require specific conditions. Cod eggs need a salinity of 11 psu and an oxygen concentration of > 2 ml l^{-1} for successful hatching (Hansson and Rudstam, 1990; Nissling and Westin, 1991). Therefore, poor oxygen concentrations in the Belt Sea may have a negative impact on fish spawning, although cod, plaice, and flounder in this area spawn from February to April, when oxygen conditions are normally improved (HELCOM, 1990).

However, altered patterns in the phytoplankton spring bloom caused by eutrophication has had a negative impact on the food sources for fish, especially for survival of the young spring-spawning species such as cod (review in Lundberg, 2005). Therefore, cod and other fish populations may still be affected due to eutrophication processes.

As described in Chapter 2.7.10, porpoise in the Baltic and surrounding seas have predominantly been found to feed on herring, cod, sprat and gobies. Given the dependence on these fish species (albeit with the ability to switch prey), combined with the vulnerability of Baltic fish communities (especially cod) to eutrophication, impacts on porpoises are possible but can't be assessed with any certainty at present. In addition, what site specific impacts this will have in the Fehmarn region remains to be seen.

2.7.4.1. Conclusions

Eutrophication is definitely a pressure on ecosystem health in the Fehmarn region and so is potentially also a pressure on the fish community and, therefore, on harbour porpoise.

2.7.5. Shipping

The current pressures of shipping on porpoises can be divided into three main categories:

- Physical presence of the vessels – disturbance and risk of collisions
- Noise disturbance from propellers, water hitting the hull etc. (see chapter 2.7.7)
- Pollution and contamination, either from day to day use or from accidental spillage (see chapter 2.7.3)

Noise can be viewed as the main impact arising from shipping activities. As this is dealt with in detail in chapter 2.7.7, we focus here on activity of ships and provide some information on their potential to cause disturbance to harbour porpoises.

For this chapter, we used the analysis of AIS (Automatic Identification System) data as undertaken by Rambøll A/S (Rambøll 2011). They analysed AIS data for the years 2007-2009. In addition, we present results from an initial Cefas survey of the 2010 AIS data.

Both datasets indicate that in terms of shipping, the Fehmarnbelt and surrounding Baltic Sea region can be regarded as a busy area (see Figure 2.7-1, Figure 2.7-2) with the high volume of shipping traffic and many narrow straits creating a significant challenge for navigation. Since 2005 the ship traffic has been monitored through a variety of means including:

- AIS (Automatic Identification System)
- Radar data
- Pilot registrations
- IHS-Fairplay ship register
- Accident registrations.

Among these the HELCOM Automatic Identification System (AIS) is mandatory for ships above 300 BRT and represents the primary method of ship tracking within the region. From the HELCOLM data it is know that 3,500-5,000 ships travel through the Baltic region each month (HELCOM, 2010b). Figure 2.7-1 shows the main shipping lanes as identified by Rambøll (2011). The main navigational routes of the Fehmarn Belt area include:

- H route
- T-DW route (DW stands for Deep Water)
- Kiel-Ostsee route
- T route
- Rødby-Puttgarden route
- Lübeck-Gedser route

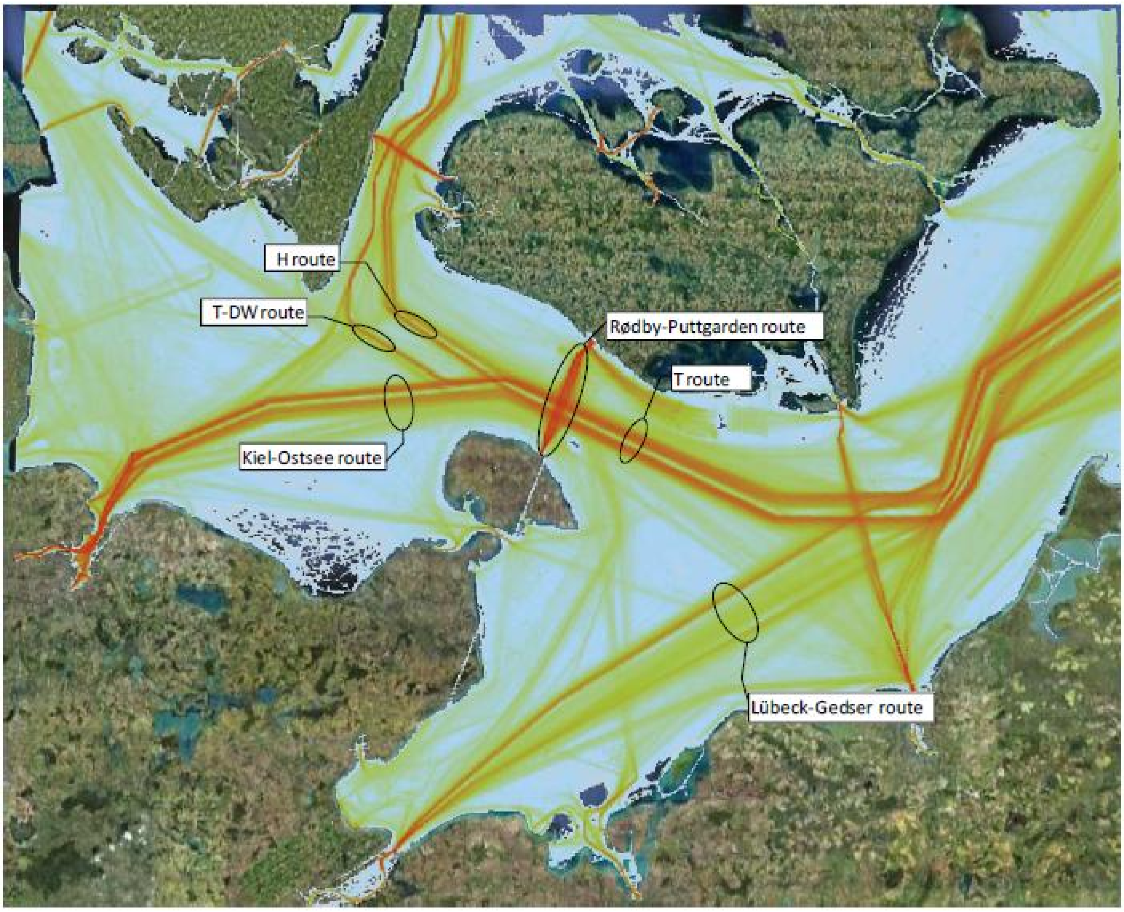

Figure 2.7-1 Primary shipping lanes of the Fehmarnbelt area based on 2009 AIS registrations; (figure from Rambøll, 2011).

Among the key shipping lanes the T-route is identified as the main transit passage, with over 20,000 westbound ship movements and 17,300 eastbound ship movements recorded each year during 2009 (Rambøll, 2011). Shipping activity has varied little between 2007-present although evidence suggests that overall shipping pressures have experienced a moderate reduction over this period, most likely in response to the economic downturn.

Besides activity on the T-route, it can be seen that the greatest intensities of shipping activity occur on the Rødby-Puttgarden route (between Fehmarn and Lolland) and to the east of Fehmarn between Rostock and Lolland. These routes are expected to intersect the movement of porpoises within the region.

A detailed look at the results by Rambøll (2011) indicates that overall, very little change in the volume of shipping traffic transiting primary Fehmarnbelt navigational routes occurred between

2007-2009 (see Figure 2.7-2). This is borne out by consistent ship movement records for H, T-DW, Rødby-Puttgarden and Lübeck-Gedser across each year.

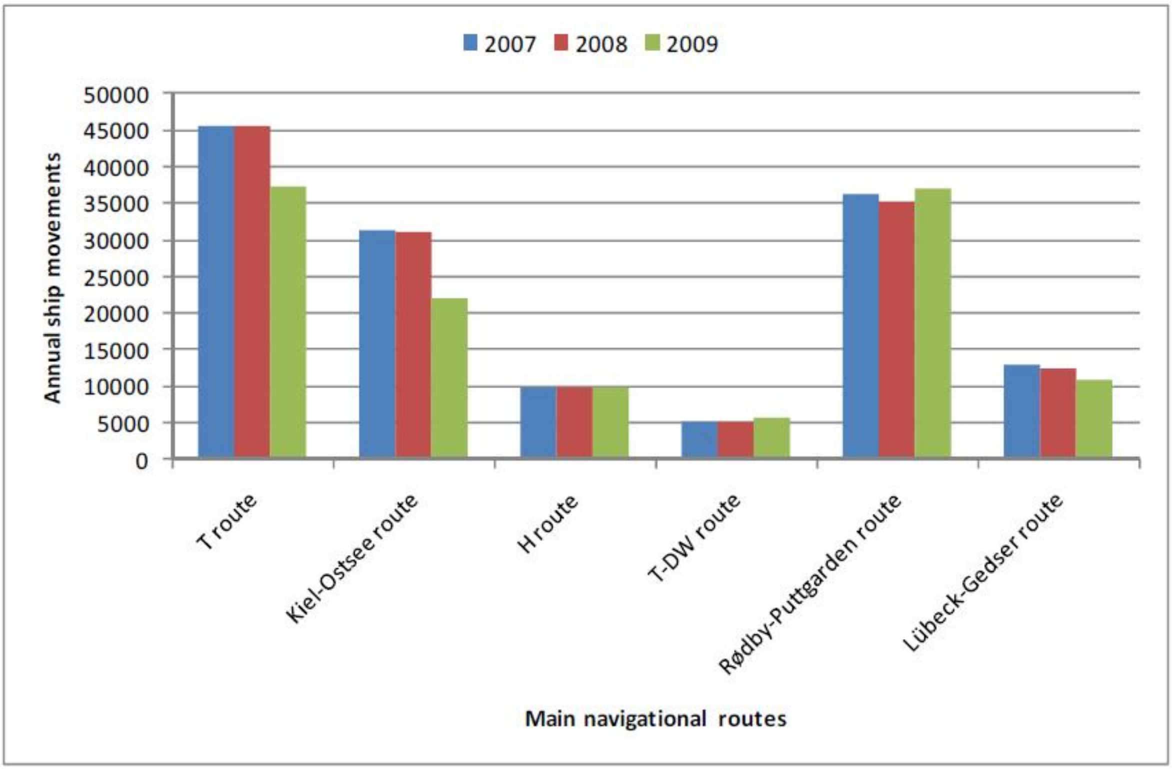

Figure 2.7-2. Development in number of ship movements on main navigational routes figure from Rambøll, 2011).

However, while levels of shipping traffic on the T and Kiel-Ostsee routes were highly comparable between 2007 and 2008, a significant reduction in shipping pressure on each of these routes (reduction >5000 ship movements) was observed in 2009. It is speculated that such fluctuation may have occurred as a function of the recent economic downturn (Rambøll, 2011).

Discrete shipping traffic in Fehmarnbelt is dominated by general cargos and tanker vessels, except for the Rødby-Puttgarden and Lübeck-Gedser routes where passenger ships are by far the most common transiting vessel type (see Figure 2.7-3).

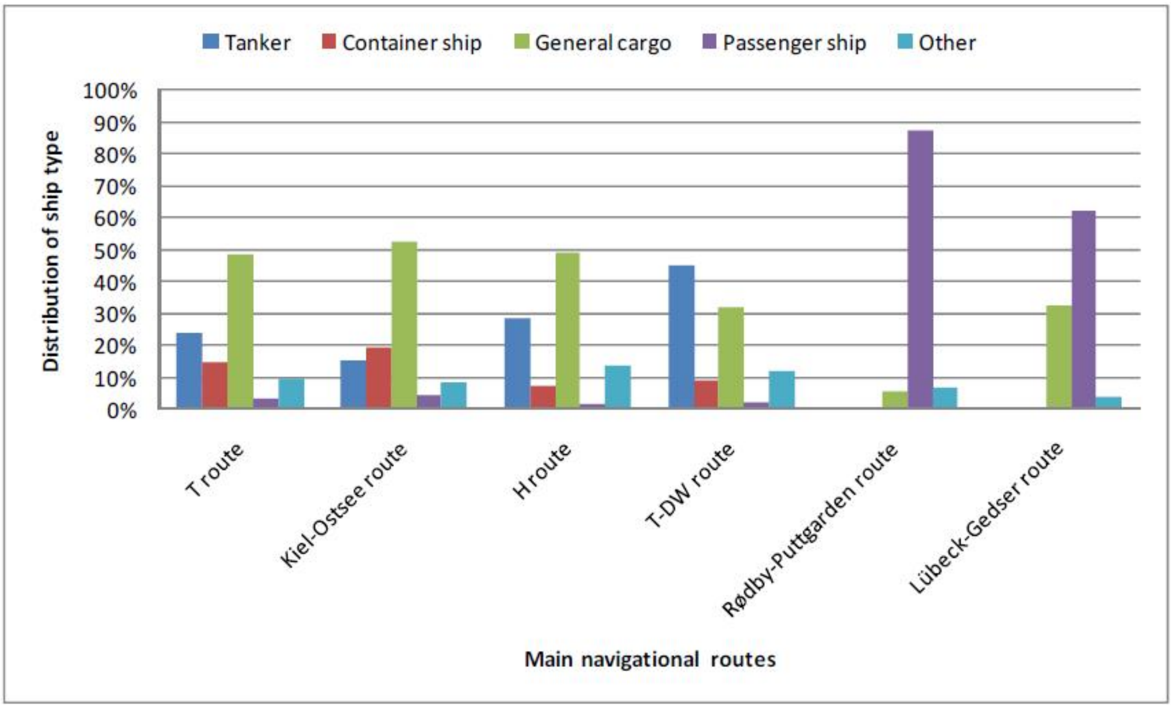

Figure 2.7-3. **Distribution of ship movements on main ship types for each main navigational routes in 2009 (figure from Rambøll 2011).**

Approximately 87% of ship movements at the Rødby-Puttgarden route consist of passenger ships, with four high speed Scandlines ferries (greater than 30 knots) accounting for about 86% of the passenger traffic on the route. Cargo traffic is mainly 'dangerous goods' and is dominated by a single operator (Holger Danske) which accounts for ~91% of traffic on the route.

For 2009, the monthly levels of ship movements through the Fehmarnbelt area are broadly comparable and equate to approximately 2 ship movements per hour in each direction over the course of a typical year.

The Speed Over Ground (SOG) for each ship type is known for nearly all registrations (~96%) on the T route as shown in Table 2.7-1.

Table 2.7-1 **Distribution of ship movements on ship speed for each ship type on the T route (2009 data taken from Rambøll 2011).**

Ship Type	0-5knots	5-10 knots	10-12.5 knots	12.5-15 knots	15-20 knots	20+ knots
Tanker	0.2%	7.3%	25.6%	54.7%	12.2%	0.0%
Cargo	0.1%	29.1%	36.0%	21.8%	12.2%	0.7%
Container	0.0%	0.5%	3.8%	22.2%	70.9%	2.7%
Passenger	0.0%	2.7%	3.4%	8.8%	44.0%	41.2%
Other	22.2%	47.1%	13.7%	6.9%	5.9%	4.2%

From this, it is apparent that ~85% of all passenger ships have speeds greater than 15 knots and ~71% of the container ships have a speed of between 15-20 knots.

OSPAR (2009a) provides an overview of the effects of shipping on marine mammals outlining the potential for behavioural response, masking of biologically relevant signals and injury (at relatively high received sound levels that can be reached only in the immediate vicinity of any vessel).

2.7.5.1. Conclusions on the effect of shipping

Data between 2007 and 2010 indicates that there is a very high intensity of shipping within the Fehmarnbelt area. Some reduction of activity was recorded in 2009, perhaps due to the economic downturn. Noise impacts due to the high shipping activity are possible and are covered in the chapter on ambient noise impacts. The published literature does not indicate that harbour porpoise populations are under significant pressure from ship-strikes. This is probably due to a combination of factors including, the harbour porpoises' agility and ability to detect and avoid passing ships, the set routes of the ship traffic and the subsequent adaptation of the porpoises to these routes. Impacts of shipping on harbour porpoise number and movements in the Fehmarnbelt area need further investigations.

2.7.6. Tourism and recreation

The current pressures on the porpoise populations can be loosely divided into three main categories:

- Disturbance due to physical presence of humans and activities
- Pollution and contamination from industry-related infrastructure
- Noise from water-based activities

The area in and around the Fehmarnbelt region is a popular coastal tourist destination with about 22 million guest nights in Germany and Denmark per year (www.visitfehmarnbelt.com, 2010). Activities that are likely to come into direct contact with harbour porpoises include water sports, bathing, recreational fishing and boating activities such as sailing, powerboats and jet skis.

Water sports such as windsurfing, and more recently kite surfing, are particularly popular in the area (Dynesen and Zilling, 2006). These activities are typically limited to within 500 m of the shore and they are also seasonal, being mostly restricted to the summer months. There is no literature on potential effects of these activities on harbour porpoises. It is worth noting however, that wind and kite surfers can reach quite high speeds, typically in shallow waters and that movement in and above the water is typically highly erratic. It is difficult to assess the potential for collisions, although greater impacts may be seen during competitions where jet skis and small speed boats are used as safety boats.

Smaller recreational vessels such as speedboats, jet skis and sailing yachts tend to be much faster and less predictable, therefore, may cause a greater impact than larger, slower moving ships and ferries. Many sailing yachts, particularly those used for racing are capable of speeds greater than 30 knots. In addition, the lack of motor noise and their erratic movements, particularly when tacking, make the yachts more difficult to predict, increasing the risk of collisions and disturbance to harbour porpoises. Figure 2.7-4 shows the marinas and the number of moorings around Fehmarnbelt. Based on the location and size of the marinas it is estimated that the greatest intensity of recreational boat activity takes place east of Fehmarn, within the Mecklenburg Bight and around Rostock. (Recreational boats are not required to carry AIS equipment, therefore, exact data is not available (Dziewicki, 2007)). Numbers of recreational boats can only be estimated with possibly 2-4,000 within the Fehmarnbelt region. It is expected that recreational boat activity is seasonal and at its greatest intensity during the holiday periods. While there may be some short-term disturbance from recreational boating, there is no evidence to suggest that boat strikes occur in the Baltic region.

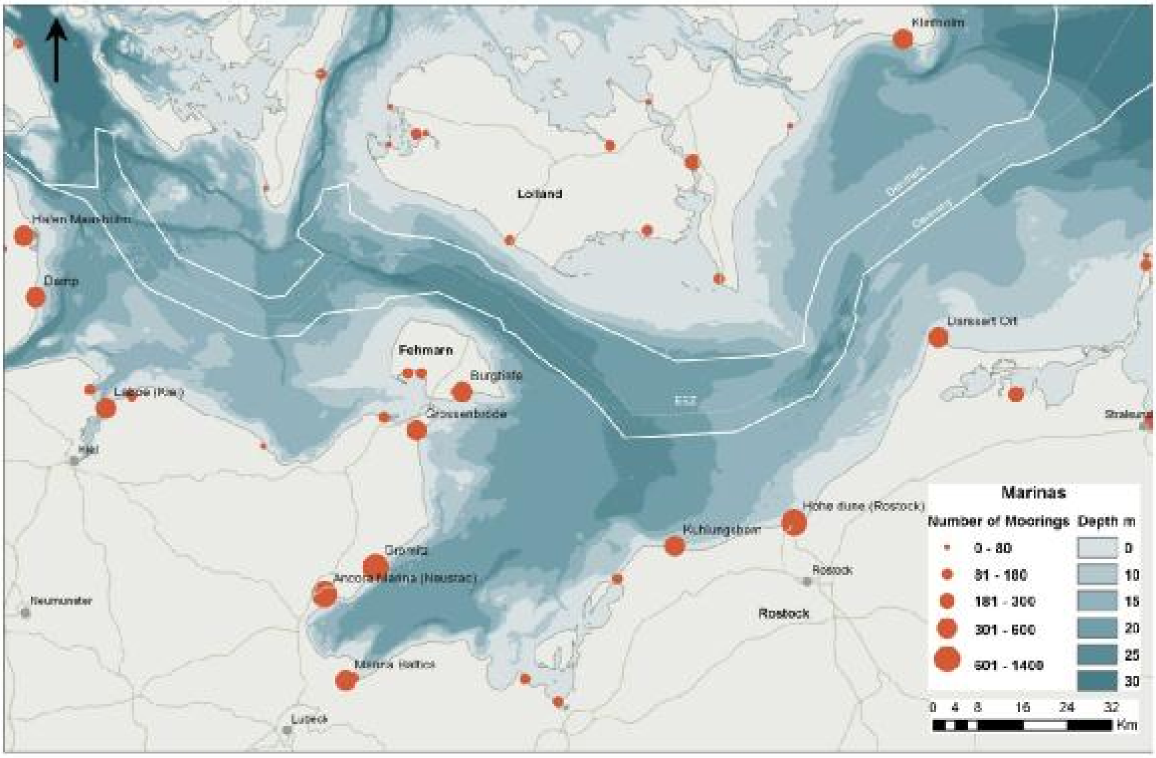

Figure 2.7-4 Marinas and mooring numbers around Fehmarn.

Jet skis and small speed boats may pose the greatest risk. In both cases, the vessels are capable of high speeds greater than 30 knots, in shallow waters and in erratic directions. This combination of factors may result in an increased risk of collision with porpoises than those posed by larger ships. The high speed and erratic movements may make it difficult for the porpoises to predict the course of the approaching vessel. In addition, shallow waters also limit the escape options for a porpoise, therefore, increasing risks further (Koschinski, 2008).

There are many beaches popular with holiday makers and bathers to the west of Puttgarden and along the south coast of Fehmarnbelt (Dynesen and Zilling, 2006). Pressures caused by disturbance, either from bathers or from people on the beaches, are thought to be negligible as these activities are confined to the very near shore waters.

Recreational fishing typically consists of either shore-based rod and line fishing or vessel-based fishing, i.e. kayak or sea-fishing. Gear type on vessel-based fishing is usually limited to lines or small gill nets, although traps may also be used. Across the EU, recreational fishing catch rates and effort are largely unreported. The lack of data on recreational fishing catch rates makes it difficult to assess whether this activity has any impact on porpoises in terms of competition. In addition, many recreational fishers also use various acoustic fish-finding devices such as sonar which could affect porpoises directly (see Chapter 2.7.7).

2.7.6.1. Conclusions on tourism

Tourism and recreational activities may add to existing pressures on porpoises. However, the extent to which they do so, if at all, is unclear. There are no reports of recreational boat strikes on harbour porpoises and a lack of data prevents any conclusions being made on whether recreational fishing places any pressure on porpoises. Overall, there is little documented evidence to suggest that tourism and recreational activities place direct pressures on harbour porpoises in the Fehmarnbelt area.

2.7.7. Underwater noise

2.7.7.1. Shipping noise

The Baltic Sea has some of the busiest shipping routes in the world with the Fehmarnbelt area being a busy shipping route from the Baltic Area towards the North Sea. AIS data show that about 2000 ships are in the Baltic Area at any given moment (HELCOM, 2010b) (see 2.7.5).

Sound emission of boats largely depends on the size and speed of the boat and originates from propeller cavitation, propeller movements and propulsion of other machinery (Richardson et al., 1995). Most of the energy emitted by boat and ships is in the low frequency range and, therefore, only overlaps with less sensitive hearing ranges of harbour porpoises (Kastelein et al., 2002). Therefore, a hearing threshold shift due to shipping would not be expected (Southall, 2005 and see Southall et al., 2007 for noise exposure criteria). Masking of biologically important sounds can be ruled out as porpoises echolocate with ultrasounds in the range of 130 kHz where ship sound is non-existent and recent investigations indicate that low frequency components of high frequency clicks are not biologically relevant (Southall, 2005; Hansen et al., 2008). However, behavioural changes can appear with potential effects on foraging, navigation and reproduction and with energetic costs (Southall, 2005). In summary, porpoises in the Fehmarnbelt area are exposed to relatively high levels of shipping sound which could lead to behavioural effects which in turn could lead to stress in individuals. However, the exact effects are unknown and population level consequences are impossible to assess at this stage.

2.7.7.2. Fishery sonar and sonar of small boats

As outlined above, the Fehmarnbelt area comprises a variety of fisheries including smaller vessels and is a busy tourist area involving a variety of smaller vessels. Most smaller vessels use sonar to navigate over the sea bottom and also to locate fish. Very short signals of up to 230 dB re 1µPa are emitted to listen for the echoes emitted by, for example, fish schools (Richardson et al., 1995). Most fishery sonar operate in the frequency range from 20-30 kHz but some high frequency sonar use frequencies above 100 kHz (Simrad AS, 2007). These ranges are particularly relevant for harbour porpoises; however, there have been no investigations on the effects of fisheries sonar or echo sounders on harbour porpoises to date, so potential pressures cannot be assessed.

2.7.7.3. Seismic surveys

Seismic surveys are used to explore properties of the sea bed for research purposes and for oil and gas exploration. The latter is not relevant for the Baltic as the amount of industry is negligible. The number of surveys carried out for research purposes is unknown. Seismic surveys are undertaken prior to offshore wind farm construction to analyse the seabed, for example if pile driving is planned. They have also been undertaken prior to the construction of the Fehmarnbelt Fixed Link. Seismic surveys cause high sound pressure levels of 220 to 255 dB re 1µPa with most energy in the low frequency range below 100 Hz (Richardson et al., 1995). Most of the energy is directed towards the sea bed but there are still high sound pressure levels that are propagating horizontally. OSPAR (2009) summarises the studies undertaken on the effects of seismic surveys on marine mammals and mentions mostly behavioural effects that can happen at relatively long ranges. One recent study showed temporary threshold shift in a harbour porpoise exposed to relatively low levels of airgun sound (164 dB re 1uPa SEL, Lucke et al., 2009) indicating a lower tolerance in this individual than previously assumed for high frequency cetaceans (see Southall et al., 2007). At this stage, the overall pressure on porpoise due to noise from seismic surveys cannot be assessed due to lack of data.

2.7.7.4. Explosions

Explosions are the strongest anthropogenic sound source in the sea. The sound pressure level depends on the charge weight. With their extremely short rise times explosions can cause deadly injuries, acoustic trauma and permanent or temporary threshold shift in marine mammals (Society for the Conservation of Marine Mammals, 2007b; review on injuries in Gordon et al., 2004; OSPAR, 2009). As an example, the Society for the Conservation of Marine Mammals, (2007b) calculated a source level of 294 dB re 1µPa for a 350 kg TNT bomb.

A known dumping and detonation ground for munitions is found at Heidkate south of Kiel, off the coast of Schleswig-Holstein about 40 km from the Fehmarnbelt area. This process started in October 2006 in an area where harbour porpoises are present (Society for the Conservation of Marine Mammals, 2007b). Large amounts of munitions have been dumped in the Baltic Sea (see Chapter 2.7.3), which cannot be recovered in many cases. Explosions are likely to affect harbour porpoises at long distances from the explosion sites. Recently, noise emissions have been mitigated with the use of a bubble curtain.

2.7.7.5. Conclusions on noise effects

Harbour porpoises are exposed to relatively high sound pressure levels in the Fehmarnbelt area mostly related to heavy ship traffic. This could cause behavioural reactions such as avoidance which in turn, at least theoretically, could lead to stress. Additionally, harbour porpoises in the area have been exposed to seismic surveys in preparation for the two existing offshore wind farms and will be exposed to additional surveys when plans for the other wind farms go ahead. Further noise effects can be expected from explosions of munitions in the area.

2.7.8. Analysis of Ambient noise

2.7.8.1. Introduction

Anthropogenic underwater sound can affect all three marine mammal species occurring in the Fehmarnbelt area in various ways. Tasker et al. 2010 make a distinction between short term impacts which are mostly induced by pulses such as pile driving and seismic surveys that could lead to short and long-term effects, and those that relate to impacts from non-pulses such as shipping sound that could lead to a more permanent change of the acoustic environment. Studies undertaken in some regions indicate that levels of ambient noise[3] have increased over the last decades which is mainly due to increased shipping activity (see Ross 1993; Andrew R.K. et al. 2011). Not surprisingly low frequency continuous sound has been identified as one of the indicators for measuring Good Environmental Status for the EU Marine Strategy Framework Directive (Tasker et al. 2010).

Although the impacts of ambient noise on marine mammals have been identified as an important issue in marine environmental management, little information exists on ambient noise levels in most marine areas. Measurements have been undertaken rather sporadically indicating enormous differences in noise levels across sites (see for example Nedwell *et al.* 2008 and Ainslie 2010). The development of 'noise maps' especially, which can be used to characterize the acoustic environment in an area, is very much in its infancy (see for example ICAMST, 2006; Richards *et al.* 2007). This is partly due to the fact that in most cases noise measurements have only been conducted on a limited number of stations, so that extrapolations of sound levels between stations come with large uncertainties.

In the present study, FEMM conducted a systematic analysis of ambient noise levels in the Fehmarnbelt area. Due to the highly frequented shipping route, underwater noise in this area is of special interest and sound measurements are needed to characterise the Fehmarnbelt with regards to baseline pressure due to ambient noise. We will present results on the range of ambient noise levels at various stations on different temporal scales (e.g. days and seasons). We will also describe the spectrum of ambient sound over defined periods of time. A key result will be the documentation of the acoustic environment that the three species of marine mammals are exposed to during different seasons in the form of ambient noise maps.

The study takes a new approach in modelling the acoustic environment based on local measurements and large-scale recordings of shipping activity, taking environmental variables such as water depth, sediment types and seasonal effect into account. The results of the study will be compared with those obtained in other regions.

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[3] Ambient noise is defined here as noise that is composed of 1) Background noise, 2) Foreground noise. Background noise is defined as sound arriving at a receiver from distant sources that cannot be resolved as coming from spatially distinct sources; Foreground noise comprises all sound that can be resolved by a receiver. Measurement noise – that is noise not caused by sound waves reaching the receiver (e.g. electrical self noise, platform noise, flow noise, cable strum, etc) may contribute to the recorded signals, but these should be minimised during measurement and should not be considered in the analysis of trends (see Ainslie 2010).

2.7.8.2. Material and Methods

2.7.8.2.1. Data Collection

Underwater noise measurements were conducted using autonomous measurement buoys deployed at different locations in Fehmarnbelt. These noise recording systems are capable of recording sound for up to 4 weeks. They are equipped with low noise hydrophones of type B&K 8106. These hydrophones show a high receiving sensitivity of nominally -173 dB re 1V/µPa and are equipped with a built in low noise preamplifier. The bandwidth of the noise recordings is between 16 Hz and 16 kHz.

The buoys are deployed directly at POD stations in the Fehmarnbelt (see chapter 2.6). With the help of a flotation body the hydrophone is kept approximately 1.8 m above the ground. Measurements were conducted at various locations from September 2009 to November 2010.

During some campaigns when buoys were serviced additional noise measurements were done from the vessel. Automatic Information System (AIS) signals of all ships crossing the Fehmarnbelt were recorded and stored on a computer. Additionally sound speed profiles were measured with the help of CTD measurements.

With the help of AIS recordings it was possible to identify ships passing near the measurement buoys. This information, together with the recorded sound pressure, was used to evaluate the apparent transmission loss for individual ships. Apparent transmission loss means the way that the sound pressure level caused by the ship drops with increasing distance from the hydrophone position. Information about this experimentally estimated transmission loss was used for the modelling stage in order to compute noise maps.

2.7.8.3. Data Analysis

The noise recordings were analysed in various ways in order to gain information about the temporal variation, spectral content and absolute values of the sound pressure at the measurement positions. At first every recording underwent a quality check. With the help of a calibration signal at the start of each recording the sound pressure level Leq[4] was computed in intervals of 10 seconds.

After passing a quality check the data were analysed with respect to their percentile levels. We computed the median L50 and values for L95 and L5.

The median Leq is statistically more robust than the overall Leq because the latter is dominated by the loudest period during the measurement and can give a false picture of the noise situation. For instance the nearby passage of one single ship during the 30 day measurement interval can lead to a very high Leq that doesn't adequately describe the noise situation.

The level of the L95 is the sound pressure level that is exceeded during 95% of the time. It can be interpreted as a lower bound of permanent ambient noise level during the measurement time

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[4] Leq is the 'Equivalent-sound-pressure-level (as Leq / L_{eq}) – dB_{eq} / dB_{Leq} : Sound level averaged over integration time T. In this case T = 10 s.

at that location. Accordingly the L5 is the sound pressure level exceeded during 5% of the measuring time and thereby contains information on the highest levels occurring. The difference between L5 and L95 thereby characterises the variability of the noise situation.

2.7.8.4. Noise Maps

The exploratory analysis (see for example Figure 2.7-6) showed that the main source of underwater noise in the Fehmarnbelt turned out to be shipping noise. Natural sources of sound like wind, breaking waves and rain did not contribute much to the overall measured broadband noise levels. The model therefore needed input in the form of a raster map of shipping traffic. AIS data were obtained from Ramboll A/S (2011) for each month in the years 2009 and 2010. The raster for the shipping density has a grid length of 750 m.

Each cell containing at least 30 ships passing through per month, i.e. only cells with at least one ship per day, were treated as sound source for other cells. The source level of those sound emitting cells was computed as a fixed level + 10*lg(No. of ships). The constant part of this source level was evaluated in an iterative way by comparison of the sound measured at a suitable reference station and the modelled sound pressure at this position. We chose the station A6 for reference as it is located directly in the shipping lane.

The Transmission Loss TL which describes how the source level decreases as a function of distance from the source usually is of the form TL(r) in dB = k * log(r/r0), where k is the propagation constant. We computed the propagation constant to k=22 for the model by analysis of noise recordings of individual ship passages that were identified by AIS messages.

The influence of the sediment on sound propagation was considered as well. In muddy regions the bottom loss due to absorption of sound in the bottom is not negligible (see for example Urick 1983). Based on models predicting bottom attenuation in dependence of grain size this effect was incorporated in the noise maps. For this analysis, we used data published by Kibblewhite (1989). In summary the model takes into account the shipping density, the water depth between source and emission cell and the grain size of the sea bottom along the propagation path.

2.7.8.5. Results

Table 2.7-2 summarizes the measurement intervals at the different POD stations and the resulting noise levels measured there.

Table 2.7-2 **Compilation of noise measurement locations, measurement intervals and resulting noise levels. The positions are given as the corresponding name of the POD the buoy was attached to.**

Position	Measurement time (regular operation)	Median dB re 1 µPa	L5 dB re 1 µPa	L95 dB re 1 µPa	Leq dB re 1 µPa
A5	26.09. - 26.10.2009	132	142	123	134
A6	26.09. - 14.10.2009	133	140	125	134
A6	11.12. - 12.01.2010	130	137	122	131
A6	16.03. - 15.04.2010	133	140	126	134
A6	10.05. - 10.06.2010	131	137	123	131
A6	21.06. - 16.07.2010	134	141	128	135
A6	26.07. - 26.08.2010	130	137	123	131
A6	31.08. - 01.10.2010	129	136	122	130
A6	17.10. - 01.11.2010	132	133	124	133
W1	10.05. - 11.06.2010	118	124	112	119
W2	21.06. - 16.07.2010	116	123	111	117
W3	26.09. - 17.10.2009	126	139	115	130
W4	27.07. - 27.08.2010	117	129	108	120
W5	27.07. - 12.08.2010	103	109	96	104
W8	17.03. - 15.04.2010	128	143	116	133
W10	17.03. - 15.04.2010	118	132	105	122
W12	11.12. - 11.01.2010	117	131	110	121
E1	21.06. - 23.07.2010	118	125	112	120
E2	27.11.2009, 8 hours	131	141	120	132
E2	12.12. - 12.01.2010	131	140	120	133
E3	02.09. - 02.10.2010	107	115	101	109
E3	17.10. - 17.11.2010	109	117	104	111
E4	28.07. - 28.08.2010	125	137	112	128
E5	17.10. - 01.11.2010	120	130	110	122
E6	17.10. - 28.10.2010	115	120	110	115
E7	13.05. - 12.06.2010	114	120	107	114
E8	02.09. - 02.10.2010	118	132	110	122
E9	02.09. - 02.10.2010	117	126	108	119

Figure 2.7-5 shows the percentile levels L5, L50 (Median) and L95 together with their corresponding position in Fehmarnbelt.

It appears that average sound levels varied between Leq50 of 103 dB re 1µPa (W12) and 132 dB re 1µPa (A5, A6). It is also apparent that most of the noisy areas are located in the middle of the channel well within the main shipping lane. By contrast, the quieter areas are located outside areas of major traffic, especially near the coast.

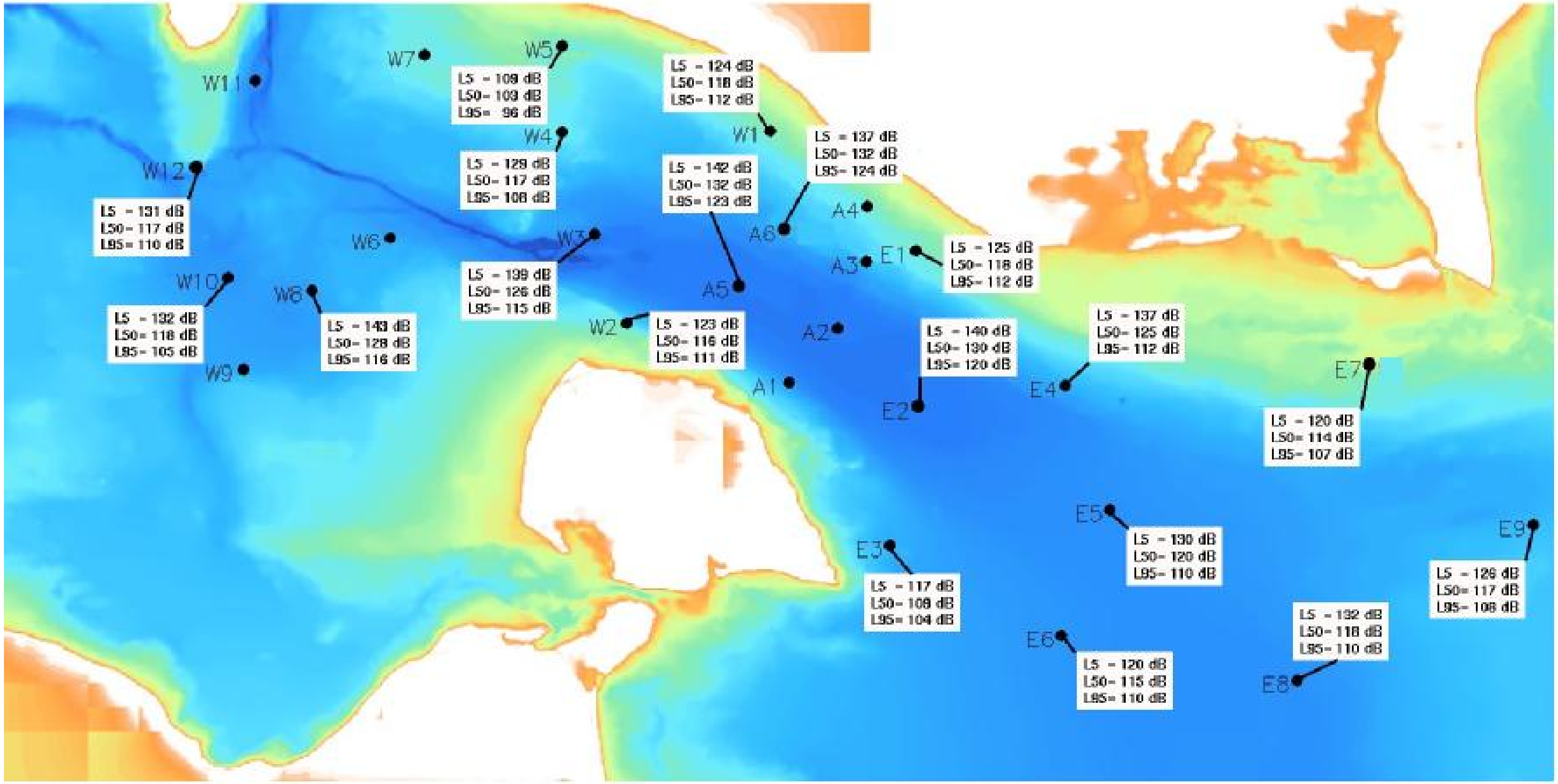

Figure 2.7-5 Map with POD positions in the Fehmarnbelt area. Noise levels for L5, L50 and L95 are annotated at those PODs where noise measurement buoys were deployed.

The analysis shows that shipping is by far the most important source of underwater noise in the Fehmarnbelt area. This is illustrated in the following graph showing broadband levels and levels of selected bandwidth over time at a location near the ferry route.

With the help of an AIS receiver the passing ships were identified and their names are annotated at the corresponding local maximum in the graph.

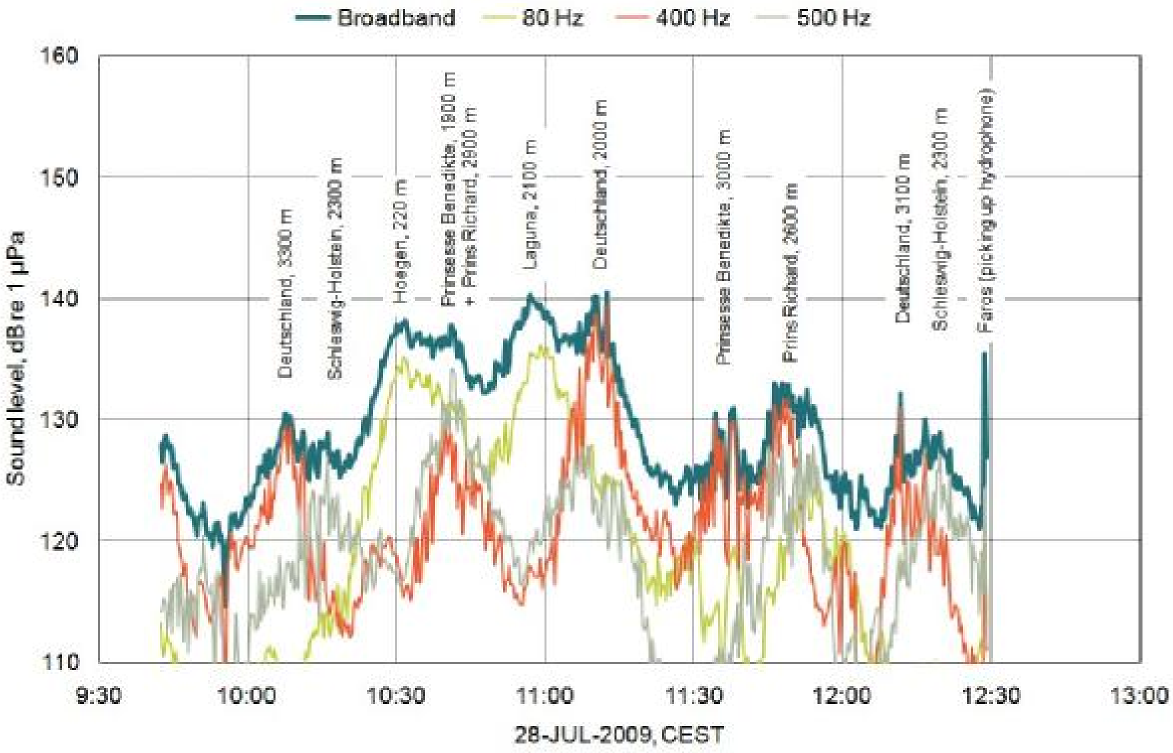

Figure 2.7-6 **Time series of sound pressure levels measured at a central position in the Fehmarnbelt near the ferry route. The name of the ship passing nearest for a given time is indicated together with its distance. Levels are given as broadband, and in 1/3-octave bands for 80 Hz, 400 Hz and 500 Hz.**

Graphs of the distribution of the 10-second Leqs give an insight on how the noise level varies at a specific position. It can be seen that the level distribution for a three-day period is quite similar to the final distribution for the whole measurement interval of 4 weeks. This was true for noisy as well as quieter positions (Figure 2.7-7 and Figure 2.7-8).

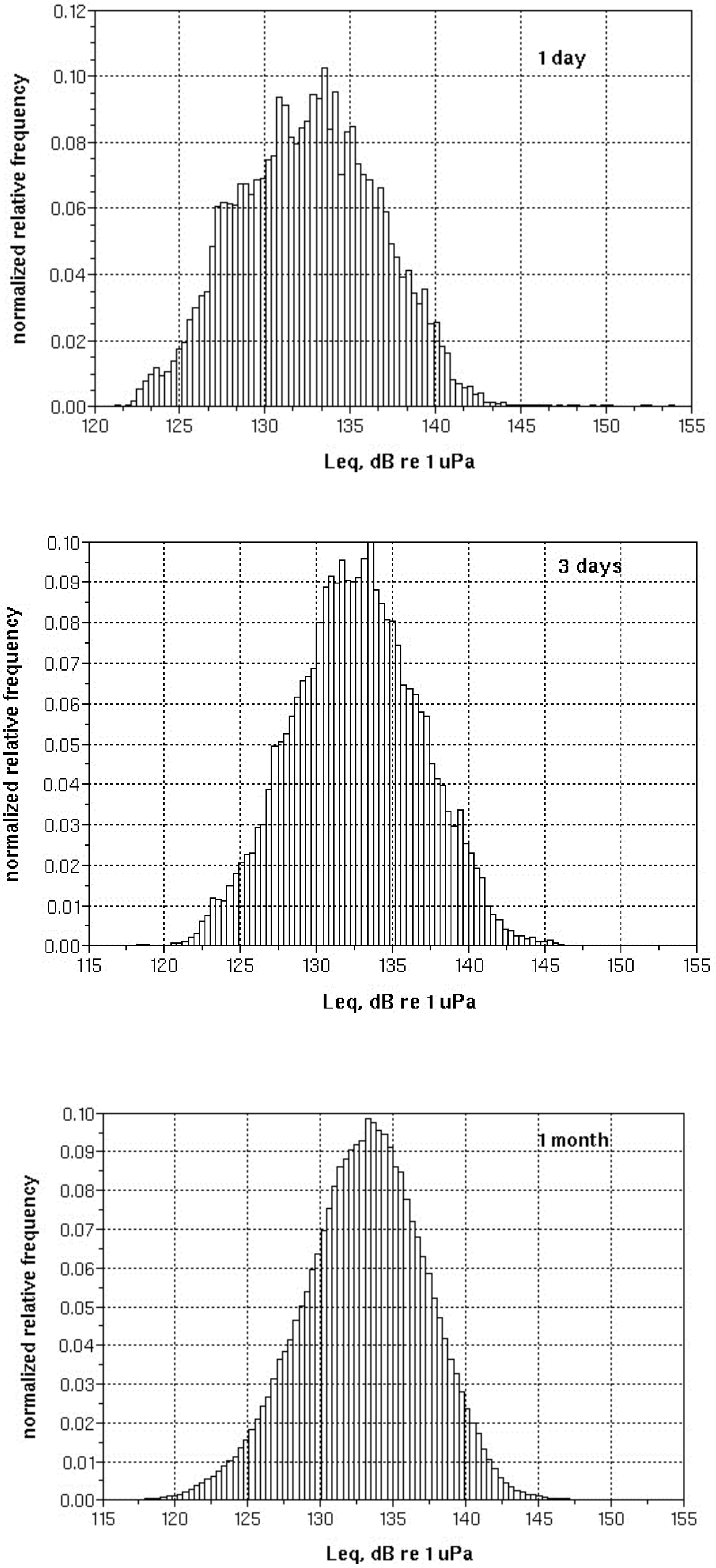

Figure 2.7-7 **Sound level distributions measured at position A6 near the ferry route. The distributions are computed from the 10-second-Leqs of 1 day (top), 3 days (middle) and 1 month (bottom) respectively.**

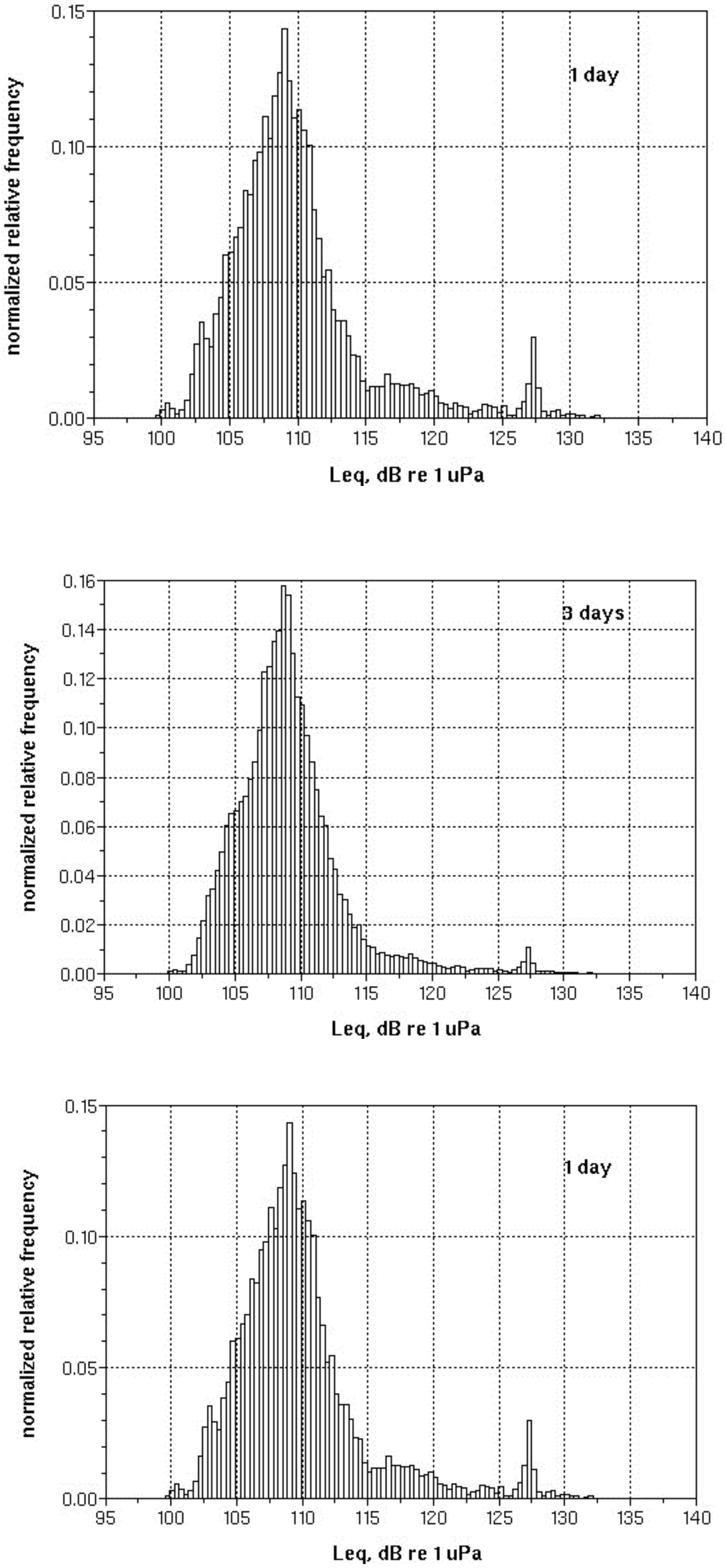

Figure 2.7-8 **Sound level distributions measured at position E3, a quiet location east of Fehmarn. The distributions are computed from 10-second-Leqs of 1 day (top), 3 days (middle) and 1 month (bottom) respectively.**

There was in general little variation in the ambient noise levels at the stations. As an example, the daily variation of the percentile levels L5, Median (L50) and L95 is shown at position A6. As can be seen from Figure 2.7-8 the variation of the daily median about the median of 133 dB for the whole month is not more than 1 dB.

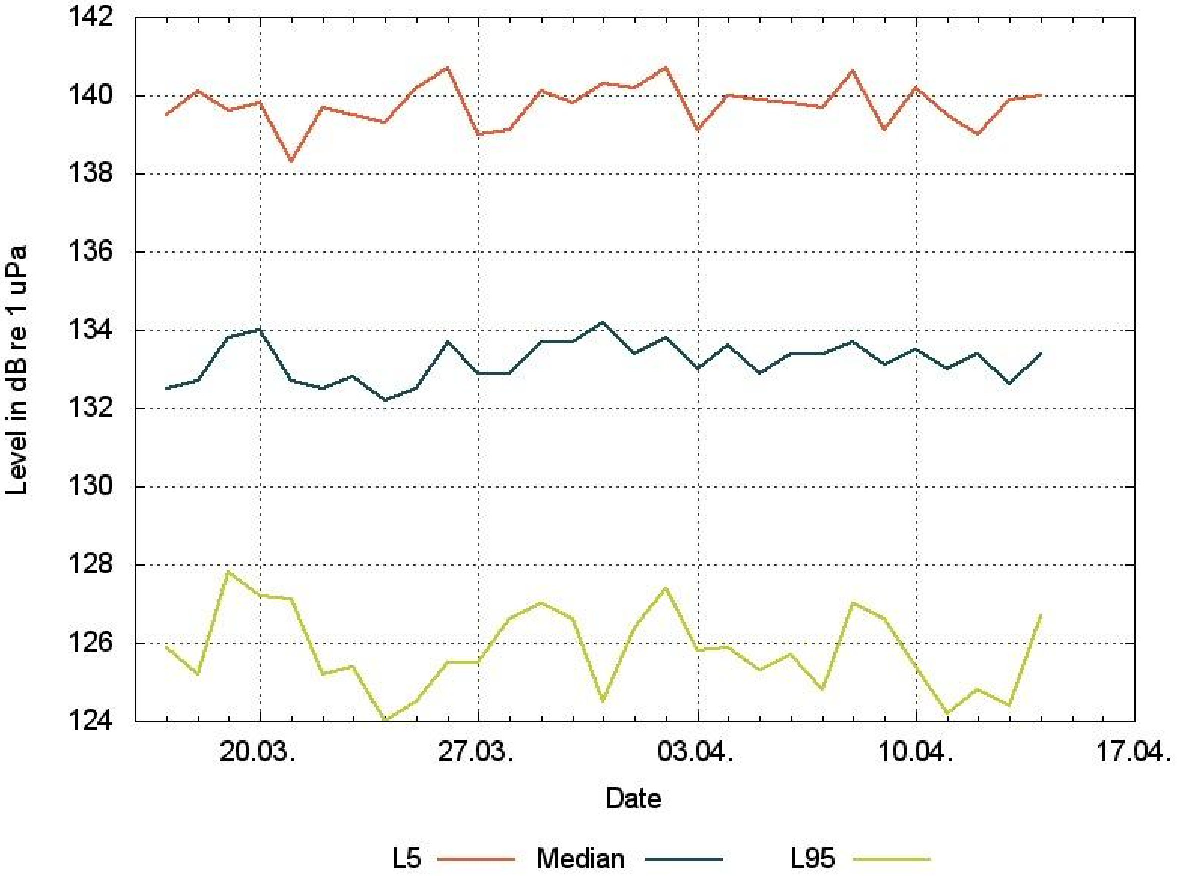

Figure 2.7-9 **Daily variation of sound pressure levels L5, L50 (Median) and L95 in March and April 2010 at position A6.**

On a smaller time scale, variation was more visible. As an example, Figure 2.7-10 shows the measured 10-second Leq at position A5 during a 2 hour interval together with the L5 and L95 percentiles computed over the measurement time of 1 month. It can be seen that sound levels varied strongly due to the signals from a passing ship.

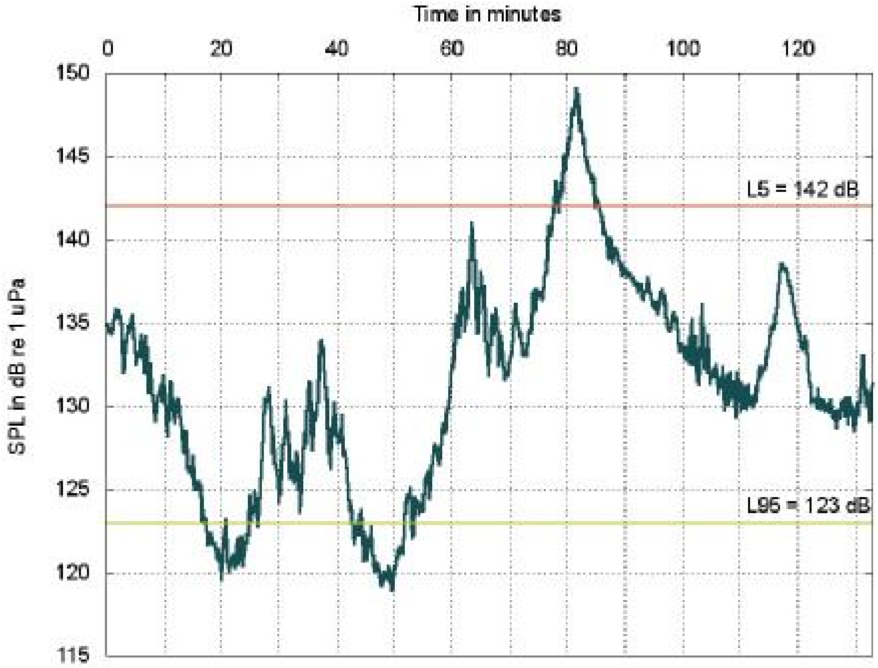

Figure 2.7-10 Time series of 10-second Leq at position A5 during a 2 hour interval. The L5 and L95 levels characteristic for this position are indicated by straight lines.

Most of the ambient noise was of lower frequency well below 1 kHz. But spectra could differ based on the presence of passing ships. Figure 2.7-11 shows 1/3-octave SPL spectra for minute 49 (background) and minute 81 (ship passing nearby). The background level is dominated by the always apparent noise from the ferries that exhibits strong tonal components at 400 Hz and its harmonics.

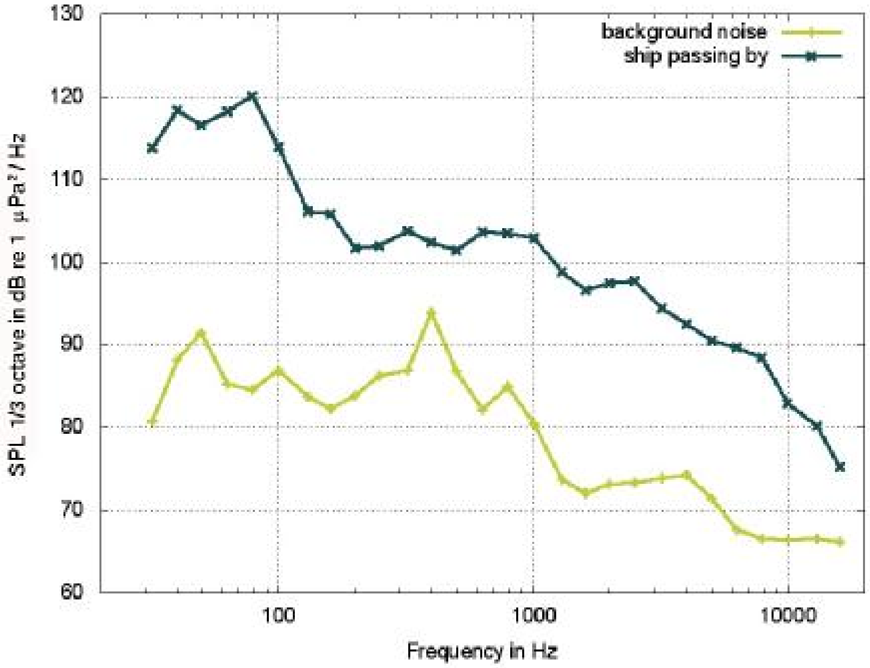

Figure 2.7-11 1/3-octave spectra of sound pressure during a ship passage (minute 81) and for a quiet period (minute 49), corresponding to the measurement shown in Figure 2.7-10.

Figure 2.7-12 to **Fehler! Verweisquelle konnte nicht gefunden werden.** show the ambient noise maps as derived from the modelling described earlier. The first map (Figure 2.7-12) provides a snapshot of the sound field produced by 19 ships in the area of interest and is based on a real AIS snapshot. This simulation was done in order to visualize how the noise maps were developed. The sound sources (ships) are clearly separated as hot spots (red). The resulting noise levels however do not just decrease on concentric circles around the ships. Because of the varying bathymetry and bottom constitution the transmission loss is strongly dependent on the propagation path. As a result, regions with extremely shallow water and regions with muddy sediment show lower sound levels.

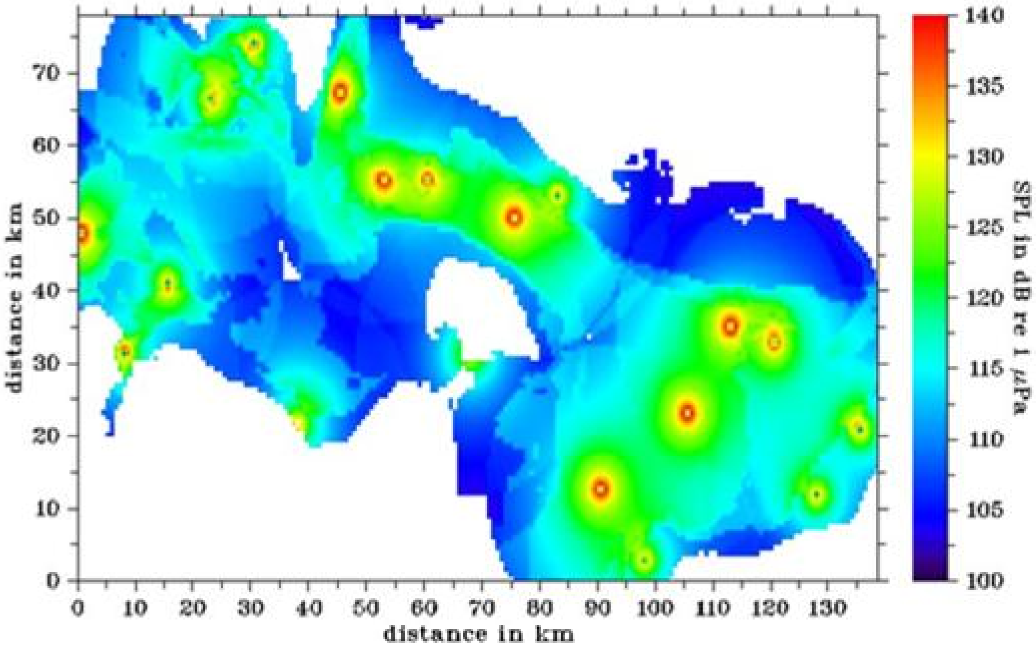

Figure 2.7-12 Noise map in form of colour coded sound pressure levels as a function of position. Depicted is a snapshot resulting from AIS positions of 19 ships.

A summarized noise map for the mean shipping density for the year 2010 is shown in Figure 2.7-13. For the reasons given above this map is not just a reflection of the shipping density. There are areas west and east of Fehmarn with a highly absorbing sediment which lead to lower sound pressure levels in the water column. Especially along the Kiel-Ostsee route the model predicts variations of sound level of 10 dB and more.

The quietest areas can be identified as the shallow waters of the Rødsand lagoon, the coast east of Gedser and the German waters near Fehmarnsund.

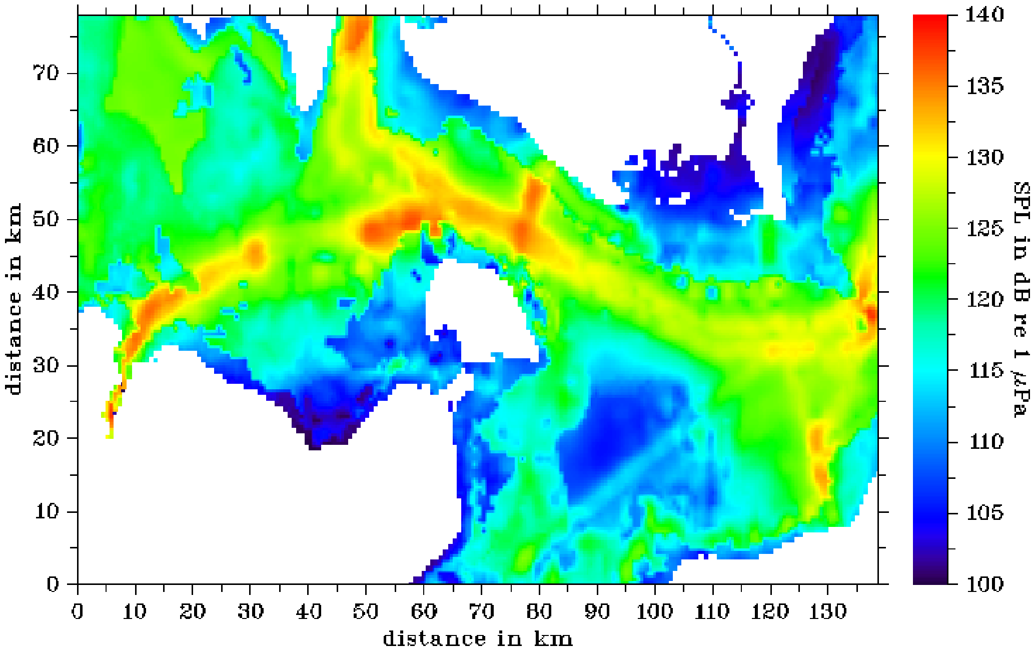

Figure 2.7-13 Noise map based on 12 months of shipping data for 2010.

The following 4 maps are computed based on AIS data for the corresponding 4 seasons in 2010. Since the variation in shipping density between months in 2010, when expressed in dB, is at most 0.7 dB the sound maps for the different seasons are nearly equal.

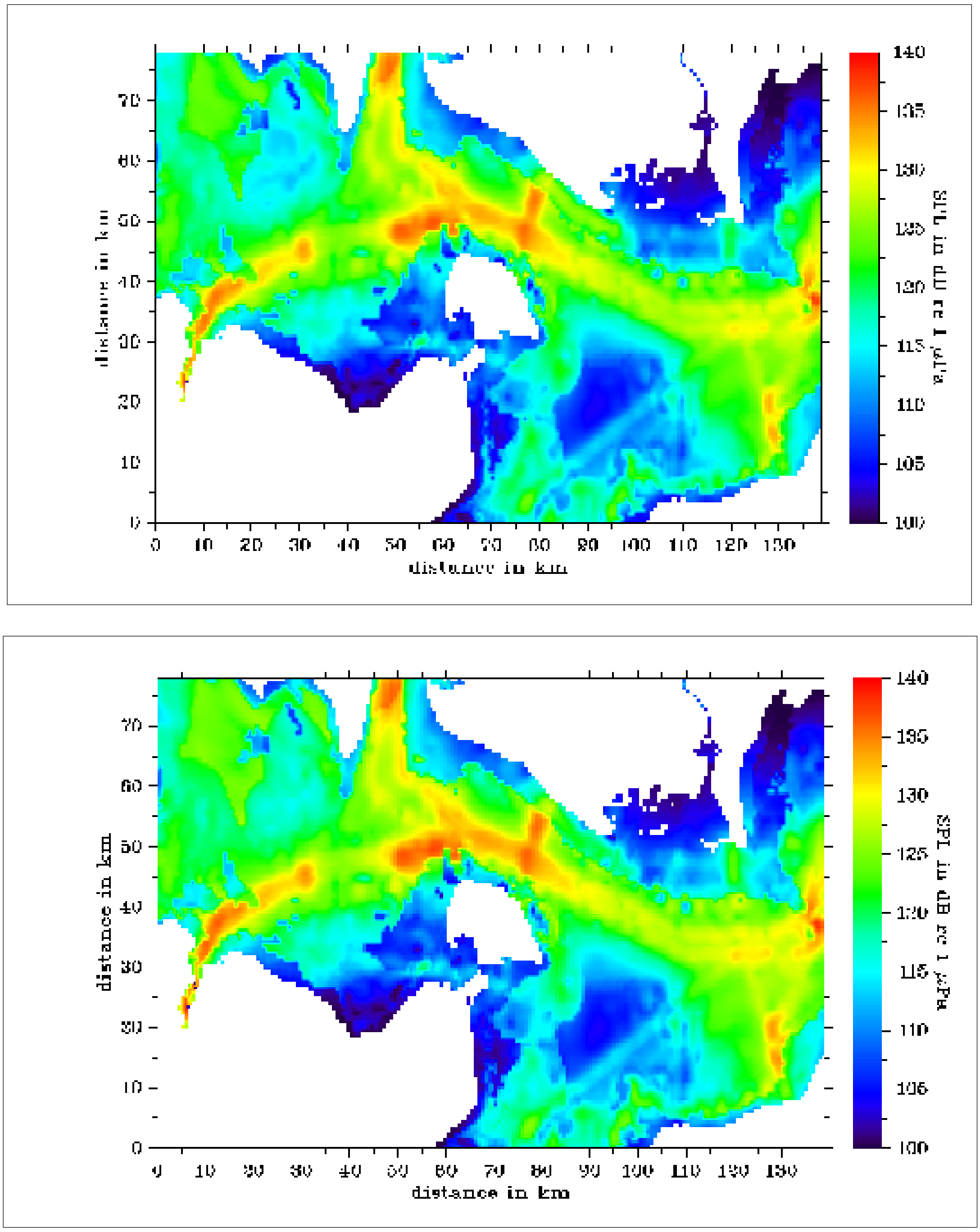

Figure 2.7-14 Seasonal noise maps for spring (top) and summer (bottom) 2010.

2.7.8.6. Conclusions

Our investigation represents the most detailed account of ambient noise that has been undertaken in an area of this size. The data allow us to characterize the area with regards to noise pressure. We also found variations in ambient noise within the study area, although there was little temporal change.

As expected, we measured highest underwater noise levels near the main shipping routes, i.e. the T-route crossing the Fehmarnbelt from northwest to southeast and the Puttgarden-Rødby ferry. The level distributions converge after only a few days of measurements to those gained from a full measurement period of 4 weeks.

The results of the study show average noise levels between 103 and 132 dB re µPa and the values correspond well with results from other studies in high traffic areas. For example Bailey et al*.* 2010 reported background noise levels between 104 and 119 dB re 1µPa in a Marine Protected Area off the coast of Scotland rising to 138 dB re 1µPa during times of high shipping activity. Nedwell et al*.* 2007 measured ambient noise at five offshore wind farm locations off the UK East and West Coast and found levels to be as high as 132 dB re 1µPa. Thus, although the levels we found are relatively high, they do not exceed those reported for other busy areas.

It has to be noted, however, that we found little variation in the temporal trends either on a daily or seasonal basis, indicating that pressures from ambient sound in the Fehmarnbelt is almost constant. This is perhaps not surprising as traffic around shipping lanes was constant as well. However, it is in contrast to observations in other regions where daytime recreational traffic is the largest contributor to ambient noise (own observation).

It is clear that most of the energy of the ambient sound is well below 1 kHz where porpoise hearing is relatively poor (Kastelein et al*.* 2002). Hearing thresholds of a porpoise were between 80 dB re 1µPa (rms) at 1 kHz and 115 dB re 1µPa (rms) at 250 Hz (Kastelein et al. 2002). Our analysis of the distribution of sound energy in the different frequencies indicates that most of the ambient sound – due to its loudness – is clearly audible to porpoises and it will be audible to seals as they have better hearing in lower frequencies compared to harbour porpoises (see summary in Thomsen et al. 2006). Increased levels of ambient noise have the potential to mask biologically relevant signals such as the low frequency calls of both harbour and grey seals. Yet, they could also mask perception of other low frequency sounds that are of importance to all three species such as sounds from an approaching ship (for a review on masking see Clark *et al.* 2009 and OSPAR 2009b). It has also been suggested that elevated levels of ambient noise could lead to stress which in turn could affect the health of marine mammals (Wright *et al.* 2007). The results of the CPOD investigation show that background noise affected the acoustic activity of porpoises at levels above 113 dB re 1µPa. This is a further indication that ambient sound exhibits a relatively high pressure on porpoises, although – as shown by the studies using visual methods - this does not necessarily lead to a complete avoidance of high traffic areas by the porpoises.

Although noise levels could be high in some areas, these were far from uniform. Based on a semi-empirical noise propagation model we computed noise maps that reproduce the measured noise levels quite well. Since seasonal variation in shipping density is negligible the noise maps computed are quite similar to each other.

However, the maps also show that there are areas in the Fehmarnbelt where the noise levels are lower than would be expected from a simple model that only takes into account the distance from the shipping lanes. Water depth as well as sediment constitution have to be incorporated into a realistic model for sound propagation in the area.

2.7.9. Construction

2.7.9.1. Offshore wind farms

Two offshore wind farms are in operation Rødsand I (also known as Nysted), and Rødsand II and three are planned (Beltsee, Beta Baltic, GEOFReE) for the area west of Fehmarnbelt.

Pressures from existing wind farms can be divided into those caused by the construction and those caused by the operation. Construction impacts are mainly those associated with shipping activity around the site, seabed disturbance by dredging and construction noise. During operation, impacts may be caused by porpoises avoiding the area. Reasons for this include the visual impact of the wind farm, disturbance from maintenance boats and operational noise.

The amount of sound emission related to the construction of wind farms depends mostly on the type of foundation used. Additional sound sources during construction are ship movements, trenching and dredging (Nedwell and Howell, 2004). The two Rødsand wind farms are based on gravity foundations causing far lower sound levels during installation than pile foundations that need to be hammered into the sea bed (see OSPAR, 2009 for a review). But even during construction of Rødsand I the number of harbour porpoises in the area decreased significantly which might be partly attributed to the hammering of steel sheet piles to stabilise the sediment during the construction period. It should also be noted that porpoise density was relatively low prior to the start of the observation and that the power of the statistical methods establishing a change is, therefore, presumably low (Henriksen et al., 2003; Carstensen et al., 2006). High sound pressure levels of more than 250 dB re 1µPa can be produced during pile driving activity (OSPAR, 2009). Pile driving each pile, with around 40 hits per minute, can take more than an hour. Therefore, marine animals are exposed to high sound energy (Bailey et al., 2010) with frequency and sound level depending on hammer and pile size and seabed conditions (Rodkin and Reyff, 2004 in Madsen et al., 2006). Pile driving could be audible for harbour porpoises at a distance well beyond 80 km and could affect their behaviour at distances of up to 20 km (Thomsen et al., 2006).

The effects of offshore wind turbine operation sound are likely to be less pronounced due to far lower sound levels and therefore the pressure from the existing wind farms at Rødsand can be viewed as low. Wahlberg and Westerberg (2005) back-calculated low frequency source levels from measurements lower than 145 dB re 1µPa$_{rms}$ while levels did not exceed 120 dB re 1µPa $_{rms}$ at 100 m. Madsen et al. (2006) pointed out that operational sound, even of noisy offshore wind turbines, would be detectable to porpoises only over a range of a few hundred metres and they expected minor effects on small toothed whales due to their poor hearing ability in low frequency ranges. But the results on reactions to existing wind farms are so far inconclusive. While the number of harbour porpoises in the Horns Rev wind farm (North Sea) increased again after pile-driving construction was completed and the wind farm was in operation, the number of harbour porpoises in Rødsand remained at a lower level even after two years of operation (Anonym, 2006, but see above). Diederichs et al. (2006) assessed the effect of the Horns Rev and Nysted wind farms on the occurrence of the harbour porpoise and could not detect any consistent trends, concluding that there was no significant effect caused by the wind farms. The reasons why the porpoise numbers have so far not returned to baseline levels at Rødsand I are not clear.

2.7.9.2. Conclusion on wind farm effects

The construction phase of a wind farm will most likely have a negative behavioural effect on individual porpoises. However, this effect might be only short term. Effects from operational wind farms will be of short range, if any.

2.7.10. Competition with fisheries

Lindroth (1962) found that harbour porpoise in the Baltic predominantly feed on herring, sprat and cod. Lindroth (1962) also concluded that porpoises were opportunistic in their prey choice, given the large number of transparent gobies, of which there had been a large influx that year, found in some of the stomachs. A more recent systematic study of Baltic porpoise identified a total of 13 fish species in the stomach contents of harbour porpoises. However, despite this prey total, it was concluded that the most important food species in the Kattegat and Baltic proper were herring and cod (Aarefjord et al., 1995). In addition, stomachs from animals of the Baltic proper contained a substantial number of eelpout and Benke et al*.* (1998) also found a high number of gobies in stomach samples. Other studies have also shown a predominance of herring, sprat, cod and gobies in the diet of the Baltic porpoise (Lick, 1991; Santos and Pierce, 2003; Berggren, 1996; Benke and Siebert, 1996; Malinga and Kuklik, 1996; Malinga et al*.*, 1997).

Therefore, as Santos and Pierce (2003) stated, while there is considerable variation in the overall diet of porpoise within the Baltic and adjacent regions, there are preferred prey species, namely; herring, sprat, cod and goby.

Yet, Berggren et al*.* (2002) and Horackiewicz and Skóra (1996, 1998) did not consider food limitation to be a factor affecting the conservation status of harbour porpoises in the Baltic region. The most important species, herring, sprat and goby (Lindroth, 1962; Aarefjord et al*.*, 1995; Horackiewicz and Skóra, 1996, 1998; see above), have been abundant during the last two decades in the Baltic Sea, indicating that food shortages or competition with fisheries are unlikely to affect porpoises in this area (Berggren et al., 2002; Horackiewicz and Skóra, 1996, 1998). Cod is also an important prey species, but while there is a cod fishery in the Baltic, Santos and Pierce (2003) found that generally, porpoise tend to take smaller fish than those targeted by commercial fisheries.

Should competition between commercial fisheries and porpoises develop, it seems likely that the harbour porpoise could switch prey species. However, should multiple prey species be targeted by both commercial fisheries and porpoises, porpoises could be forced into a suboptimal niche or habitat, which could have, at least in theory, a long term impact on the distribution and viability of porpoise stocks (Koschinski, 2002).

2.7.10.1. Conclusion on competition with commercial fisheries

While there is some overlap with commercially important fish species, these species seem abundant in the Baltic region or different size classes are targeted. Therefore, at the present time, it looks unlikely that there is sufficient competition between porpoises and commercial fisheries to cause any significant impact to the porpoise population in the Baltic.

2.8. Pressures from exiting bridges and tunnels

2.8.1. Case study on the Great Belt Bridge, Denmark

The case study on potential barrier effects of the Great Belt Bridge (GBB) in Denmark on harbour porpoises (*Phocoena phocoena*), is aiming to support future assessment of potential effects of the planned Fehmarnbelt fixed link on this species. The GBB represented an excellent opportunity to study the effects of a bridge on harbour. Investigations were carried out to study porpoise relative abundance and movements in relation to the bridge and absolute densities in the area using a combination of different methods. This report presents the results of acoustic measurements of potential noise from traffic on the bridge or in the tunnel transmitted into the water, aerial surveys of marine mammal abundance, passive acoustic monitoring using stationary C-PODs to record harbour porpoise relative abundance, onshore visual observations of harbour porpoises and acoustic tracking of harbour porpoises using a hydrophone array. The acoustic methods used the recording of harbour porpoise echolocation clicks to gain information on porpoise relative abundance (with C-PODs) and porpoise movements (with a hydrophone array) in relation to the bridge, while the aerial surveys gathered data on absolute harbour porpoise density in the area.

2.8.1.1. Study site

The Great Belt is a channel of water up to 25 km wide dividing the islands of Funen and Zealand. It is the largest passage route from the Kattegat to the Baltic Sea. The Great Belt has a very complex bathymetry with shallow waters towards the coasts and a deep trench in the middle of more than 35 meters of depth. The seabed consists of a hard bottom complex, sand and mud.

The GBB was opened in June 1998 for road traffic after nine years of construction. It consists of two separate bridges that converge at Sprogø, a small island in the middle of the Belt. The West Bridge, built for rail and road traffic, is 6611 m long with 63 sections founded on 62 pillars. It has a ship clearance of 18 m. The East Bridge constitutes of a 6790 m long suspension bridge for road traffic only. It has a free span of 1624 m and a ship clearance of 65 m. Trains cross the eastern Belt through an 8000 m long immersed rail tunnel between Zealand and Sprogø.

2.8.1.2. Noise and vibration measurements

Underwater noise measured underneath and close to the bridge and the tunnel, mainly originated from shipping activity. No underwater noise that might have originated from traffic on the bridge or in the tunnel could be distinguished from general background noise. Furthermore, vibration measurement did not detect any vibrations caused by the tunnel. Results suggested that barrier effects of the bridge or tunnel on marine mammals caused by underwater noise is highly unlikely.

2.8.1.3. Aerial surveys

Aerial surveys were conducted at an altitude of 600 feet along twelve 15-30 km long transects with a spacing of 2 km, of which six were located north and six south of the bridge. Porpoise densities were calculated using distance sampling methodology. Eight survey flights were carried out between July and November 2009 and six were carried out between May and June 2010. The only marine mammals regularly observed were harbour porpoises. Harbour seals

(*Phoca vitulina*) were only occasionally spotted, and observations were too few to calculate absolute densities. Harbour porpoise densities ranged between a minimum of 0 Individuals/km² (Ind./km^2)on the 9th of September 2009 to a maximum of 2.98 Ind./km^2 on the 6th of August 2009. Porpoise density was highly variable even between surveys conducted on the same day. Most harbour porpoises were observed in one area to the southwest and one to the northeast of the bridge at great distances from the bridge. Generalised Additive Mixed Model (GAMM) analyses revealed statistically significant effects of water depth, distance to land and survey number, but no statistically significant effect of distance to the bridge on harbour porpoise density. Therefore, no statistically significant effect of the bridge on harbour porpoises was detected. However, as densities were highly variable between surveys and often very low, statistical power to detect slight effects caused by the bridge may also be relatively low. Therefore, caution is required when interpreting these data with regard to potential barrier effects caused by the bridge.

2.8.1.4. Passive Acoustic Monitoring

Passive Acoustic Monitoring using C-PODs was conducted during two time periods: between October 2009 and January 2010 (winter) at 16 POD-positions and between May and August 2010 (summer) at 27 POD-positions.

Patterns in porpoise relative abundance varied strongly between positions and seasons. During both seasons the highest recordings were made at POD-positions along the East Bridge near the deep channel. Analyses of daily porpoise detection rates (Porpoise Positive 10 Minutes per day: PP10M/day) and the parameters that potentially affect it were conducted separately for the winter and the summer data subset. These revealed some major effects of water depth, temperature and current speed. Furthermore, there were some effects of salinity, the strength of North-East (U) current, East-West (W) current and upwelling (W), whose effects differed between seasons. There was no effect of distance from the bridge on porpoise relative abundance during either winter or summer. Therefore C-POD recordings of daily porpoise acoustic detection rates did not reveal any statistically significant effects caused by the presence of the bridge, and we found no indication of any barrier effect.

Analyses of daily activity rhythms in porpoise detection rates using the parameter Porpoise Positive Minutes per Hour (PPM/h) revealed that porpoise detection rates were not evenly distributed over the day at any POD-position in either winter or summer. There were seasonal changes in porpoise activity rhythms which may relate to seasonal changes in diet. Furthermore, porpoise daily rhythms were more pronounced near the bridge and in deeper waters with a higher detection rates during the night than during the day. It is possible therefore, that due to artificial reef effects (where bridge pillars become overgrown with benthic organisms and consequently attract higher fish biomass), higher night time feeding activity occurs near the bridge leading to more pronounced activity rhythms. This is supported by the finding that a higher proportion of feeding click trains was detected during the night than during the day, which was not the case for approach sequences, showing that high detection rates during the night may largely reflect porpoise feeding behaviour and associated higher clicking activity.

2.8.1.5. Visual Observations

Visual observations were conducted at eight observation points along the bridge and at four reference points more than 5 km to the north-east, north-west, south-east and south-west of the bridge for a total of 715 hours between July and October 2009 and between May and June 2010. Whilst there was a high variability in sighting rates between observation points, there was no statistical difference between observations points under the bridge and reference points. Behavioural observations showed that feeding activity was not evenly distributed amongst observation points, but this was irrespective of the observation positions' distance to the bridge. We therefore found no indication that porpoises avoided the bridge or showed a different behaviour when close to the bridge. Thus, there was no evidence for the existence of a barrier effect on harbour porpoise movement being caused by the bridge. There was also no evidence of porpoises being attracted to the bridge or showing more feeding behaviour next to it, which could have been caused by bridge pillars functioning as artificial reefs that attract a higher abundance of available prey. However, there was only limited statistical power to detect potential bridge effects since sighting rates and observed behaviours were highly variable over time, and because sample size especially at reference points was rather small. Furthermore, POD-recordings indicated that porpoise feeding activity occurs during the night to a much greater extent than during the day. This would then be missed by behavioural observations, which are restricted to daylight hours. Therefore, conclusions should be treated with caution. However, several observations of harbour porpoises crossing under the bridge in 2009 suggested that there is no general avoidance behaviour of the bridge. During the observation period in 2010, though, only one porpoise was noted under the bridge. While these data give no indication that there is a barrier effect caused by the bridge on porpoise movement, this does not rule out that some animals do not cross under it. Due to the inability to identify individual porpoises, we cannot address inter-individual differences. Furthermore, the reasons for the low number of Under Bridge Crossings (UBS) observed in 2010 are not entirely clear.

2.8.1.6. Hydrophone array

A hydrophone array was applied to study fine-scale (i.e. directional movements within 100 m of the hydrophone array) movements of harbour porpoises. A four element hydrophone array was deployed from a stationary vessel to calculate sequential bearings to porpoises in an effort to estimate their swimming direction in relation to the GBB, and thus investigate whether the existing bridge constituted a barrier to porpoise movements within the region of the Great Belt. Acoustic recordings were made using the open source PAMGUARD software. The click detector module within the PAMGUARD software was configured to detect the echolocation clicks of harbour porpoises when they were within detection range of the hydrophone array.

Useable harbour porpoise events were detected at 13 out of 30 separate sampling stations. At least one event occurred in each of the four defined geographic locations that covered north and south and far and near with respect to the GBB. This spread of detections over a short number of days is consistent with the Great Belt supporting a high density of harbour porpoises. Whilst no porpoises were actually recorded swimming under the bridge during the study, they were regularly recorded in close proximity on both sides of the bridge. They also exhibited a variety of swimming patterns on both sides of the bridge that suggests the bridge is unlikely to present a barrier effect.

2.8.1.7. Conclusions

A large amount of data was generated with the use of different approaches to study a potential barrier effect of the GBB on harbour porpoises. There was no indication from any of the results that harbour porpoises perceived the GBB as a barrier to movement. However, statistical power was limited for some of the analyses due to high spatial and temporal variability in porpoise relative abundance, behaviour and density. Underwater noise measurements using low noise hydrophones could not detect sound or vibrations caused by traffic on the bridge or in the tunnel that could be distinguished from the general background noise caused by wind and waves. It is highly unlikely, therefore, that these structures disturb harbour porpoises acoustically. Harbour porpoises were regularly observed and recorded in close proximity to and under the bridge, and there was no indication that sighting or recording rates differed between near the bridge and at greater distances. Furthermore, porpoises were also directly observed crossing under the bridge, providing further evidence that such crossings probably occur regularly. Daily rhythms of porpoise click detection rates were more pronounced near the bridge with higher detection rates during the night than during the day. As a higher proportion of feeding click trains was identified during the night than during the day, this may be related to intensive night time feeding of porpoises close to the bridge. This could indicate that bridge pillars function as artificial reefs attracting higher prey biomass and thus feeding porpoises. As visual observations could only take place during daylight, this effect was not detectable by these methods. All things considered, no evidence was found for the existence of a barrier effect on harbour porpoise movement caused by the GBB as no effect of the GBB on either harbour porpoise abundance or behaviour could be detected during any of the studies conducted under this ATR.

2.8.2. Noise measurements at Drodgen Tunnel, Øresund

The FEMM consortium conducted measurements to investigate wether the Drodgen Tunnel induced noise and vibrations of the sea bottom lead to an increase in underwater sound level. The measurements were carried out in the Øresund, directly above and 400 m away from the tunnel connecting Amager with Peberholm.

In order to separate tunnel induced from ambient noise, like shipping noise etc., a geophone and a hydrophone were placed directly above the tunnel alignment to record vibrations of the sea bottom and the resulting underwater noise. The measurements were made on July 19, 2011. The recording bandwidth was 10 Hz to 20 kHz. The upper limiting frequency range of the geophone, however, was about 1 kHz. The recordings were evaluated later with the aid of software written in MATLAB by itap. Sound and vibration levels versus time and 1/3-octave frequency spectra were computed

None of the underwater noise recordings contained audible signals that unambiguously were caused by car-traffic in the tunnel. The same holds for the vibration measurements. Directly above the tunnel, however, there are measurable vibration immissions during train passages, causing an increase in underwater sound pressure, i.e. noise immissions. A typical train passage lasts ca. 10 seconds and causes an increase in sound level to about 140 dB directly above the tunnel. Cargo trains lead to comparable level increases for about 20 seconds. This has to be compared to shipping noise that, for each passing ship, lasts several minutes and can reach noise levels above 140 dB at more than 400 m distance.

However, at a distance of about 400 m away from the tunnel, underwater noise level, caused by trains passing the tunnel, was hardly measureable and do not contribute to the overall broadband level caused by shipping.

3. Seals in Fehmarnbelt

3.1. Biology and historical data

3.1.1. Introduction and conservation status of seals in the Baltic Sea

Two species of seal live and breed in the Fehmarnbelt area: harbour (also known as common; *Phoca vitulina*) and grey (*Halichoerus grypus*) seals. The harbour seal population in the Baltic is a remnant of a formerly more widely distributed population (Helander and Bignert 1992). Harbour seal numbers have suffered in the past primarily due to hunting pressures and disease events. However, since the 1990s, their numbers have steadily increased in the Fehmarnbelt area. Similarly, numbers of grey seal are also increasing in the region despite historical hunts, disease events and pollution effects. Both species are protected by a number of international, European, regional and national initiatives.

Since 1990, NERI has been undertaking haul-out and moult counts of these species at several locations within Baltic Management Area 4 (Teilmann et. al., 2003; and see Teilmann et al., 2010 for the location and extent of all Baltic Management Areas), which includes the area of the Fehmarnbelt Fixed Link. These surveys are carried out as part of a regular Danish monitoring program, but have also been supplemented at times for specific EIA purposes (e.g. construction of Rødsand wind farm). This section presents the compiled count data from 1990 – 2009, and also provides a brief summary of the biology of these two species.

3.1.1.1. International frameworks

- **IUCN**

The IUCN Species programme was established to assess the conservation status of species. The Red List of Threatened species provides “taxonomic, conservation status and distribution information on plants and animals that have been globally evaluated using the IUCN Red List Categories and Criteria” (IUCN, 2011). The grey seal is listed as a species of *Least Concern* meaning that this species is generally widespread and abundant (Thompson and Härkönen, 2008). Over the last 30 years, all sub-populations of grey seal (East Atlantic, West Atlantic and Baltic) have increased. The harbour seal is also listed as species of *Least Concern* (Thompson and Härkönen, 2008). The general trend over this species’ entire range is one of a stable population.

- **Bonn Convention**

The Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention or CMS) relates to the conservation of migratory species throughout their range. The Baltic harbour and grey seal populations are listed on Appendix II of the convention, and as such the convention encourages Range States to formulate regional agreements for the benefit of conservation of these species.

3.1.1.2. EU frameworks

- **Bern Convention**

The Bern convention is the Convention on the Conservation of European Wildlife and Natural Habitats (1979 in Bern, Switzerland). The convention is aimed towards the conservation of wild flora and fauna and their natural habitats. The main focus is those species and habitats whose conservation requires the cooperation of several states and the further promotion of such cooperation. Particular emphasis is given to endangered and vulnerable species, including endangered and vulnerable migratory species. Harbour and grey seals are listed on Appendix III of the Bern Convention which requires any exploitation of these species to be regulated. The Bern Convention was implemented primarily through the Council Directive 92/43/EC on the Conservation of Natural Habitats and of Wild Fauna and Flora**.**

- **Council Directive 92/43/EC on the Conservation of Natural Habitats and of Wild Fauna and Flora**

Within the framework of the European Union, the “Habitats Directive” (92/43/EEC) lists harbour and grey seals on Annex II and Annex V of the agreement. As Annex II listed species, they require protection through the designation of Special Areas of Conservation (SAC). The conservation objectives of the Fehmarnbelt SAC consider the harbour seal which occurs within the area. Species listed on Annex V are of Community Interest and exploitation may be subject to management measures.

3.1.1.3. Regional frameworks

- **Convention on the Protection of the Marine Environment of the Baltic Sea Area**

The primary goals of the Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Commission) are to “protect the marine environment of the Baltic Sea from all sources of pollution and to restore and safeguard its ecological balance”. The grey seal is considered to be of Baltic-wide importance in the HELCOM area. The harbour seal is considered to be of sub-regional importance in the HELCOM area. In relation to seals, a specialist Seal Group was established in 2001 which has led to the establishment of guidance for the management of the (three) seal species in Baltic waters and encourages range states to develop national Action Plans in that respect. A seal management plan has not been established in the German Baltic Sea area due to the absence of breeding grey and harbour seals in their area of jurisdiction.

3.1.1.4. National measures

- **Prohibition of Seal hunting**

In 1977, harbour seals received strict protection from hunting in Denmark. This was the result of severe declines due to hunting throughout the 1900s. However, in 2002, HELCOMs Seal Group proposed a recommendation to permit the controlled hunting of seals in certain areas and 14 licences were consequently issued in Denmark to kill harbour seals. The licences may be obtained to shoot seals to prevent damage to fishing gear (Edrén, 2009). The numbers of seals removed each year as a result of these licenses is in the order of between 10 and 18 animals in Denmark (see Edrén, 2009, and references therein).

- **Rødsand Seal Sanctuary**

Under national law, a seal sanctuary was established on Rødsand in the late 1970s. This measure prohibits ship traffic within the borders of the sanctuary throughout the year and was an important measure in reducing disturbance to breeding sites.

3.1.2. Harbour seals

3.1.2.1. Biology

Harbour seals are found around the coasts of the North Atlantic and North Pacific from the subtropics to the Arctic. Five subspecies are recognized. The European subspecies (*Phoca vitulina vitulina)* ranges from northern France in the south, to Iceland in the west, to Svalbard in the north and to the Baltic Sea in the east.

Female harbour seals are smaller than males, averaging 1.7 m (60-110 kg) and 1.9 m (70-150 kg) respectively (Burns 2002). They are long-lived animals, living up to 20-30 years.

Harbour seals regularly haul-out on land (typically on sandbanks and in estuaries, but also in rocky areas), usually in a pattern related to the tidal cycle. They also come ashore to give birth to their pups. The latest age of sexual maturity in both sexes tends to be around five years. The timing of the pupping and breeding season varies with latitudinal location; in the Fehmarnbelt area, harbour seals give birth annually to a single pup during the second half of June (Tougaard and Teilmann 2006). The gestation period is 10-11 months together with a 2+ month delayed implantation (Thompson & Härkönen, 2008). Pups are able to swim from birth but remain close to their mother for suckling on land throughout June and July. Mating is thought to occur in the area during August. Moulting also occurs during the summer months (Tougaard and Teilmann 2006).

Between hauling out, harbour seals undertake foraging trips. They normally feed within 40-50 km of their haul-out sites. They consume a wide variety of fish and cephalopod prey. Their diet varies seasonally and from region to region. Andersen et al. (2007) processed 26 faecal samples and digestive tracts collected in the Rødsand area over a five year period and found evidence of 20 different prey species. The diet at Rødsand was mainly made up of cod (*Gadus morhua*), herring (*Clupea harengus*), sandeel (*Ammodytes tobianus*), flounder (*Platichthys flesus*), plaice (*Pleuronectes platessa*) and dab (*Limanda limanda*).

European harbour seal populations have suffered from two phocine distemper virus (PDV) epidemics in recent times (1988 and 2002). The Skagerrak/Kattegat harbour seal population was also hit by a third epidemic in 2007 which was caused by a virus (though not PDV; Härkönen et al., 2008).

3.1.2.2. Count data

For management purposes, harbour seals within the Baltic have been divided into sub-populations. Management Area 4 (see Figure 3.1-1) covers the Fehmarnbelt, and consists of the haul-out sites at Rødsand, Vitten, Aunø Fjord, Dyrefod, Bøgestrømmen, Saltholm, and the Swedish site, Falsterbo. Harbour seals are resident in this area all year round, although numbers counted ashore are lower during the winter months. Since 1990, aerial surveys have been conducted in this area every year, or every second year, during the harbour seal moult in late August (e.g. Teilmann et al., 2003). These sites are considered to host parts of the same stock of harbour seals, which means that there may be regular movements between these sites.

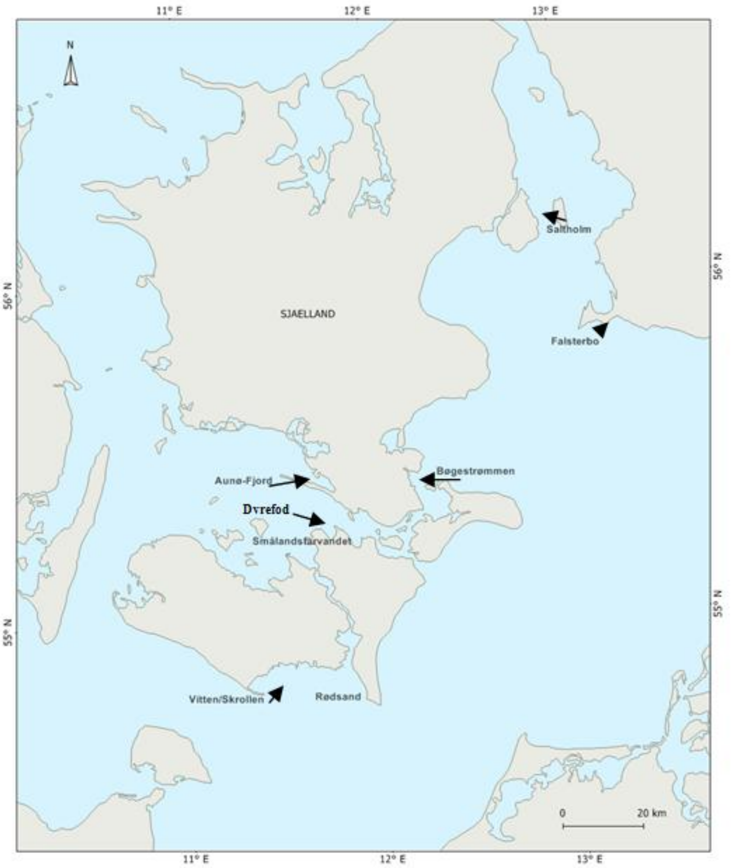

Figure 3.1-1 Seal haul-out sites in Baltic Management Area 4 (after Teilmann et al., 2003)

It should be noted that counts of animals ashore do not represent total population size. Moult counts are the minimum population size and are generally considered to represent between 55 and 70% of total population size (ICES, 2008).

Since 1990 the harbour seal population in this Management Area has generally been increasing (Figure 3.1-2; NERI annual moult survey data) with the exception of PDV/viral epidemic years, when lower numbers of animals were counted. In 1990 there were approximately 160 harbour seals counted in the Southern Baltic; by 2009 there were approximately 560 (Figure 3.1-2). While natural fluctuations in numbers counted at haul-out sites during the annual moult do occur, there continues to be an increasing trend in harbour seal numbers in this region of the Baltic. Use of different haul-out sites can be affected by factors such as weather (Grellier et al., 1996) and disturbance (e.g. Edren et al., 2010; Johnson and Acevedo-Gutierrez, 2007). It is considered good practice to carry out a series of counts at each site within a region and calculate a mean count for that site with associated error.

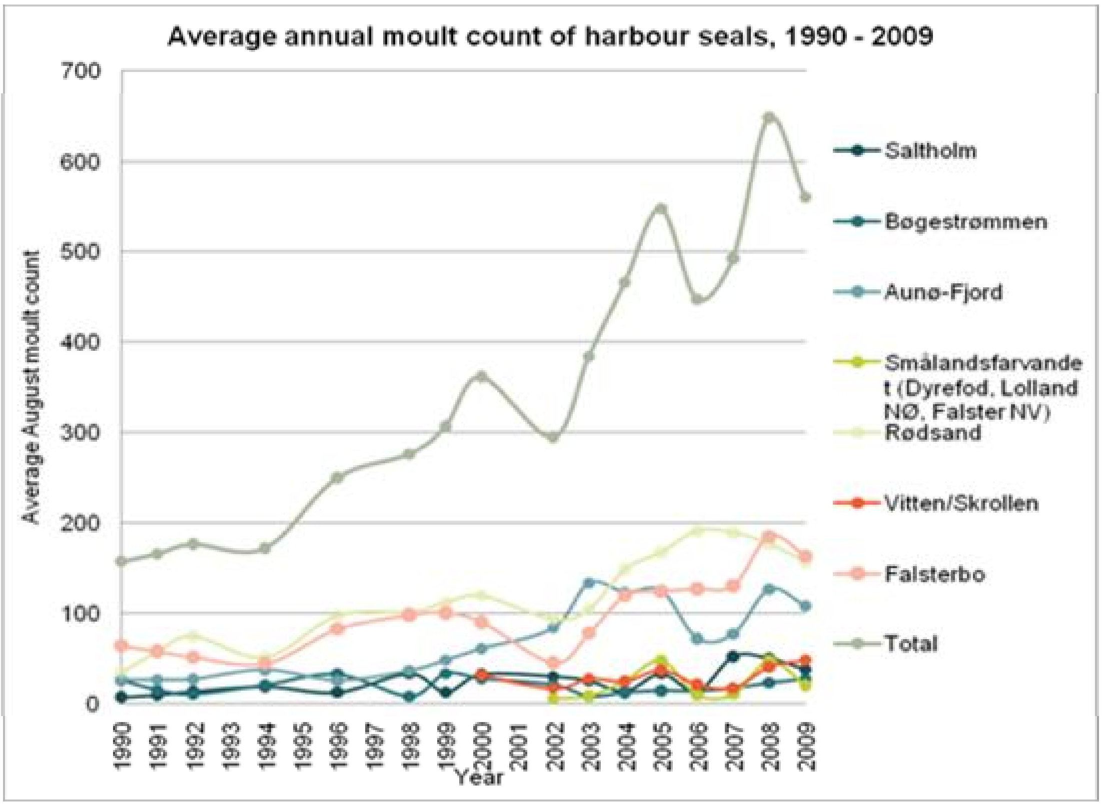

Figure 3.1-2 **Average moult counts of harbour seals at the haul-out sites in Management Area 4. Count data courtesy of NERI**

Rødsand and Vitten/Skrollen are the closest haul-out sites to the proposed Fehmarn Belt fixed link. Because of its importance for harbour seals, the haul-out site at Rødsand was designated as a seal sanctuary in the late 1970s. It is protected from public access during the main period of use by seals (March to September). Between 1990 and 2009 the number of animals counted during NERI's annual moult surveys at Rødsand and Vitten/Skrollen ranged from between 22% and 47% of the total count in Management Area 4 (Figure 3.1-2). Since 2006, the number of harbour seals counted during the moult has been declining at Rødsand and increasing at Vitten/Skrollen (Figure 3.1-3). Because of the close proximity of these sites compared to other known haul-out sites in the region, exchange of animals between the two sites could explain these contrasting trends.

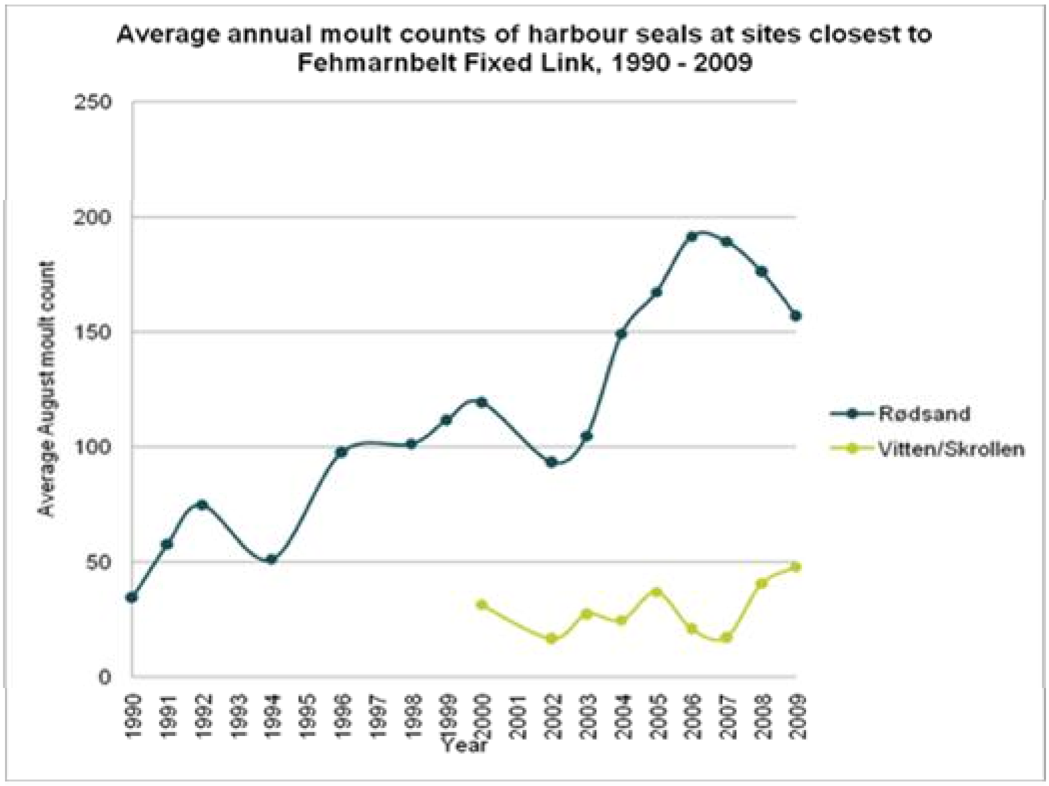

Figure 3.1-3 **Average moult counts of harbour seals at the haul-out sites closest to the proposed Fehmarnbelt fixed link. Data were collected and provided courtesy of NERI. These are the same data that were presented in Figure 3.1-2.**

3.1.3. Grey seals

3.1.3.1. Biology

Grey seals are found in the North Atlantic, Barents and Baltic Sea with their main concentrations on the northeast coast of North America and in north-west Europe. Populations in Canada, the USA, the UK and the Baltic are increasing, although numbers are still relatively low in the Baltic where the population was drastically reduced by human exploitation and reproductive failure (probably due to pollution; SCOS, 2009).

Grey seals are the larger of the two seal species present in the southern Baltic. Adult males can weigh over 300 kg while females weigh around 150-200 kg. Like harbour seals, grey seals are long-lived animals. Males may live for over 20 years and begin to breed from about age 10. Females often live for over 30 years and begin to breed at about age 5.

Breeding occurs in the winter months and peak pupping in the Baltic population occurs in late February and early March (Thompson and Härkönen, 2008). The ‘white coated’ pups remain mainly on land throughout the suckling phase (average 15-18 days) before they are abruptly weaned (Kovacs 1987); this coincides with the moult of the white coat. Mothers will temporarily leave pups at the haul-out during this phase to forage. Adult females mate at the end of lactation and then depart to sea and provide no further parental care. The pup will remain on the haul-out for a further 2 weeks before going to sea themselves. Females generally return to the same colony to breed in successive years, often breeding at the colony where they were born. In the Baltic, adults moult between late May and June (Tougaard and Teilmann 2006).

Grey seals forage at sea but return regularly to haul-out on land where they rest, moult and breed. They may range widely to forage and frequently travel over 100km between haul-out sites. Foraging trips can last anywhere between 1 and 30 days. Individual grey seals based at a specific haul-out site often make repeated foraging trips to the same region, but will occasionally move to a new haul-out site and begin foraging in a new region. Grey seals are generalist predators. Their diet varies both seasonally and geographically but is generally mainly made up of small demersal and pelagic fish species. In the Baltic, herring (*Clupea harengus*) appears to be the dominant prey item followed by species such as common whitefish (*Coregonus lavaretus*), flounder (*Platichthys flesus*), cyprinids (*Cyprinidae*), sprat (*Sprattus sprattus*), lumpsucker (*Cyclopterus lumpus*), cod (*Gadus morhua*) and eelpout (*Zoarces viviparus*; Lundström et al., 2007). These data came from hunted, by-caught and stranded grey seals recovered from throughout the Baltic. There have been no dedicated diet studies in the Fehmarnbelt region to date.

3.1.3.2. Count data

The number of grey seals in the Baltic Sea has increased from only a few thousand in the 1970s to some 21,000 in 2004 (Lundström et al., 2010). Historical counts of grey seals in the southern (mostly Danish) Baltic have been made by NERI since at least 1990, and numbers have generally been increasing over recent years (Figure 3.1-4). Counts are variable throughout the year, mainly as a function of weather, ice cover and food availability, but generally peak during the summer months (May–September). August is the most consistently surveyed time of year.

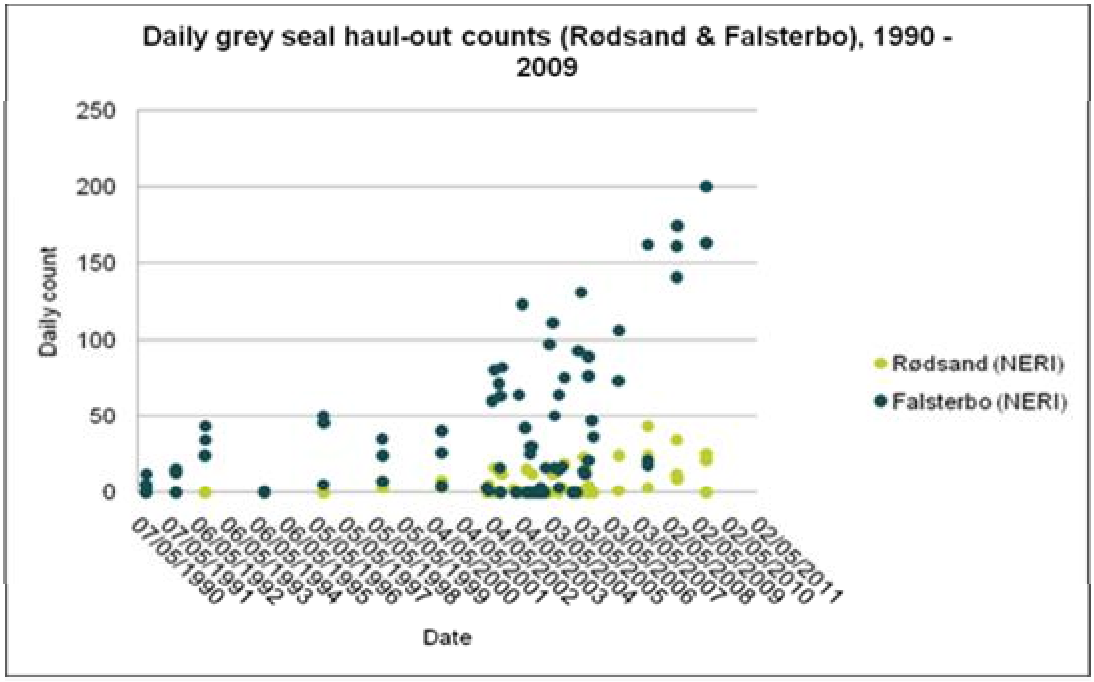

Figure 3.1-4 **Daily grey seal counts at Rødsand and Falsterbo haul-out sites (1990 – 2009). Data collected by and provided courtesy of NERI.**

At the grey seal haul-out site most local to the proposed Fehmarn Belt fixed link (Rødsand) the average number of animals hauled out during August surveys is low and has ranged between 15 and 23 since 2007 (Figure 3.1-5). The Rødsand lagoon is at the southern-most breeding range of the Baltic grey seal, and in recent years a handful of pups have been born there. Breeding occurs during the winter months when surveys are limited due to poor weather so no pup counts are available. Grey seal pup production in the whole Baltic (based on the total number of seals hauled out during the moult divided by 4.5, ICES, 2008) is approximately 4900 (ICES, 2008).

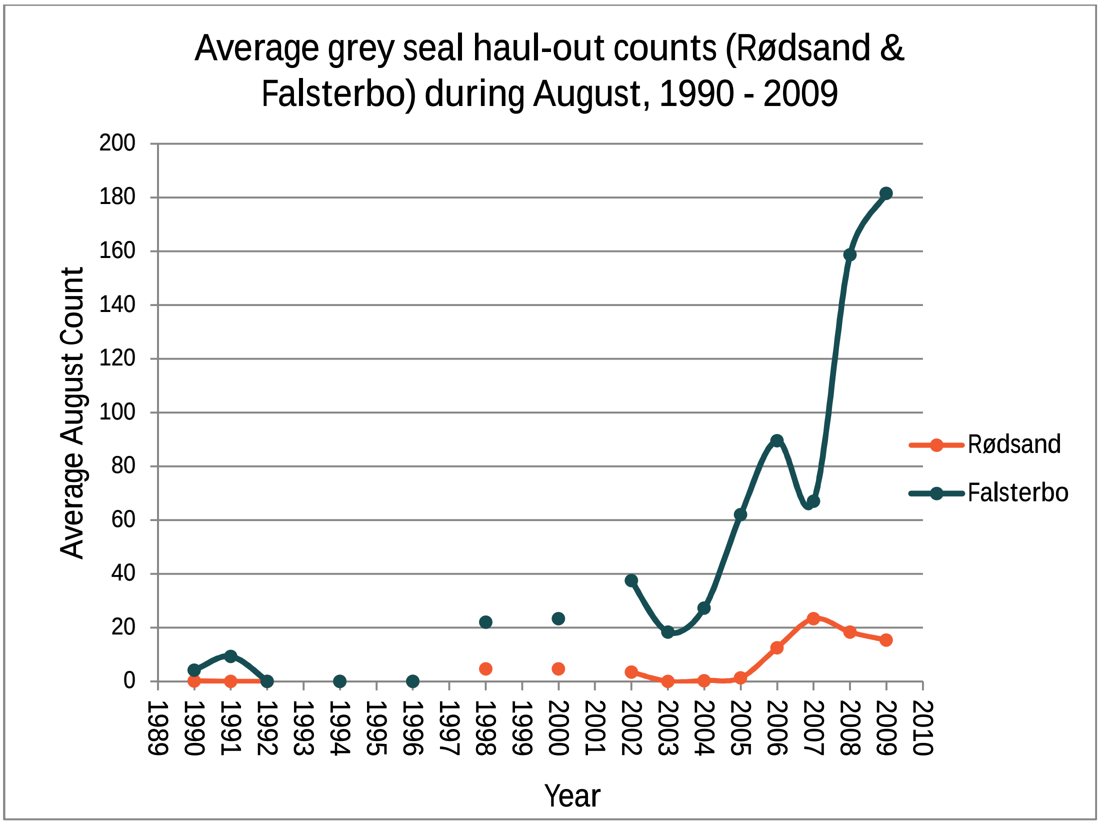

Figure 3.1-5 **The average number of grey seals hauled out at Rødsand and Falsterbo during August surveys (1990 – 2009).**

3.2. Aerial surveys

3.2.1. Introduction

In the Fehmarnbelt area, the Rødsand Lagoon is the only regular haul-out site for both grey and harbour seals. In order to monitor population size and investigate seasonal variation in numbers of animals ashore, aerial surveys were conducted in 2009 and 2010. These count data, along with those on seal movements and at-sea distribution collected (using telemetry) as part of the baseline studies undertaken by FEMM, are also used to model at-sea usage (see Section 3.3.2.4). They are further used for comparison with the historical count data collected by NERI (see Teilmann et al., 2010).

3.2.2. Methods

The aim was to conduct surveys on a monthly basis from January 2009 to December 2010. However, surveys could not be undertaken in some months due to poor weather conditions or ice cover (see Results section). Surveys covered the area of Rødsand Lagoon, which is situated southeast of Lolland (and is connected to the Fehmarnbelt area), spanning from 54°35’’59’N, 11°27’’42’E in the south-west to 54°39’’42’N, 11°52’’54’E in the north-east. Rødsand Lagoon is to the east of the planned Fehmarnbelt Fixed Link.

Survey flights were undertaken at an altitude of 500 feet (160 metres) and at a speed of 100 knots.

The survey aeroplane was a high-winged, twin-engine Partenavia, equipped with bubble windows by the rear seats. This provided the observers with a good view to count and photograph seals. Two principal observers were placed in the rear seats, equipped with a geo-referenced map of the Lagoon. The observer seated next to the pilot (or behind the principal observers) took high-resolution digital photographs of seal groups with a DSLR camera. The plane circumnavigated the Lagoon following the shoreline and sandbank. On occasions when observers had restricted visibility (mostly caused by the plane turning, and therefore not being completely level), a second pass was made. Observers searched continuously for seals hauled out or swimming in the shallow water of the Lagoon. Seal data collected include information on group size, species, age class (e.g. juveniles and adults) and behaviour. A handheld GPS recorded positional information to log survey effort.

In order to differentiate between the two seal species, and determine their numbers, the images taken from the plane were analysed after the flight. The methodology of using high resolution images for species identification purposes improved greatly after September 2009, when a higher quality zoom lens was used.

3.2.3. Results

There are two seal haul-out areas in the Rødsand Lagoon. In the western part of the Lagoon there is a sand hook and also a stony area in shallow waters (Vitten/Skrollen) where seals haul-out dispersed on rocks. In the eastern part of the Lagoon, seals haul-out on the Rødsand sand bar and in the shallow waters in front of it. Both seal species may occur close together which facilitates species identification by size. Seals have been observed several times partly hauling out in shallow waters.

A total of 14 full surveys were achieved between January 2009 and September 2010. Survey conditions on full surveys were always considered to be good to moderate (sea state less than Beaufort 3; visibility greater than 5 km). Surveys could not be undertaken in some months due to poor weather conditions or ice cover.

Most groups of seals were sighted at the eastern end of the Rødsand Lagoon (Figure 3.2-5). Count data are presented in Table 3.2-1.

Grey seals were observed in five out of the 14 months when full surveys were carried out. Harbour seals were observed in eight out of the 14 survey months. There were six survey months when seals were observed and counted but the species was not able to be identified (Table 3.2-1).

The largest number of grey seals (n=57) were counted in June 2010 followed by August 2010 (n=16); the largest number of harbour seals were counted in August 2010 (n=223) followed by January 2009 (n=107), July 2010 (n=62), June 2010 (n=54), September 2009 (n=47) and September 2010 (n=39). Very few seals of either species were counted outside these times.

Figure 3.2-1 Harbour seals hauled out on stones at Vitten/Skrollen.

Figure 3.2-2 Harbour seals partly hauled out in shallow water at Rødsand.

Figure 3.2-3 **Mixed species group (harbour and grey seals) hauled out at Rødsand.**

Figure 3.2-4 **Grey seals hauled out at Rødsand.**

Table 3.2-1 **Count data from completed aerial surveys carried out between January 2009 and September 2010**

Survey month	Grey Seal	Harbour Seal		Undetermined Seal		Total
	Hauled out	Hauled out	Swimming	Hauled out	Swimming	
January 2009	8	107			8	123
April 2009					14	14
May 2009				26		26
June 2009				34		34
August 2009				43		43
September 2009	1	47			43	91
October 2009		7		30		37
March 2010				4		4
April 2010			2			2
May 2010				40		40
June 2010	57		54			111
July 2010	3	62			9	74
August 2010	16	223				239
September 2010			39			39

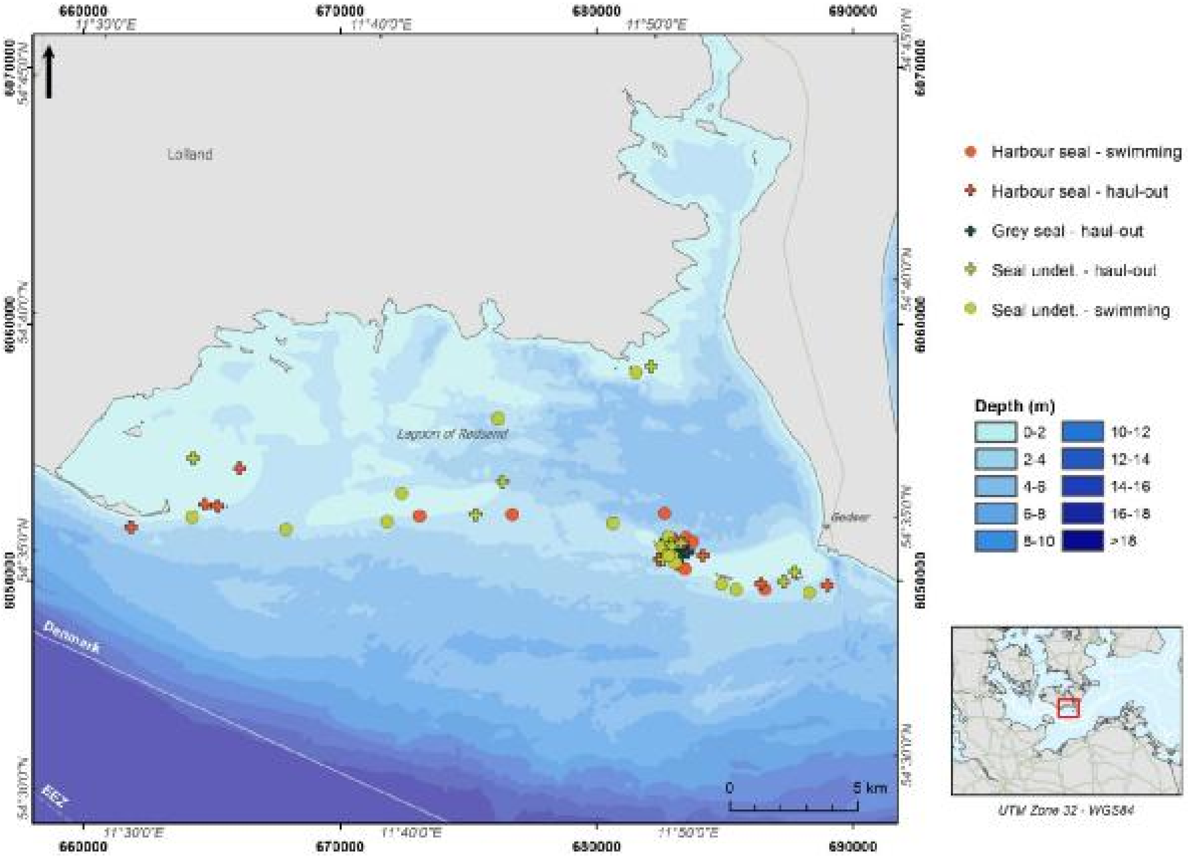

Figure 3.2-5 **Map of the distribution of grey seals and harbour seals (data combined across all survey flights).**

3.2.4. Discussion

Seals are present in the Rødsand Lagoon all year round. With the exception of January 2009, the highest numbers were recorded in September 2009 and August 2010. Spring numbers in 2009 were substantially lower than winter numbers and numbers increased over summer, up to a maximum of 91 seals counted in September 2009, tailing off again in October. The first survey in 2010 was not carried out until March when small numbers of seals were counted. Numbers increased through spring to summer peaking at 239 seals counted in August 2010, tailing off again in September. Because of the difficulty encountered when identifying seals to species, this seasonal pattern cannot be attributed to one species or the other. However, it would be expected that harbour seal numbers would increase during the summer months and peak during the breeding (June/July) and moult (August) seasons (Thompson and Miller, 1990). It is not possible to ascertain whether the large number of harbour seals counted in January 2009 is related to a local annual cycle because no surveys were carried out in January 2010 due to poor weather; however previous surveys conducted by NERI in winter resulted in very low numbers at that time of the year. Total numbers obtained were lower than those from surveys conducted by NERI in August 2009 (during three surveys in August 2009, counts of harbour seals ranged from 33-82 at Vitten/Skrollen and 118-196 at Rødsand). Since there were roughly two weeks in between the seal counts by NERI and ourselves, it remains unclear what caused this discrepancy in counted seal numbers. It might refer to natural variation in numbers due to the seals' behaviour or may indicate a disturbance which has caused a temporal displacement of seals.

The maximum counts (57 for grey seals, 223 for harbour seals) may be referred to as minimum estimates of population size for these species in this area as not all seals will be hauled out at any one time. Maximum counts can be multiplied by a correction factor in order to obtain estimates of population size. For example, population estimates for harbour seals are typically calculated using a combination of counts from moult surveys (when animals spend most time ashore) and data from telemetry that take into account the period of time animals spend at sea during this period. It is estimated that 60-70% of the harbour seal population will be counted during moult surveys resulting in a correction factors of approximately 1.5 (SCOS, 2009). Given the lack of species identity information, it is not recommended that this approach be applied in this study. As noted in the Methods section, improvements to the field methods were made in September 2009 (with the addition of a high-quality zoom lens for the digital SLR camera). However, being able to identify the different species while using the new equipment has still been an issue, e.g. none of the 40 seals counted in May 2010 were able to be identified to species (animals were only partly hauled out in shallow water and did not tolerate the plane approaching).

These counts took place on a monthly basis over a 21-month period during 2009 and 2010. Additional information on seal numbers in the area comes from counts undertaken by NERI, whose harbour seal moult counts from 1990 - 2009 have been summarised in Chapter 3.1. Differences to NERI surveys highlight the importance of carrying out multiple surveys during the time period of interest, and calculating an average count. Single monthly counts may not be representative because factors such as disturbance or weather conditions may have influenced the number of animals ashore on that day.

The number of harbour seals counted during the moult has trebled in the last two decades (Chapter 3.1). Unlike harbour seals, the number of grey seals using Rødsand has remained relatively constant over the last decade (increasing from the previous decade when relatively few were counted). For grey seals, up to 50 animals have generally been counted during NERI's surveys of Rødsand (Chapter 3.1), comparable to the maximum number counted in this study (57 in June 2010).

Rødsand is the most important haul-out and breeding site for harbour seals in the western Baltic Sea and about half of the Danish population is found here (Teilmann and Heide-Jørgensen, 2001). The maximum number of seals counted at haul-out sites is usually used for comparison between areas for harbour seals. The maximum count for harbour seals at Rødsand was over 200 individuals (in August 2010); 600 have been counted in the whole Baltic. In this respect it has to be mentioned that the Baltic population is very small compared to that in the North Sea: over 20,000 harbour seals were counted in the Wadden Sea in both 2008 and 2009 (Reijnders et al., 2009; Wolff et al., 2010) and over 3,000 in England in 2008 (SCOS, 2009).

The data provides evidence that grey seal numbers are still increasing in this area. 57 grey seals recorded in June 2010 (Table 3.1) is the highest number obtained so far. Total numbers of grey seals in the Baltic Sea exceed 20,000 individuals and as numbers are rising they extend their distribution range leading to increasing numbers in Inner Danish waters.

3.3. Telemetry

3.3.1. Introduction

This chapter describes the methods and results for the investigation of seal movements and behaviour within the Fehmarnbelt region. Our study focused on the use of GPS phone tags and the subsequent data analysis and reporting about the seals' movement patterns and habitat use. The use of GPS allows fine-scale details of animals' usage of specific haul-out sites and foraging areas to be determined. A tagging study using this technology provides the best possible data to allow a critical assessment of habitat use by these animals in Fehmarnbelt and any potential responses to a fixed link

3.3.2. Methods

We targeted the haul-out site at Rødsand where seals haul-out on sandbanks (Figure 3.3-1). At the other local site (Vitten-Skrollen) the seals hauled out on individual boulders over a wide area and so were more difficult to approach and capture.

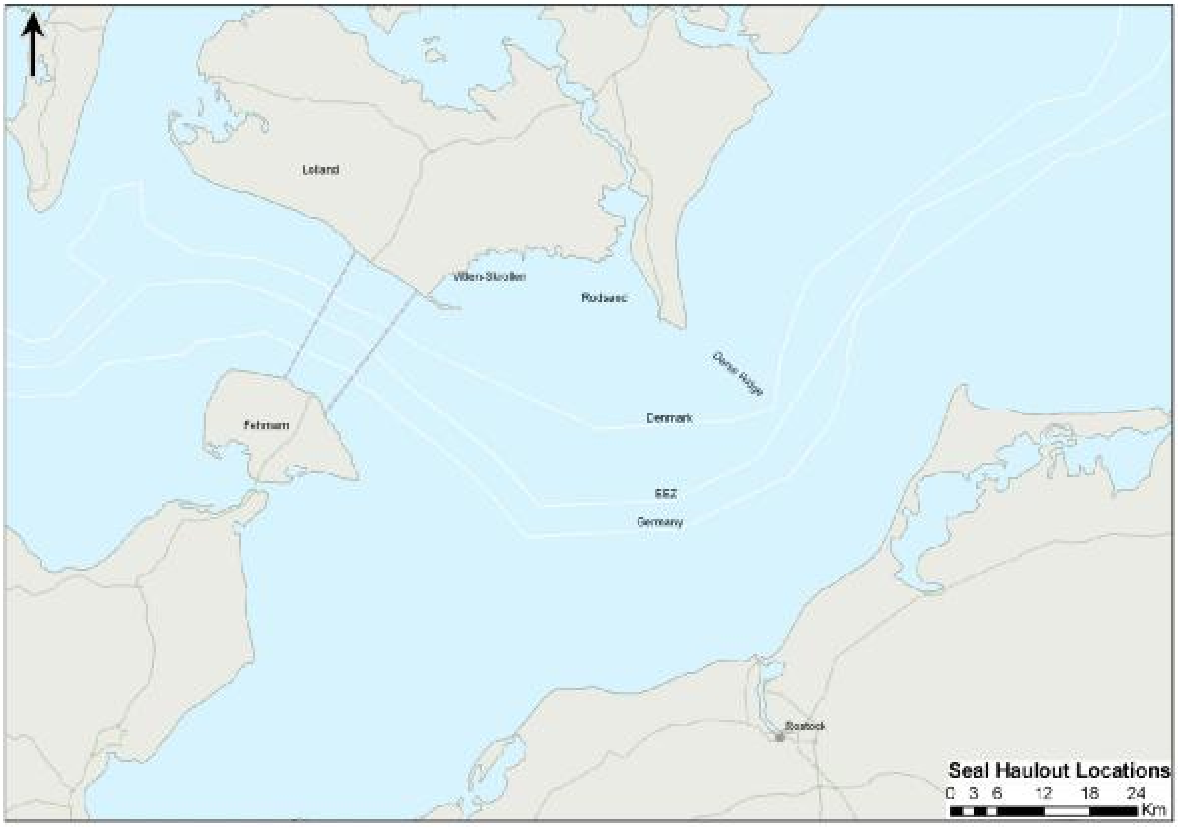

Figure 3.3-1 **Map of study area, showing haul-out locations (Rødsand and Vitten-Skrollen) and the area of the proposed fixed link (area within hatched lines).**

The primary capture method involved newly developed *pop-up nets*. 100 m of net was set off the haul-out site at Rødsand. The net was stowed within a canvas tube (c. 15 cm diameter) and was covertly anchored on the sea bed until seals hauled-out behind it and became accustomed to its presence. The net float-line comprised a deflated lay-flat fire hose and was remotely inflated from a compressed air cylinder via a radio surface buoy. This caused the covert net to suddenly surround the seals. In addition, tangle nets were also set at both haul-out sites.

To reduce unnecessary disturbance, a remote surveillance GSM camera was established overlooking the Rødsand haul-out (Figure 3.3-2). Images were relayed via the GSM mobile phone network (Figure 3.3-3). To facilitate any night-time capture an infra-red light was set up for night camera surveillance and to illuminate the area for night vision goggles.

Figure 3.3-2 **Remote camera mounted on Rødsand to monitor the presence of seals on land at the haul-out site (Photo: NERI).**

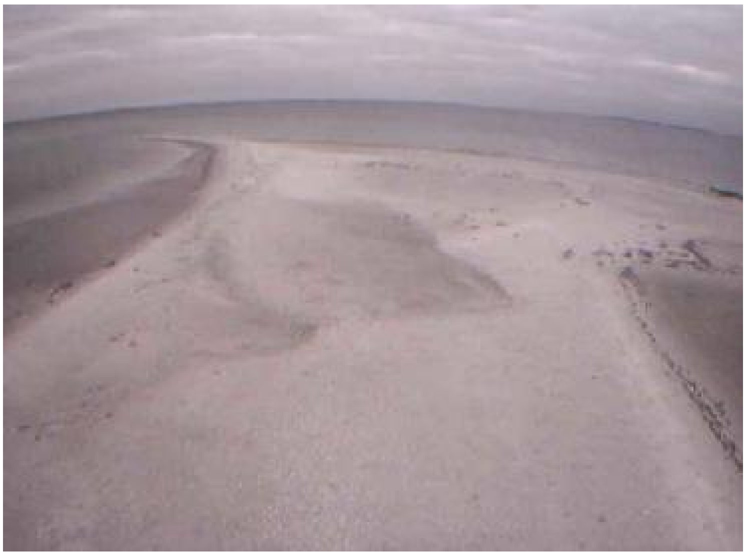

Figure 3.3-3 **Picture of the haul-out site at Rødsand taken by the remote surveillance GSM camera.**

3.3.2.1. Tagging

Once captured the seals were anaesthetised with Zoletil™. Standard morphogenetic measures were taken and samples were taken for health parameters (see chapter 3.4). Telemetry tags were then glued to the fur of the seal on the back of the neck using rapid setting epoxy (Cronin and McConnell, 2008).

Two types of telemetry tag were used: the Sea Mammal Research Unit's GPS/GSM tag[5] and the smaller Wildlife Computer Argos Spot tags[6]. The GPS/GSM tag is essentially a data logger that records the movements of a seal at regular intervals using a hybrid GPS system. Using a pressure sensor, detailed information about the depths (and depth profiles) and durations of individual dives are recorded. Also a wet/dry sensor is used to record when a seal is hauled out (continuously dry for 10 mins). These dive and haul-out records and the GPS location data are then opportunistically relayed ashore by an embedded mobile phone (GSM) modem when the tag comes within mobile phone coverage. Data are recorded continuously, whether or not the tag is within GSM coverage. The advantage of this type of tag is the frequency and accuracy of the GPS locations and the large amount of behavioural data that can be relayed over the high bandwidth mobile phone data channel (McConnell et al., 2010).

The Spot tag is a smaller and simpler device that essentially records approximate locations through time. It uses the Argos satellite system (Argos, 2008) to compute locations and to relay this information ashore. However there can be large errors (> 1 km – see Vincent et al., 2002) in these locations so fine scale movement patterns are frequently masked. The Spot tag does not record dive activity. However, it is considerably smaller than the GPS/GSM tag and thus is used on smaller animals to reveal gross movements.

3.3.2.2. Post processing

All Argos data (including historic Argos deployments) were filtered with a GAM smoother (M. Lonergan, SMRU, unpublished). GPS locations are occasionally subject to an error of > 100 m (owing to infrequent or reduced satellite availability during the signal capture phase). The GAM filter removed these erroneous location fixes. Tracks were then smoothed in x and y directions, which enabled quantification of uncertainty for each location and enhanced the accuracy of interpolation between locations. All times of day refer to GMT.

3.3.2.3. Analysis of individual tracks and behaviour

Filtered tracks were interpolated into 1 hour interval bins. The choice of bin interval was a compromise between data resolution and computational cost. Each 1 hour bin was assigned either hauled out or not hauled out using tag dry-wet sensor records. Tracks were then grouped into foraging trips. A seal was characterised as being on a foraging trip if it was >1 km from the departure haul-out site for >1 hour. The trips were indexed by the haul-out site of departure.

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[5] http://www.smru.st-and.ac.uk/instrumentation

[6] http://www.wildlifecomputers.com

3.3.2.4. At-sea usage estimation (harbour seals only)

Usage maps were constructed to describe the relative distribution of the population of harbour seals departing from the Rødsand and Vitten-Skrollen haul-out sites in Denmark. Since grey seal GPS/GSM tag data were available from only two grey seals, this analysis is confined to harbour seals. The usage estimation method is based on the two separate approaches by Aarts et al. (2008) and Matthiopoulos et al. (2004). The method constructs haul-out-specific usage maps by averaging individual usage. The maps are then scaled by the number of individuals counted at each site and combined into an aggregate map of usage, which predicts the 'average' usage by the whole population over the duration of the tagging deployment,

We aimed to model the distribution of seals foraging offshore and therefore considered only track locations that were not classed as "hauled out". Each animal was deemed to be on a foraging trip when they had departed the haul-out site for more than an hour and further than 1 kilometre away. This definition excluded usage from animals that were resting in water by the haul-out site. Each trip was then assigned departure and destination haul-out sites.

To estimate individual usage, each track location was coupled with control absence points. Absence points were used to quantify habitat availability in the study area. We generated five uniformly randomly distributed absence points for each track location. Each of the five absence points was assigned the respective time stamp, departure and destination haul-out site of the track location.

For each location and absence point, the shortest at-sea distances were calculated to the departure and arrival haul-out sites. The minimum of the two was used as an index of *accessibility* of at-sea locations. Accessibility is included in the model to account for higher usage of at-sea locations that are closer, and therefore more accessible, to the haul-out sites. Accessibility was calculated at 1x1 km grid resolution.

Environmental covariates and model selection

The presence-absence data was overlaid with 17 dynamic hydrographic variables (e.g. bottom current speed) and 4 static variables (e.g. bathymetry and sediment grain size) (Table 3.3-1).

A priori we do not suggest that any of these environmental covariates directly influence the distribution of seals. It is, however, likely that distribution is related to both the proximity of suitable haul-out sites and local prey distribution. Prey distribution might, in turn, be affected by the variables. The habitat covariates are thus considered as candidate proxies of prey distribution.

To select the set of habitat covariates that best describe the population distribution, we fitted a large set of possible models and compared their performance by information criteria (ubre score in binomial generalised additive model (GAM, mgcv package in *r* by Simon Wood, 2004)). We did not select models by step-wise selection because models with increasing number of covariates were found not to be nested in the presence of correlated explanatory variables.

Table 3.3-1 **Candidate covariates. Shading indicates similar measurements, but at different parts of the water column. The vertical component of current speed (W_10_bot) comprised vertical current speed at 10 meters and bottom vertical current speed in waters shallower than 10 metres**

	Covariate	Abbreviation
Dynamic	stratification depth	strat_depth
	stratification strength	strat_strength
	bottom current speed	CS_bot
	surface current speed	CS_surf
	bottom density	D_bot
	surface density	D_surf
	bottom current gradient	CG_bot
	surface current gradient	CG_surf
	bottom vorticity	vort_bot
	surface vorticity	vort_surf
	vertical current speed	W_10_bot
	bottom vertical current speed	W_10
	surface vertical current speed	W_surf
	bottom temperature	T_bot
	surface temperature	T_surf
	bottom salinity	S_bot
	surface salinity	S_surf
	salinity discharge	S_dis
Static	depth	depth
	distance to land	distLand
	grain size	grain
	shipping intensity	ship

Data from all animals and both haul-out sites were used to fit the different model structures. For reliable model selection, data were sampled to reduce serial correlation between subsequent track locations and avoid selecting overly complex models. One presence and five absence points were randomly sub-sampled from each trip, regardless of their duration. This down-sizing of the original presence-absence data (n=134,464) resulted in 1,120 absences and 224 presences that we could assume serially independent.

To separate the effect of habitat availability from other variables in terms of having to return to either of the haul-out sites, we assumed shortest distance to the haul-out site in the model structure without any model selection. We, therefore, fitted models with shortest distance and all combinations of 1-4 single covariates. For models with 2-3 covariates, we also allowed for 2-dimensional interactions (tensor products). Explored structures were therefore:

Presence ~ s(dist) + s(x1)	Model struct. 1.
Presence ~ s(dist) + s(x1) + s(x2)	Model struct. 2.
Presence ~ s(dist) + te(x1, x2)	Model struct. 3.
Presence ~ s(dist) + s(x1) + s(x2) + s(x3)	Model struct. 4.
Presence ~ s(dist) + te(x1, x2) + s(x3)	Model struct. 5.
Presence ~ s(dist) + s(x1) + s(x2) + s(x3) + s(x4)	Model struct. 6.

Where s(dist) is the accessibility covariate, s(x) is a single covariate and te(x1, x2) an interaction between covariates x1 and x2.

A total of 16,693 model structures were explored. There was strong support for models with 4-5 covariates, especially for 4-covariate models that included interaction terms. To check if more complex 5-covariate models could do better, we added a fifth term (either as univariate or interaction) to the best six models. All of these six models included four covariates, and five of them included an interaction term already. In other words, we also explored a limited number of models (270) with five covariates allowing for interactions, given that they performed as well as simpler model structures. Full details of the models tested are given in Appendix 7.7.

Dealing with high model uncertainty

There was little difference between the best models (1% quantile of all models) in terms of information criteria, but they fitted well to the data: explained deviances varied between 55-60% and there was strong support for all covariates. Any uncertainty in which model fitted the data best was probably due to the highly correlated covariates. For example, the stability of the water column could be partly described by both stratification strength and vertical current speed, or some interaction term of surface and bottom temperatures and salinities. Because of this model uncertainty, we considered a range of models with the lowest ubre scores (1% quantile). We re-fit these models to another 20 randomly drawn datasets from the original data. To compare models across the datasets, we ranked their ubre scores within each dataset. We also re-ran model selection for simple structures (Models 1-3) with 10 different population samples. The purpose of re-fitting all simple model structures was to make sure (within computational limits) that the original sample from the data did not have undue influence in selecting the best set of more complex models in that one sample. We would have more confidence in a complex model if its components were performing well already as a simple model structure.

Constructing usage and relative uncertainty maps

The best model was used to fit and predict usage for each tagged individual departing from each haul-out site. Predictions were made at 1x1 km grid resolution. For prediction, the significant covariates were averaged for each grid cell across the study period (October 2009 – May 2010). Accessibility was averaged using the number of transits between each haul-out site as weights. The individual usage surfaces were scaled to one and then averaged over the haul-out region. Thus every individual contributed to the haul-out-specific map in equal amount.

To give relative population distribution, the haul-out-specific maps were scaled by the number of seals counted at each site (n=149 in Rødsand and n=31 in Vitten-Skrollen). These counts were the mean counts during the 2000-2009 annual moult surveys. Since we used haul-out counts as opposed to a population abundance estimate, the predicted densities are relative rather than absolute.

Uncertainty in predictions of usage was estimated by resampling. The sampling was carried out at three levels: model uncertainty, between individual uncertainty and uncertainty related to the population size. The parameters of each individual usage model were resampled 100 times (parameter sample). The stored parameter samples were then resampled by individual with replacement 100 times for each haul-out region (capture sample). The predictions from each individual in the capture sample were then scaled up to the number of individuals at each haul-out site. The mean and variance of each offshore probability was thus calculated from [100 capture samples]*[number of tagged individuals] *[number of individuals counted] predictions.

3.3.2.5. Inference of feeding areas

The track data provide no direct indication of when (and thus where) feeding occurred. However a visual inspection of the track data suggests that there were three phases of behaviour: hauled out on land, fast movement at sea and slow movement at sea. We make the assumption that the latter is associated primarily with feeding. However, we do not discount the possibility of feeding opportunistically during travel.

In harbour seals most of their dives are to the bottom, even when seals are travelling – dives are generally V shaped when travelling and U shaped when feeding, as more time is spent at the bottom and less horizontal distance is covered (McConnell et al., 1999). We therefore picked horizontal travel rate as a putative proxy of feeding. Inspection of the frequency distribution of hourly travel rates failed to show any obvious bimodal distribution of fast and slow travel rates that might have been expected from travelling and feeding respectively. An arbitrary travel rate threshold was set at 0.3 m/s. Thresholds of 0.2 m/s and 0.5 m/s were also applied and the patterns that emerged were similar to those from the 0.3 m/s chosen threshold. Haul-out periods are omitted here. We refer to the two groups of locations as fast and slow to emphasise that there is no direct evidence for mapping the slow group to feeding. The distribution of the slow locations is overlaid with sea bed substrate type (Substrate map_FEMA, Femern EDIS).

3.3.3. Results

3.3.3.1. Harbour seals

Deployment

In October 2009 five harbour seals were tagged at Rødsand – four adult males and a female juvenile. The four males were fitted with GPS/GSM tags; the juvenile female was fitted with an Argos tag. The deployment details and tag longevity are shown in Table 3.3-2. The four GPS/GSM tags lasted for an average duration of 173 days and produced an average of 63 location fixes per day. The Argos tag lasted 152 days and produced an average of 5.9 locations fixes per day.

Table 3.3-2 Details of harbour seals fitted with tags in 2009 (GSM = mobile phone SMRU GPS/GSM tag, Argos = Wildlife Computers Spot tag)

ID	Date	Sex	Age	Mass (kg)	Length (cm)	Girth (cm)	Tag type	Duration (days)
28-12-09	27/10/2009	M	adult	103	156	123	GSM	195
28-10-09	27/10/2009	M	adult	90	137	117	GSM	177
60265	27/10/2009	F	juvenile	32	104	83	Argos	152
28-05-09	27/10/2009	M	adult	97	149	119	GSM	100
28-07-09	27/10/2009	M	adult	113	153	123	GSM	220

Individual tracks

The tracks from all four adult male harbour seals showed that they remained within 50 km of the two haul-out sites (Figure 3.3-4 to Figure 3.3-7). To the south the 20 m depth contour line delimited most of the tracks but there were several meandering trips south-east to the coast of Germany. To the east they were bounded by the Darss Ridge or an area 10 km to the northeast of the ridge. To the west the Fehmarnbelt study area formed an approximate boundary, with only a few incursions into the study area.

The tracks were marked by low intra-individual variability. Each seal targeted localised hot spots (see the *Inference of feeding areas* above).

The juvenile female harbour seal (tagged with the Argos tag) travelled much further (Figure 3.3-8). It first transited the Fehmarnbelt study area and then headed east and then northwest to Avnø Fjord and Agersø Sund where it hauled out. It later made two trips 200 km north to the island of Laesø.

Figure 3.3-9 shows the combined tracks of all harbour seals (only partial track of seal 60265).

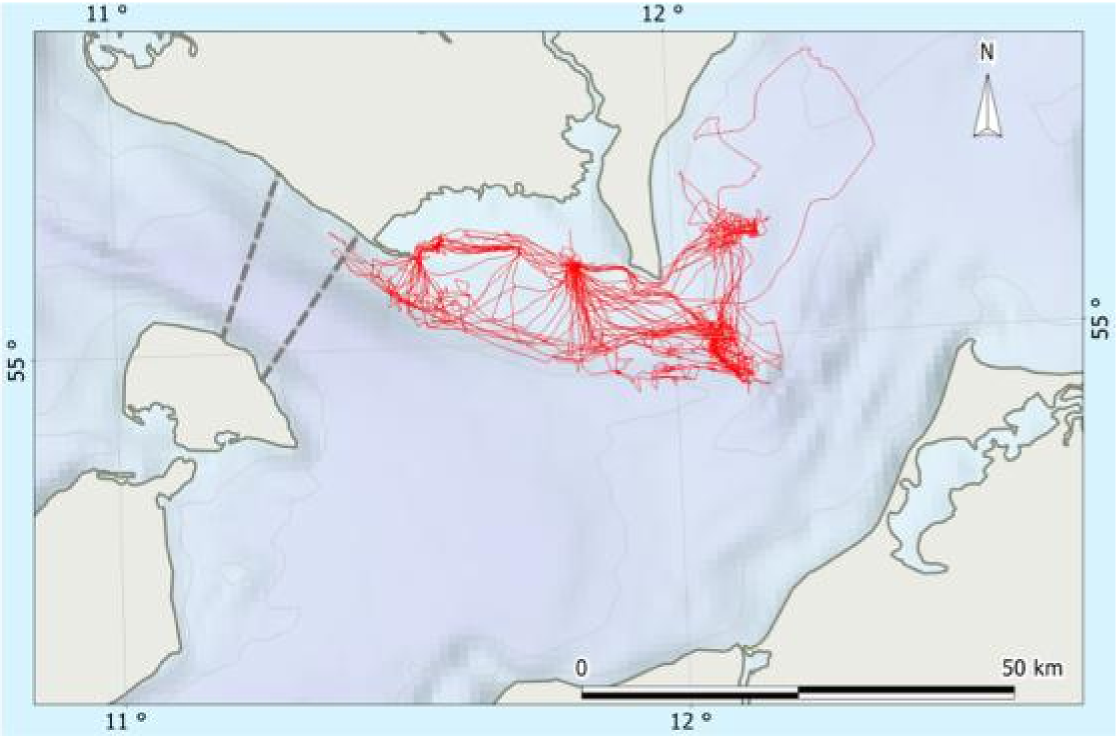


Figure 3.3-4 Tracks of adult male harbour seal ID 28_05_09.

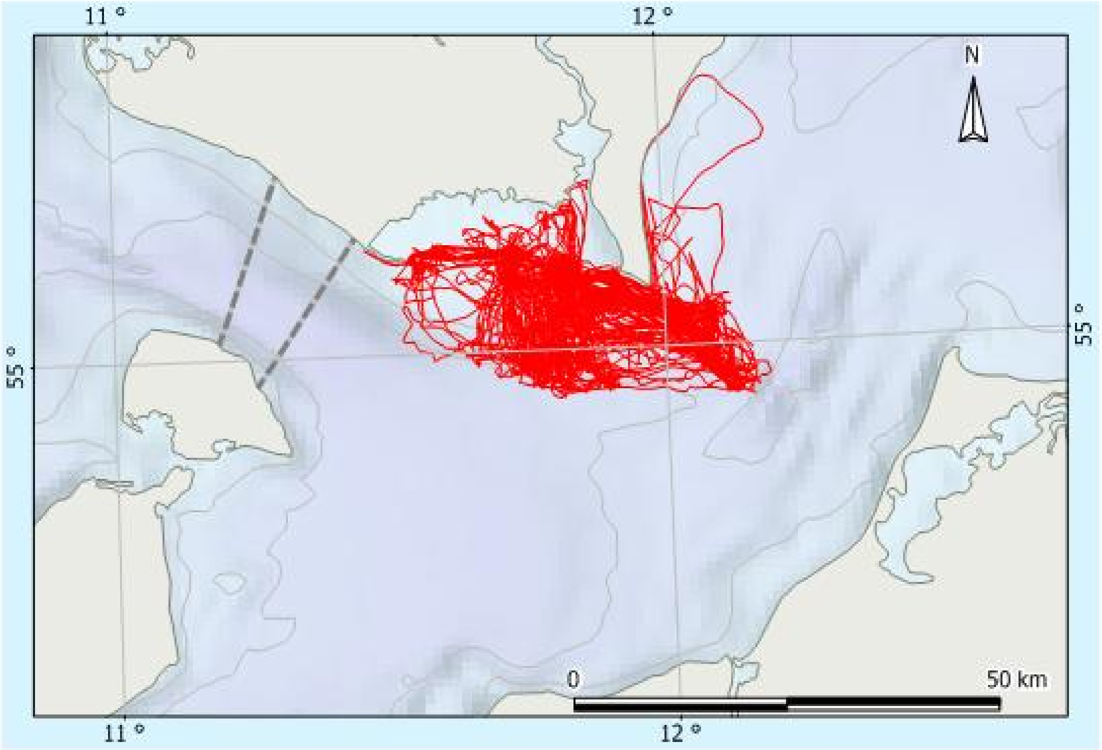


Figure 3.3-5 Tracks of adult male harbour seal ID 28_07_09.

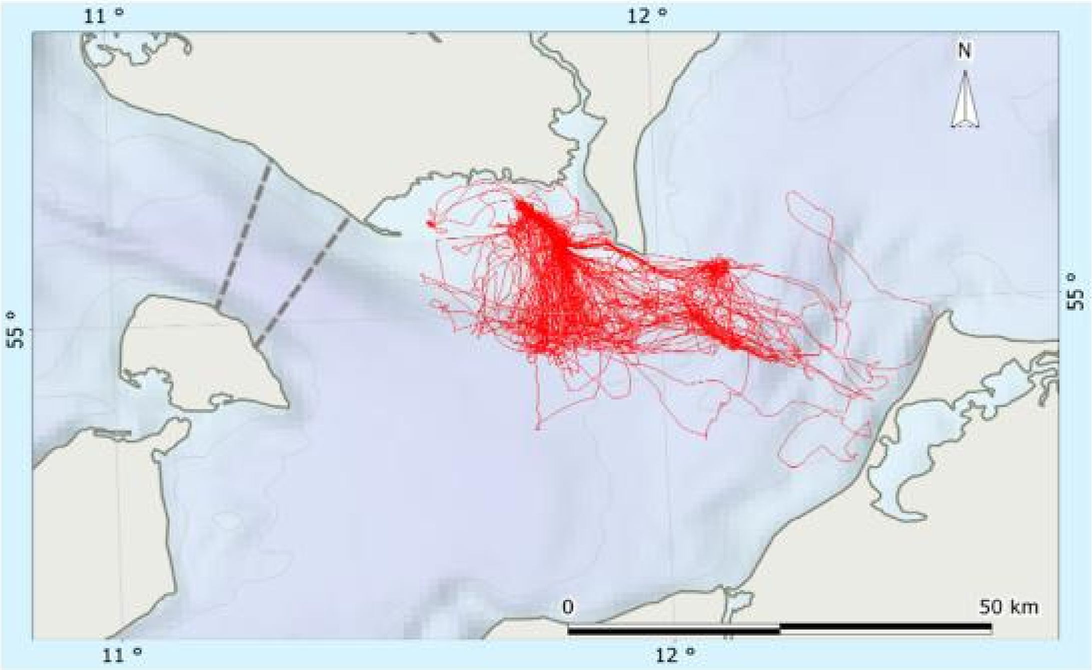


Figure 3.3-6 Tracks of adult male harbour seal ID 28_10_09.

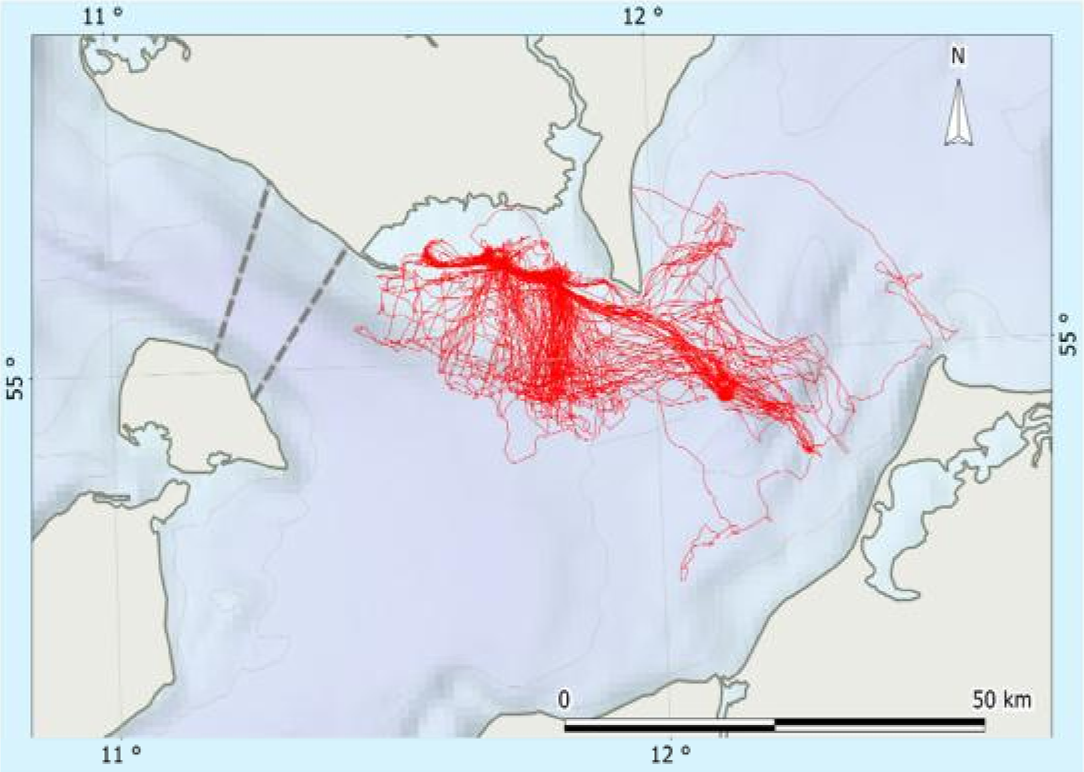


Figure 3.3-7 Tracks of adult male harbour seal ID 28_12_09.

Figure 3.3-8 Tracks of juvenile female harbour seal ID 60265.

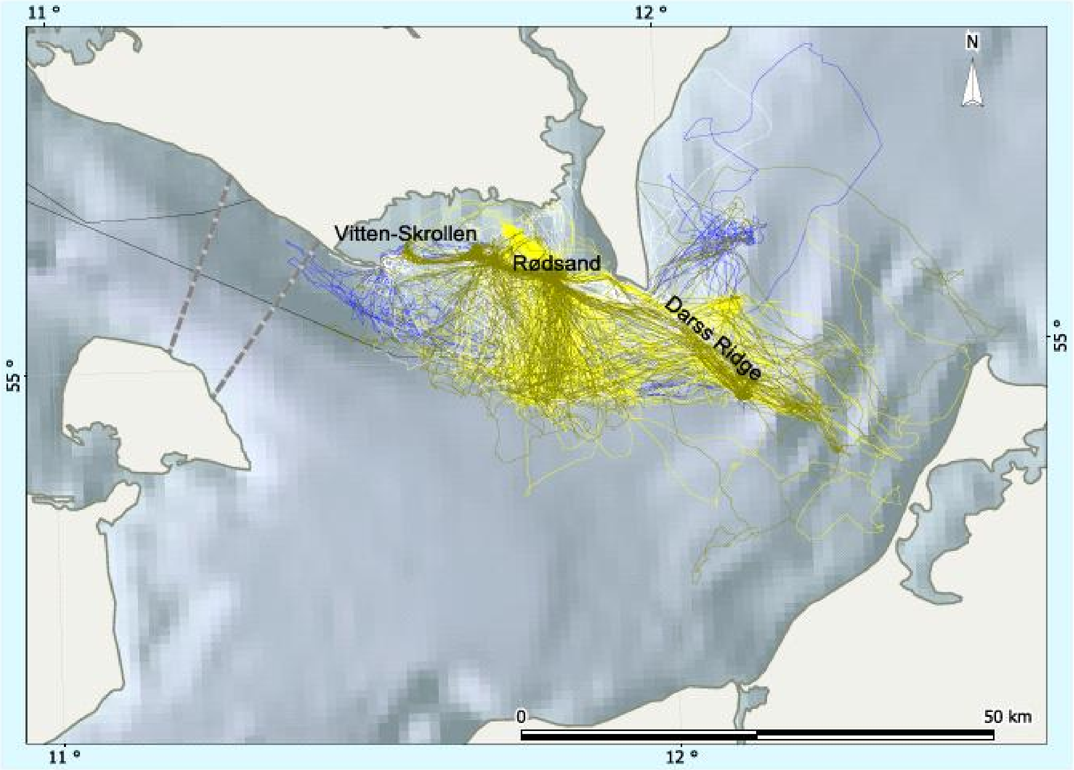


Figure 3.3-9 Combined tracks of all harbour seals (only partial track of seal 60265).

Feeding trip statistics

The tracks of the GPS/GSM tagged adults were grouped into feeding trips (see *Methods*). Overall the mean trip duration for the four adults was 66 hours and the individual means varied from 56 to 79 hours. However, the frequency distribution was skewed to the left (see Figure 3.3-10). Overall the median trip duration for the four adults was 42.6 hours and the individual medians varied from 26.5 to 61.0 hours. The mean maximum trip extent was 17 km with the individual means ranging from 13.1 to 23.6 km (Figure 3.3-11). All trips were within 50 km of the departure haul-out site (Figure 3.3-12).

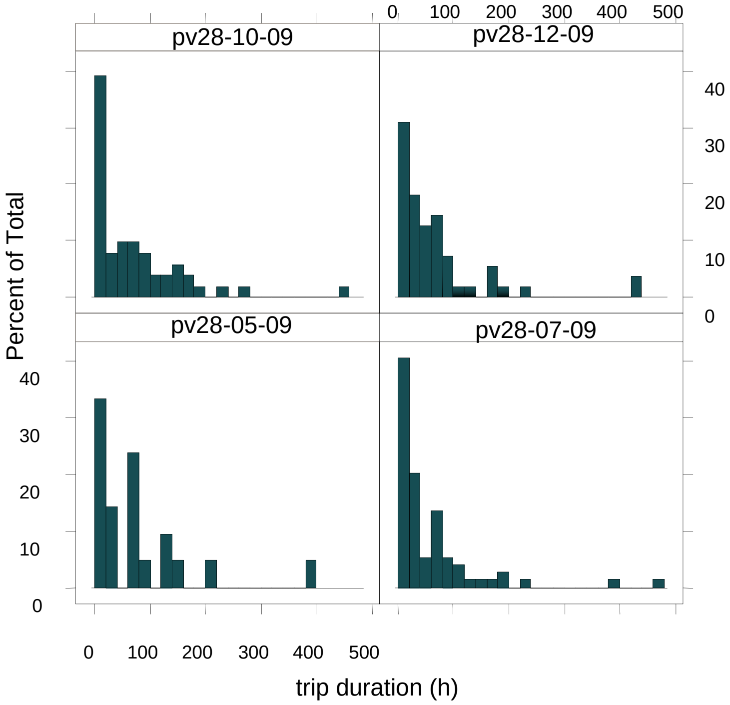


Figure 3.3-10 Frequency distribution of harbour seal trip duration by seal.

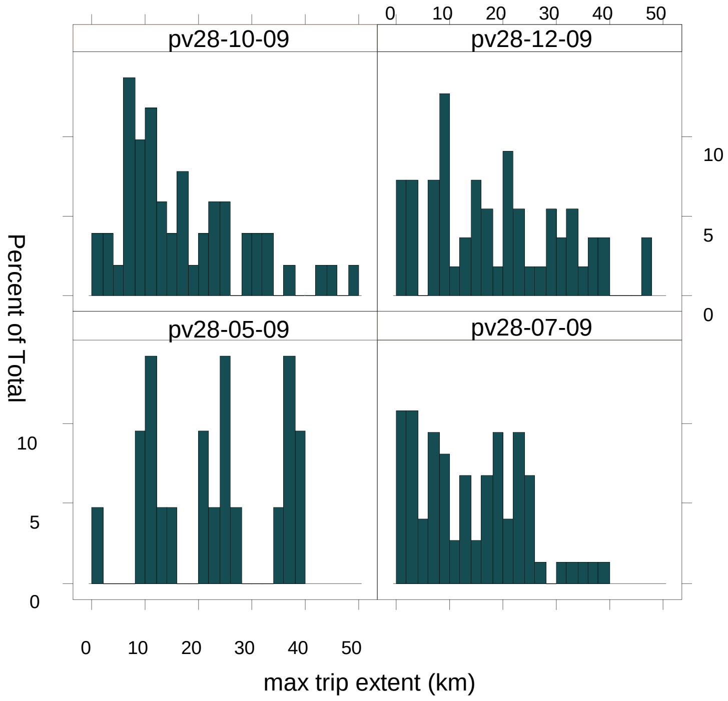


Figure 3.3-11 Frequency distribution of harbour seal maximum trip extent, by seal.

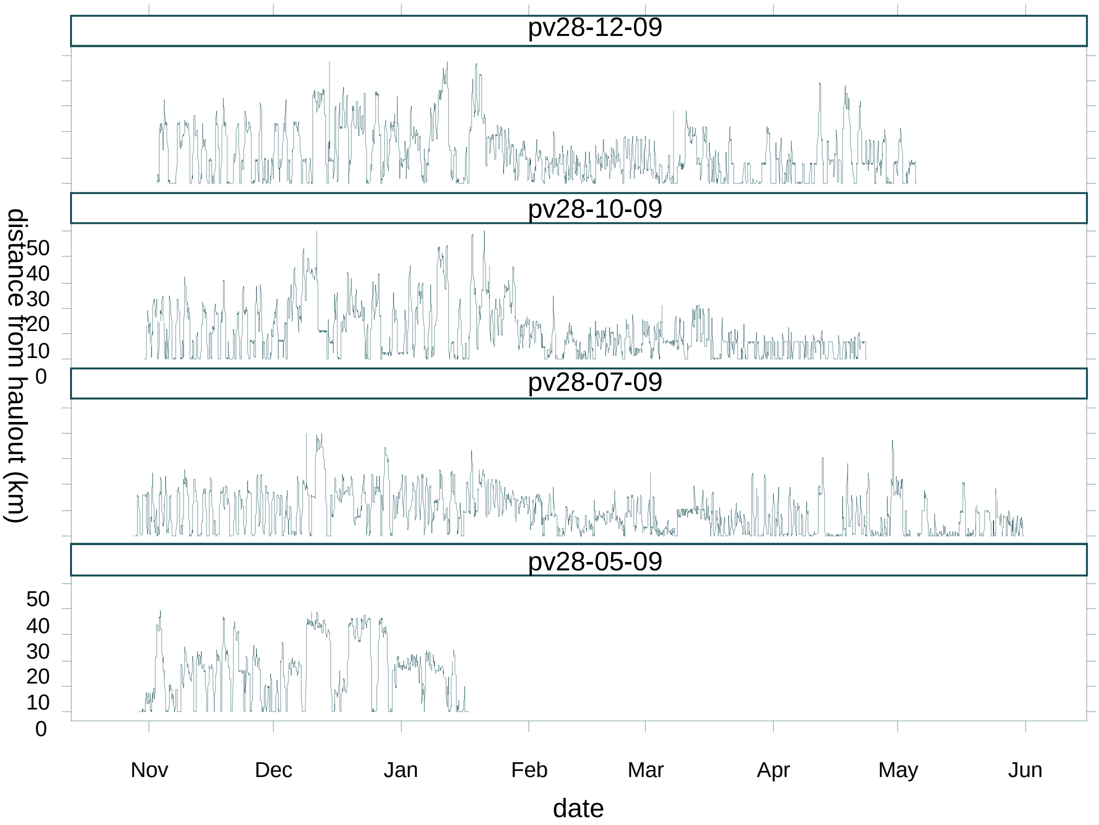


Figure 3.3-12 Distance to the next haul-out used through time.

Haul-out patterns

The four adults only hauled out at Rødsand or Vitten-Skrollen. Seals 28-10-09 and 28-12-09 approached the German coastline several times but did not haul-out there. In contrast the Argos tagged juvenile hauled out at three other, distant sites to the North (see Figure 3.3-8).

The mean proportion of time spent hauled out was 0.13 with the individual means ranging from 0.12 to 0.14 (Table 3.3-3).

There was evidence of seasonality with a reduction in time spent hauled out from November to March and thereafter an increase.

Table 3.3-3 Harbour seal mean and quantile statistics of 14-day proportion of time hauled out

	14-day proportion of time hauled out		
ID	mean	Lower 2.5%	Upper 97.5%
28-05-09	0.1235	0.04538	0.2093
28-07-09	0.1366	0.0093	0.2834
28-10-09	0.1186	0.0133	0.2535
28-12-09	0.1428	0.0019	0.3352
all	0.1319	0.1319	0.3159

Diurnal variability in the haul-out patterns is shown in Figure 3.3-13. Three animals (28-7-09, 28-9-09, and 28-12-09) initially showed a strong diurnal pattern of hauling out at night. From January there was a reduction in the time spent hauled out on land and the trips were longer. After two months the haul-out periods were more frequent, with a preference for the middle of the day. For two of these seals this phase coincided with a move from Rødsand to Vitten-Skrollen. Seal 28-5-09 showed little initial diurnal haul-out pattern and since the tag only lasted 100 days, no seasonality, as described for the other three, was apparent.

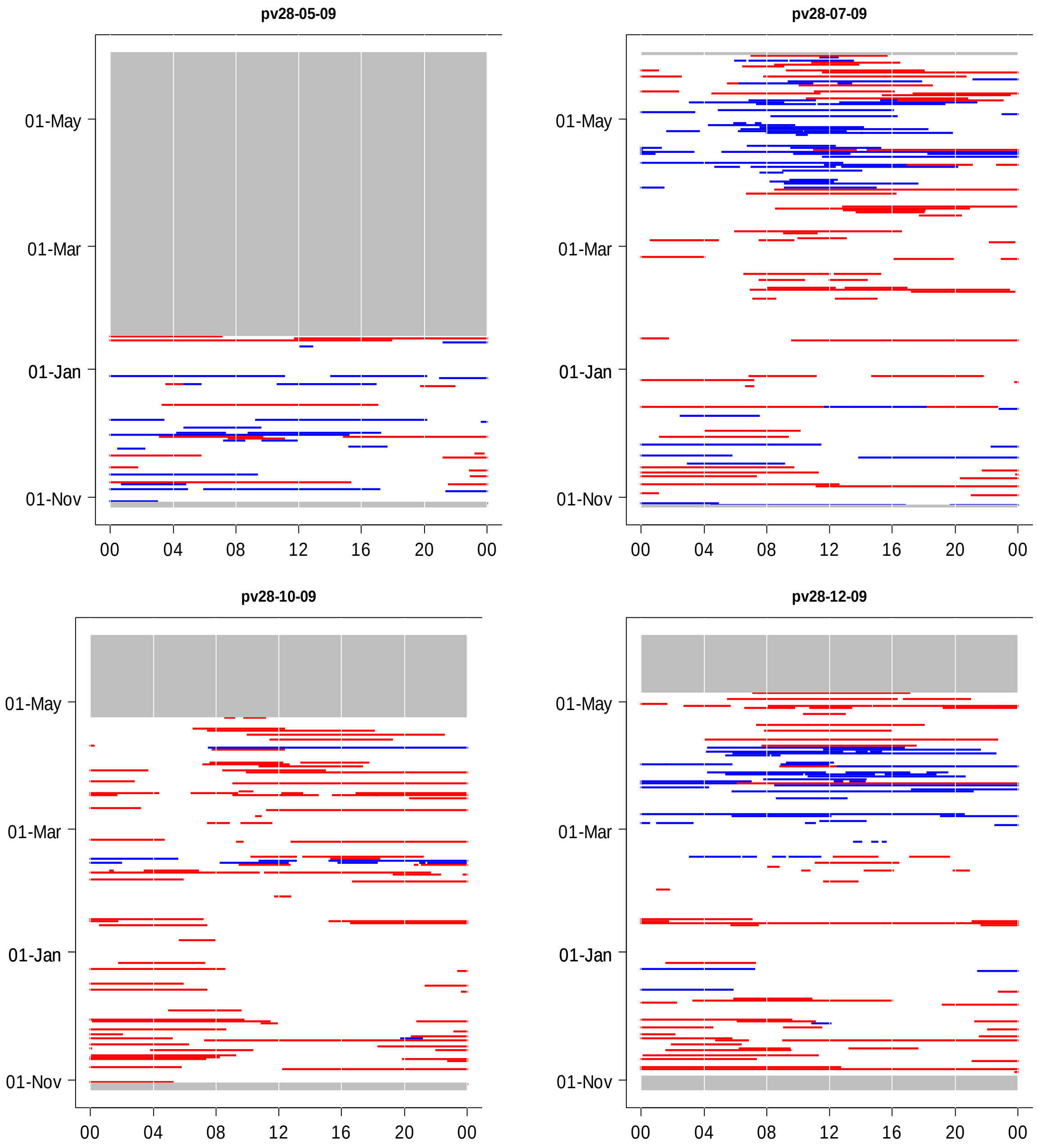


Figure 3.3-13 **Haul-out patterns of harbour seals collected by the GPS/GSM tags. The horizontal lines indicate the duration of haul-out bouts and are colour coded by the haul-out site (Rødsand = red, Vitten-Skrollen = blue, other = black). Grey shading indicates periods without data.**

Dive behaviour
Mean dive duration for four GPS/GSM tagged harbour seals was 2.8 min, with individual means ranging from 2.7 to 3.1 min. The overall mean maximum dive depth was 8.4 m, with individual means ranging from 7.7 to 10.0 m.

Figure 3.3-14 shows the maximum dive depths plotted against local seabed depth. Those dives whose maximum depth was greater than the seabed depth were due to slight inaccuracies in the geographic interpolation of the dive locations and the spatial resolution of the bathymetry. An average of 91% of all dives deeper than 5 m extended deeper than 90% of the local seabed depth. The lower plot in Figure 3.3-14 shows a subset of those dives with slow horizontal travel rate (<0.3 m/s) derived for location fixes. 91% of these dives extended deeper than 90% of the local seabed depth (compared to 86% for those with faster travel rates).

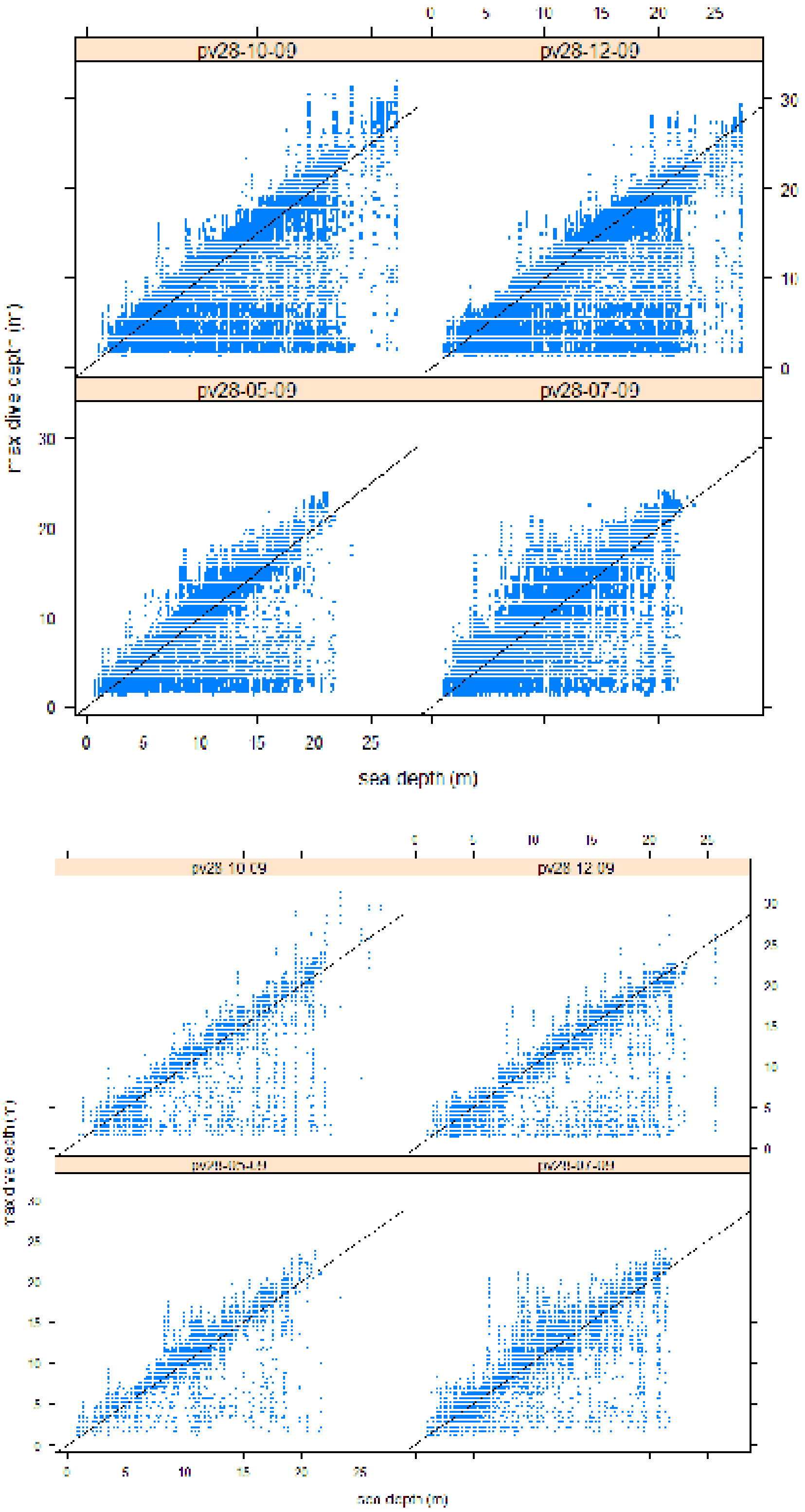


Figure 3.3-14 Maximum harbour seal dive depth as a function of local sea bed depth, grouped by seal. The black line has a slope of 1.0. The lower panel is a subset of the upper panel where the estimated travel rate is <= 0.3 m/s.

At-sea usage

The final model chosen (see Appendix 7.7.2 for details of the selection process) is expressed as:

Presence ~ s(dist) + s(CS_bot) + te(depth, T_bot)+ t(T_surf)

The important covariates were distance to haul-out, bottom current strength, a tensor (interaction term) product between water depth and bottom temperature and surface temperature. The relationships are shown in Figure 3.3-15. Figure 3.3-16 shows the estimate of relative adult harbour seal population usage. This represents the estimated population distribution when the harbour seals are not hauled out on land. Figure 3.3-17 shows the corresponding map of relative uncertainty (expressed as coefficients of variation). A ‘hot spot’ is evident within the Rødsand lagoon. This reflects that seals which had hauled out at Vitten-Skrollen spent most of their time in a localised area near the haul-out site.

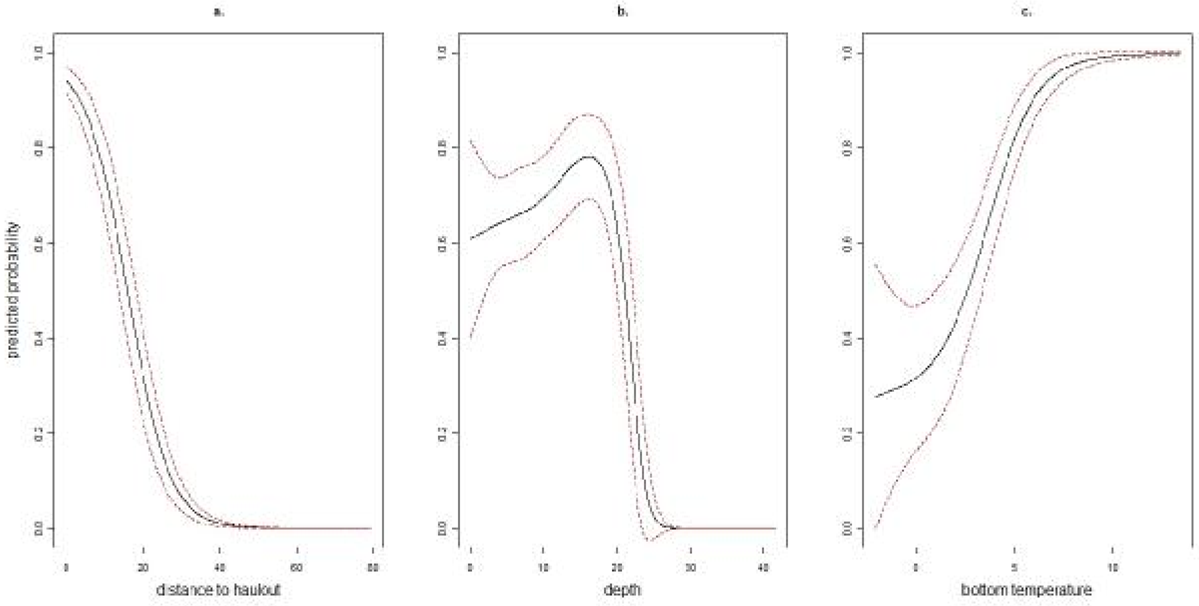


Figure 3.3-15 Predicted relationships from the chosen model Probability as a function of distance to haul-out (a), depth (b) and bottom temperature (c), given mean values for all other covariates in the presence data.

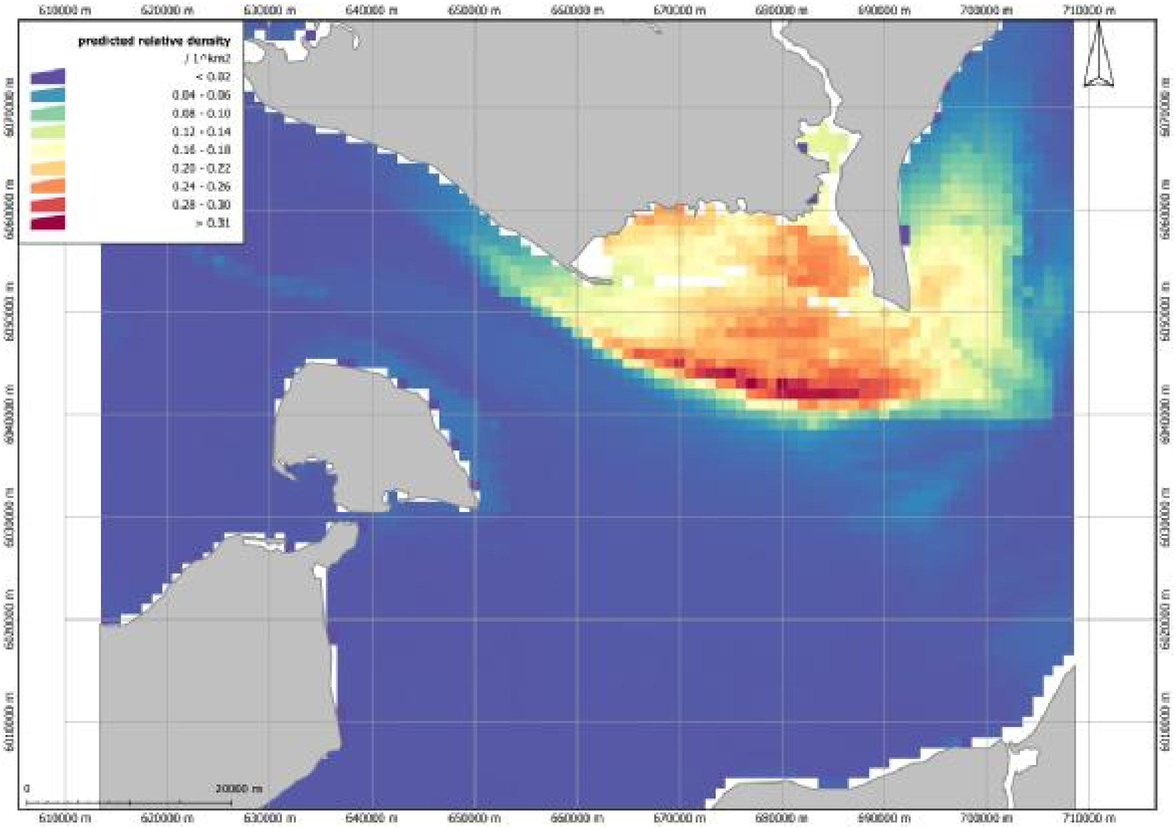


Figure 3.3-16 **Predicted usage surface for adult harbour seals. This is the mean distribution, using the mean model habitat covariates over the period of tracking.**

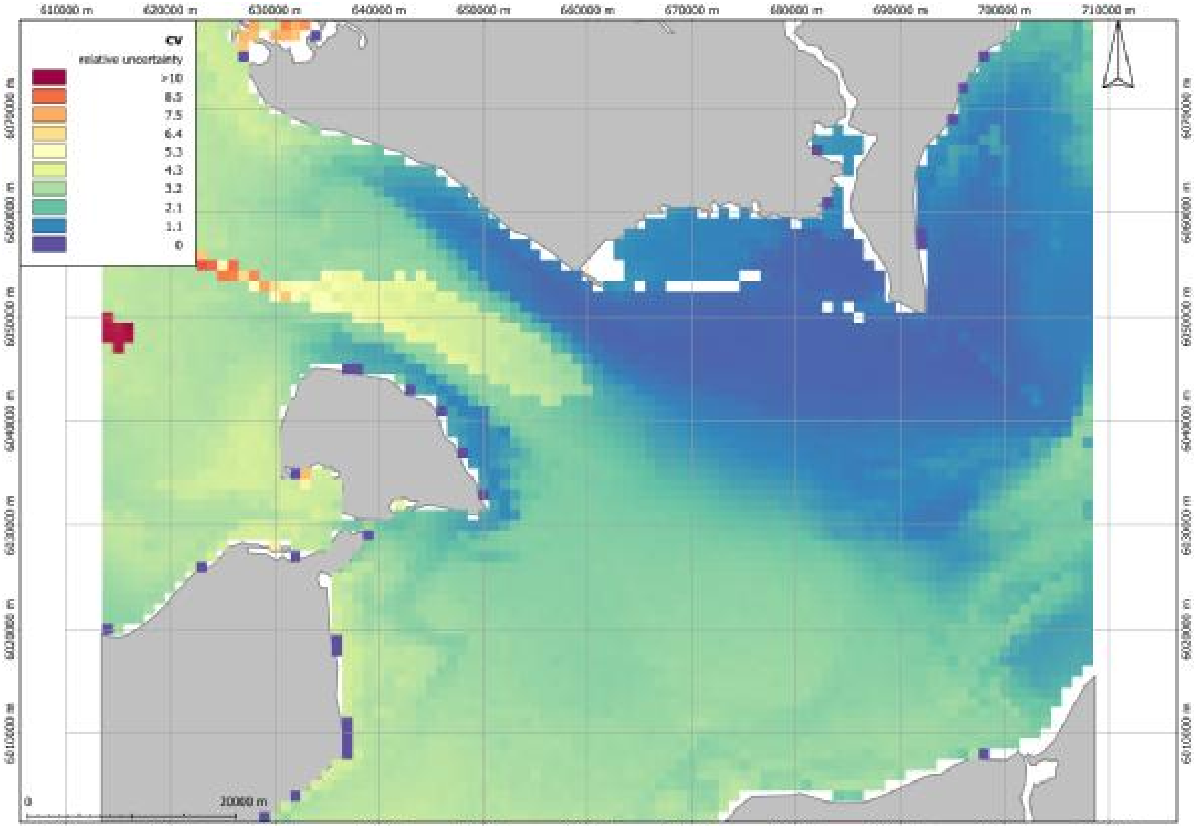


Figure 3.3-17 Relative uncertainty (coefficient of variation) of the usage surface for adult harbour seals.

Inference of feeding areas

Harbour seals positions that were classified as feeding trips were grouped by seal and overlaid on substrate type (Figure 3.3-18). Monthly subsets are shown in the Appendix 7.7.1; an example for the month of November is shown in Figure 3.3-19.

The distribution of slow-travel rate locations (< 0.3 m/s) was similar for all four harbour seals. Outside of the Rødsand Lagoon slow-travel rate locations were concentrated in localised hot spots. At a larger geographic scale they were primarily in three areas: an area up to 15 km south of Rødsand, the Darss Ridge, and an area about 10 km to the north of the Darss Ridge. Most were contained within the 20 m depth contour. Inside the Rødsand Lagoon there were very localised hot spots at, and between, the Vitten-Skrollen and Rødsand haul-out sites. This is a very shallow (< 3m) area strewn with boulders on which seals haul-out. The usage here may be activity before and after hauling out – perhaps sometimes due to disturbance by local fisheries.

There was a strong association with substrate type. 96% of slow travel rate locations (6455 / 6732), within the area where substrate data were available, were in either 'coarse sediment / boulders' or 'sand'. Finer substrates (those containing some quantity of mud) contained the remaining 4% of slow travel rate locations.

Within this substrate association, there was a change in slow location distribution through time (Figure 3.3-19 and Appendix 7.7.1). In November and December the Darss Ridge and the area to the north were heavily used. But this usage decreased in January. In February and March the slow locations outside the Rødsand Lagoon were exclusively in the area to the south of

Rødsand. From March through to May, slow locations were increasingly contained within the Rødsand Lagoon.

Slow locations from just one of the four adult harbour seals (28-05-09) occurred near or in the Bridge Study Area. In November and December this seal approached and entered the south eastern boundary of this zone – but always with in the ‘coarse sediment / boulder’ substrate zone that runs across the northern part of the Belt.

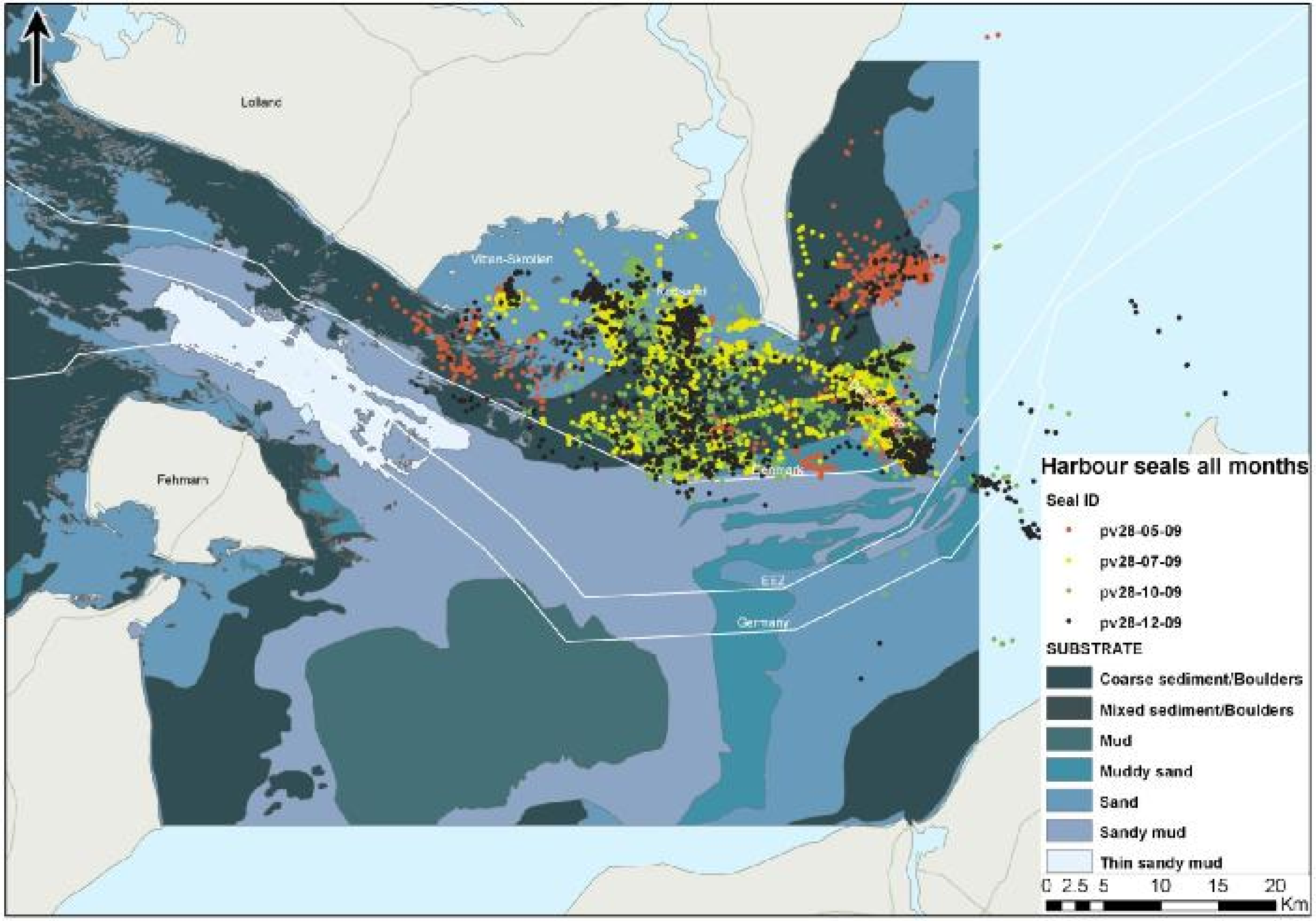


Figure 3.3-18 Map of slow locations of the four GSM/GPS-tagged harbour seals, colour-coded by seal, overlaid on substrate type.

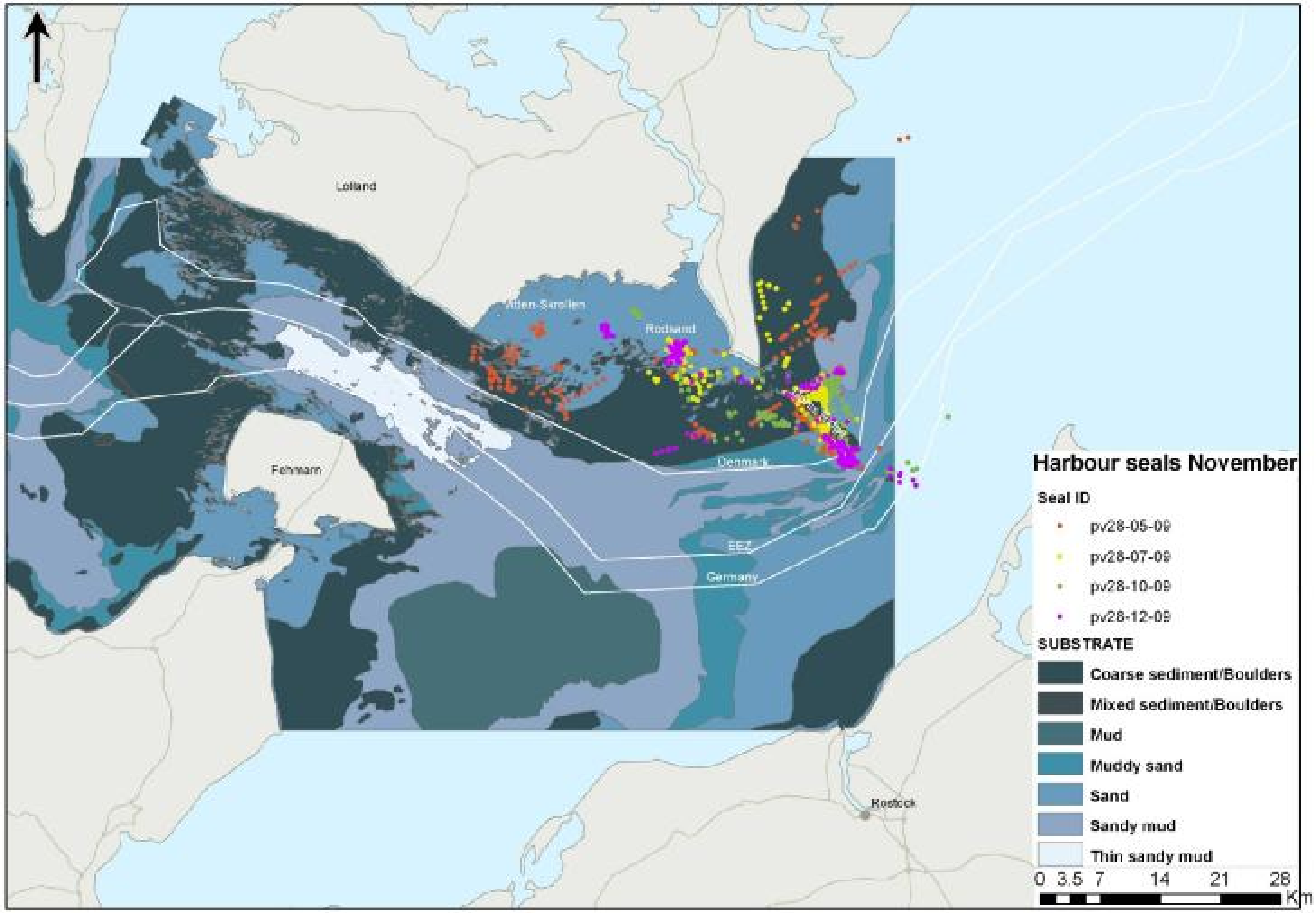


Figure 3.3-19 Map of slow locations of harbour seals for the month of November 2009, colour-coded by seal, overlaid on substrate type.

3.3.3.2. Grey seals

Deployment

In October 2009 two juvenile grey seals were tagged with GPS/GSM tags at Rødsand – one male and one female. The deployment details and tag longevity are shown in Table 3.3-4. The two GPS/GSM tags lasted for an average duration of 150 days and produced an average of 90 location fixes per day.

Table 3.3-4 Details of grey seals fitted with a tag in 2009 (GSM = mobile phone SMRU GPS/GSM tag)

ID	Tagging date	sex	age	mass (kg)	length (cm)	girth (cm)	tag type	Duration (days)
28-02-09	31/10/2009	M	juvenile	49	117	94	GSM	183
28-04-09	24/10/2009	F	juvenile	48	112	89	GSM	118

Individual tracks

The tracks of the two tagged grey seals are shown in Figure 3.3-20 to Figure 3.3-22. The temporal sequence of movements is shown as the distance away from the next haul-out site used in Figure 3.3-23. The tracks of two tagged juvenile grey seals showed more extensive movements and greater inter-individual variation than those of the adult harbour seals in this study.

Seal 28-4-09 travelled regularly (mean trip duration of 72 hours) from the Rødsand haul-out across the Fehmarnbelt to a localised area 10 km to the east of Fehmarn (Figure 3.3-22). On 28 Oct this pattern was interrupted by a two-day excursion westwards through the planned area for the fixed link. This area was not used again by this seal. In the majority of these trips the seal took a more easterly outwards route and a more westerly return route, resulting in an overall clockwise movement. The regular trips were again interrupted on 25 Jan with an eight-day meandering trip to the northeast of the Darss Ridge. For the remaining two weeks of tracking the (initially intensively used) area to the east of Fehmarn was never again visited.

For the first 10 days seal 28_02_09 meandered within 50 km of the Rødsand lagoon, crossing once to the German coast – but not hauling out there. It then undertook a 10-day excursion to the south of Sweden, hauling out at the Måkläppen Nature Reserve, Falsterbo (c. 20 km to the south of the Øresund crossing). This general pattern was repeated twice more. In Jan 2010, however, it remained within 50 km of Falsterbo for about 70 days, before returning to Rødsand. In this latter trip it hauled out repeatedly near the Øresund Bridge, once crossing past the bridge to a haul-out site on the distant side. Subsequently, one more trip was recorded, but this time it extended north-east to Nykøping, 100 km south west of Stockholm and 600 km from Rødsand.

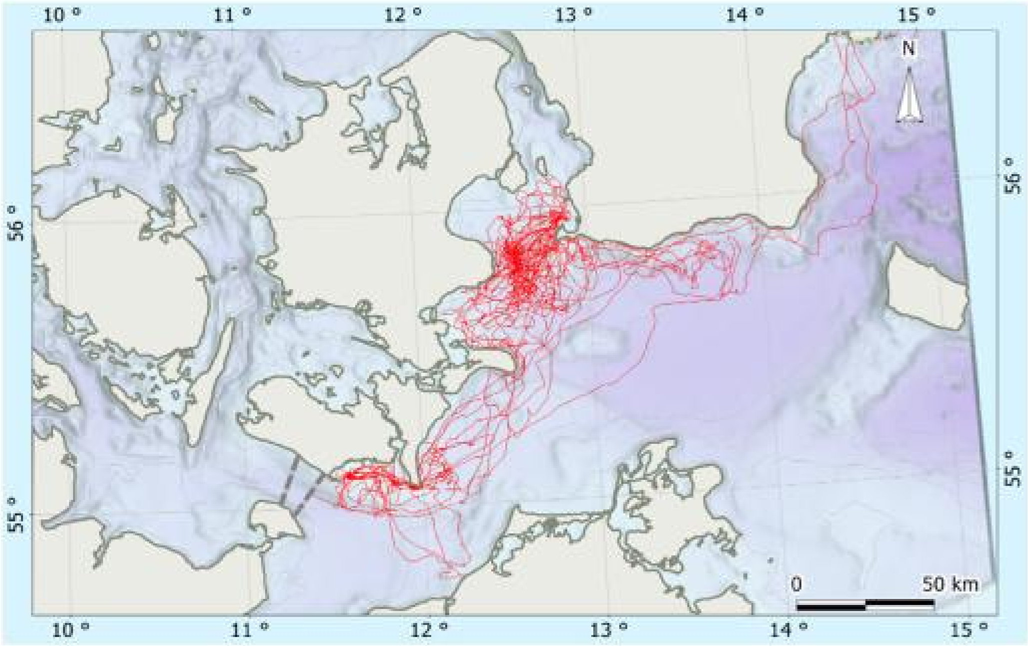


Figure 3.3-20   Tracks of juvenile male grey seal 28_02_09.

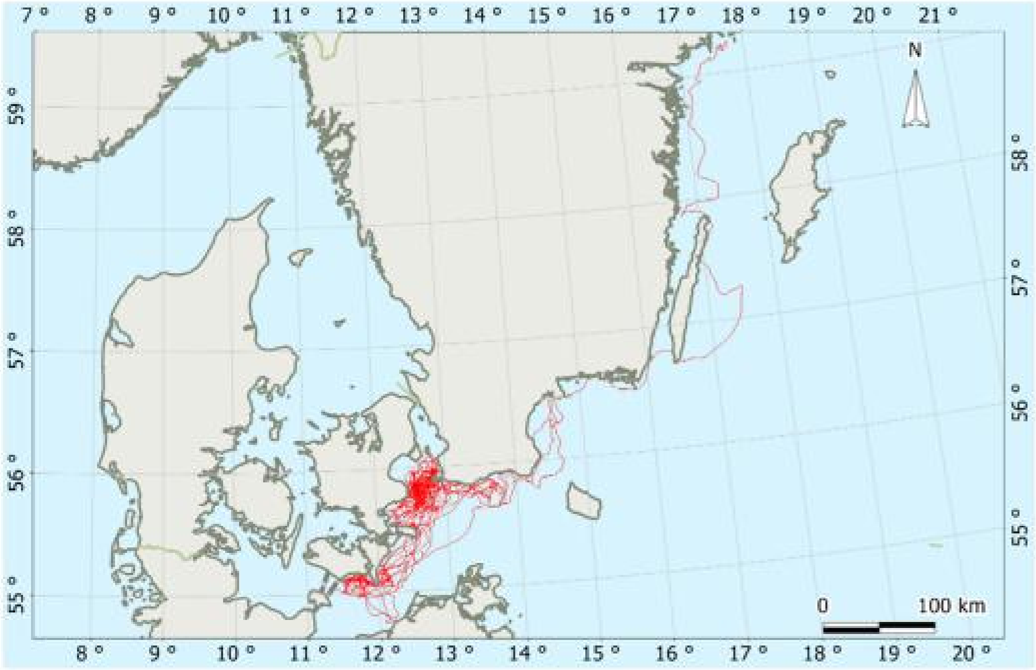


Figure 3.3-21   Tracks of juvenile male grey seal 28_02_09 (shown at smaller scale).

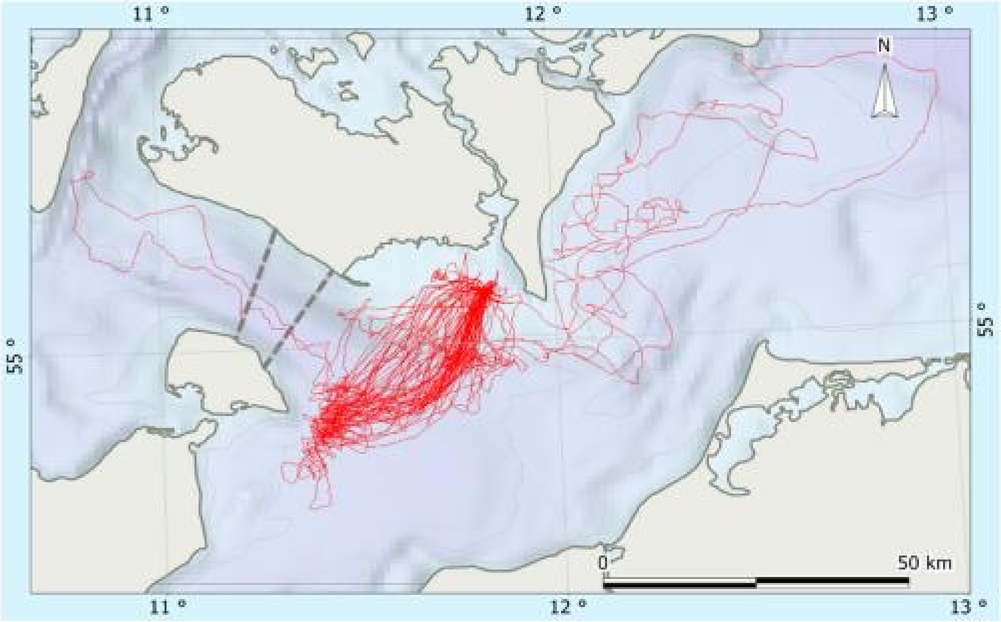


Figure 3.3-22 Tracks of juvenile female grey seal 28_04_09.

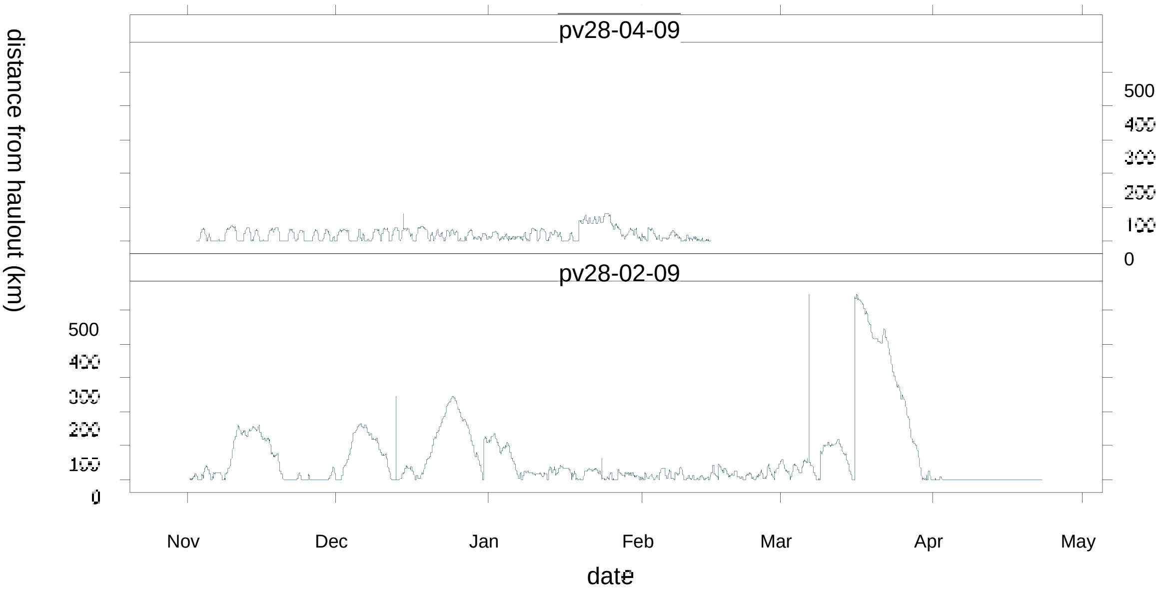


Figure 3.3-23 Temporal sequence of tagged grey seal movements illustrated by the distance to the next haul-out site used.

Haul-out patterns

The average proportion of time hauled out for the two juvenile grey seals was 0.17 (28_02_09 = 0.19; 28_04_09 = 0.16; Table 3.3-5). 28-04-09 almost exclusively used the Rødsand haul-out site. In contrast 28-04-09 hauled out in November and December almost exclusively at Vitten-Skrollen. Thereafter, it hauled out at a number of distant sites on the coast of Sweden.

Diurnal patterns were observed in haul-out behaviour. In November and December 28-04-09 hauled out less (October through February) between 10:00h and 16:00h GMT. Initially a similar pattern was evident for the other juvenile grey seal (28-02-09) during the time it was initially hauled out at Vitten-Skrollen. Thereafter it hauled out less at an earlier period: c. 04:00h to 12:00h (Figure 3.3-24).

Table 3.3-5 Grey seal mean and quantile statistics of 14-day proportion of time hauled out

	14-day proportion of time hauled out		
ID	mean	Lower 2.5%	Upper 97.5%
28-02-09	0.1870	0.0116	0.8076
28-04-09	0.1592	0.0081	0.3211
all	0.1759	0.0043	0.6915

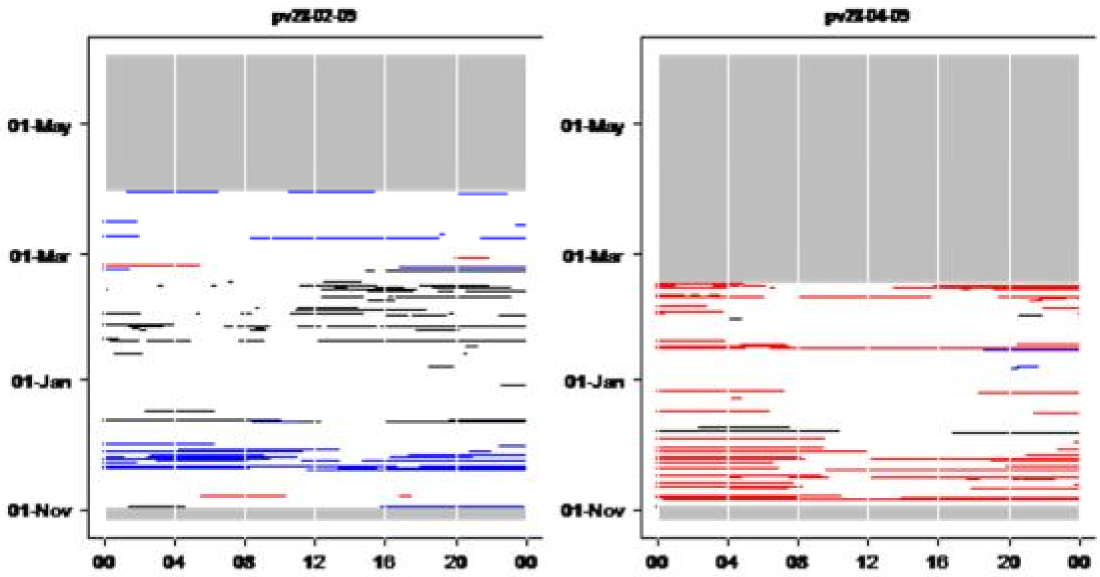


Figure 3.3-24 **Haul-out patterns of juvenile grey seals collected by the GPS/GSM tags. The horizontal lines indicate the duration of haul-out bouts and are colour coded by the haul-out site (Rødsand = red, Vitten-Skrollen = blue, other = black). Grey shading indicates periods without data.**

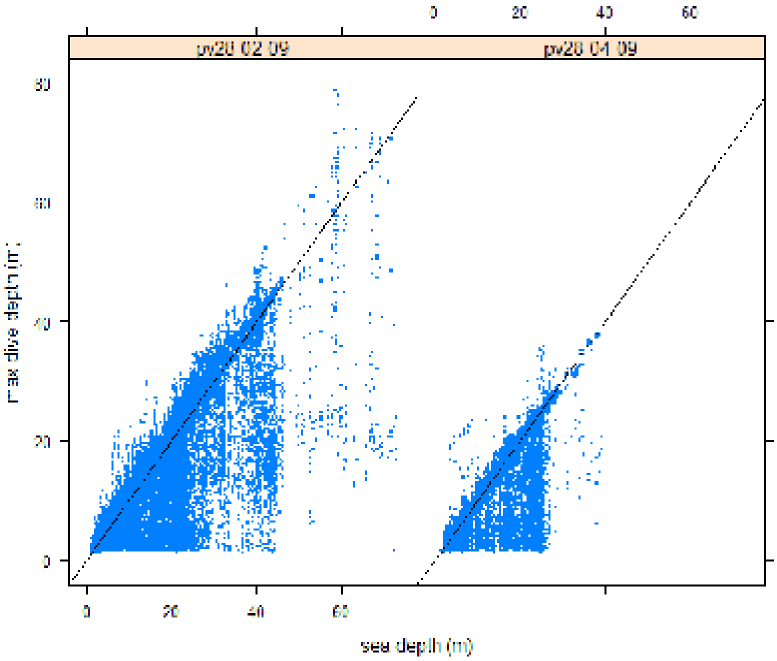
Dive behaviour

Mean dive duration was 2.10 min, with individual means ranging from 2.00 to 2.27 min. Mean maximum dive depth was 14.9 m, with individual means ranging from 14.7 to 15.1 m.

Figure 3.3-25 shows the maximum dive depths plotted against local seabed depth. Those dives whose maximum depth was greater than the seabed depth were due to slight inaccuracies in the geographic interpolation of the dive locations and the spatial resolution of the bathymetry. An average of 84% of all dives deeper than 5 m extended deeper than 90% of the local seabed depth. The lower plot in Figure 3.3-25 shows a subset of those dives with slow horizontal travel rate (< 0.3 m/s) derived for location fixes. 89% of these dives extended deeper than 90% of the local seabed depth (compared to 83% for those with faster travel rates).

Inference of feeding areas

The slow grey seal travel rate locations, grouped by seal and overlaid on substrate type, are shown in Figure 3.3-26. Seal 28-02-09 spent little time within the area of Fehmarnbelt and travelled east towards Sweden. However, the other grey seal (28-04-09) made regular trips from Rødsand haul-out to a diffuse area to the east of Fehmarn. Unlike the harbour seals, this area comprised only ‘mud’ or ‘sandy mud’ substrates.



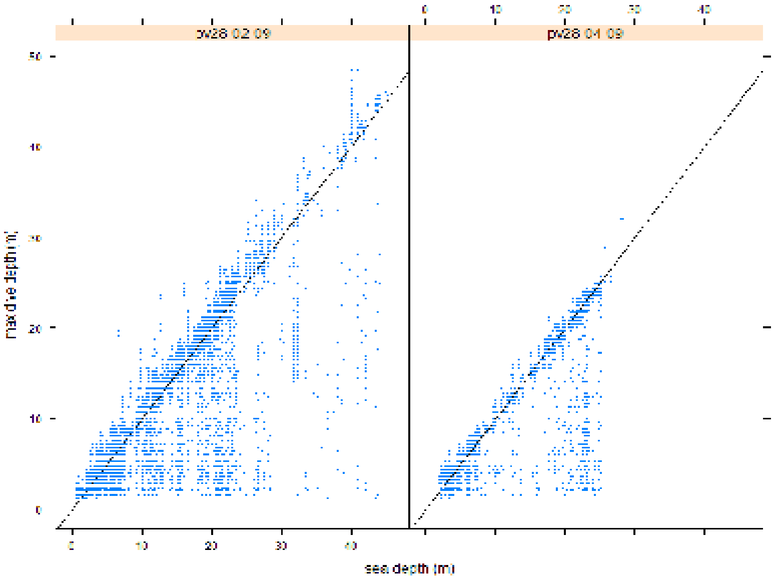


Figure 3.3-25 **Maximum dive depth in grey seals as a function of sea bed depth. The black line has a slope of 1.0. The lower panel is a subset of the upper panel where the estimated travel rate is <= 0.3 m/s.**

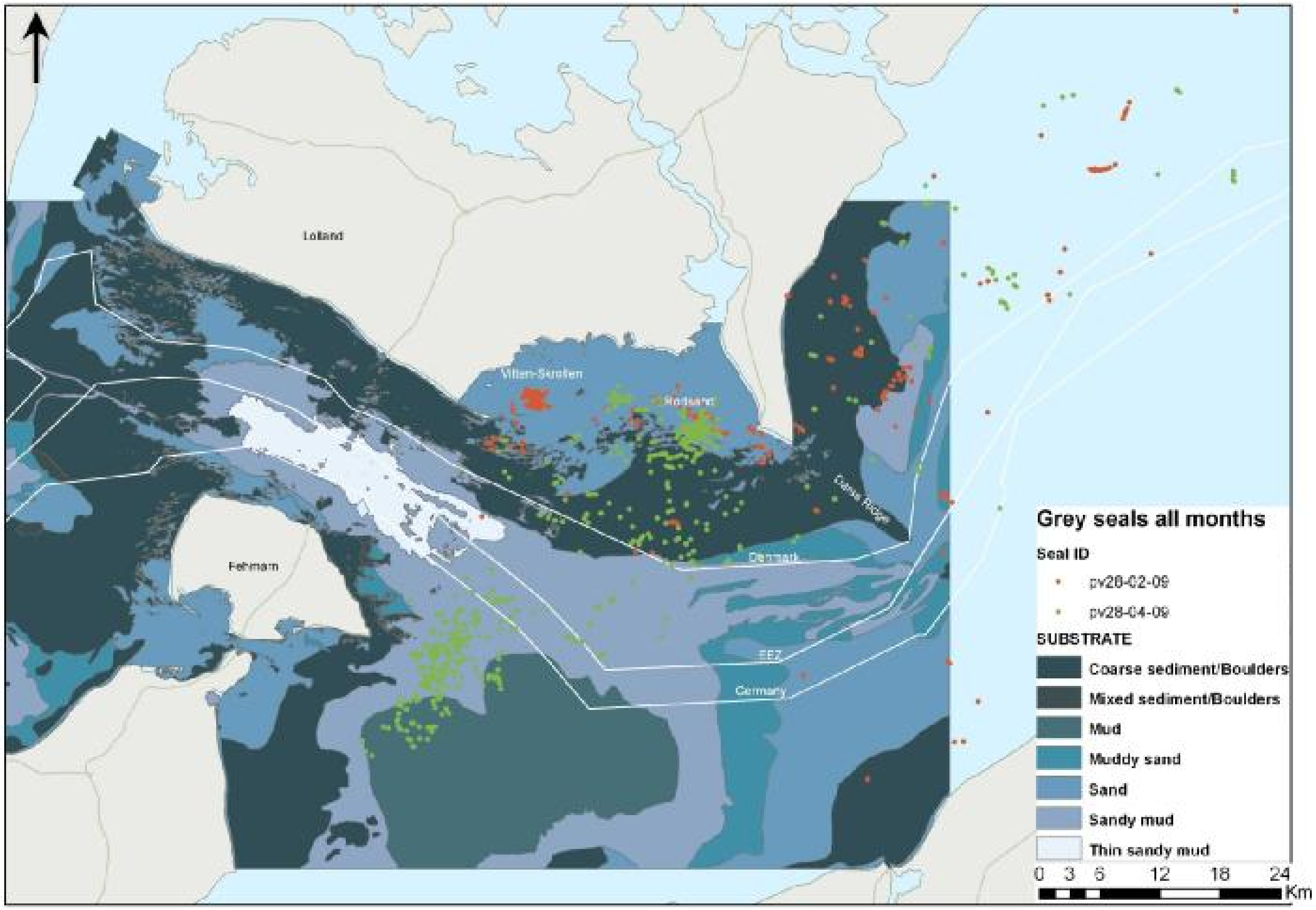


Figure 3.3-26 Map of all slow locations of grey seals, colour-coded by seal, overlaid on substrate type.

3.3.4. Discussion

Methods applied: Catching, Deployment and Telemetry Performance
The aim of this study was to tag 12 seals in the Rødsand Lagoon, in order to allow an examination of their use of the Fehmarnbelt region. Whilst the main emphasis was on harbour seals, we also chose to tag any grey seals that were caught. The target number of 12 seals was based on a compromise between having a good sample size and excessive disturbance caused by efforts in catching a larger number. Catching this number proved difficult without causing undue disturbance, owing to the very open nature of the study area and high visibility of researchers to the seals. However, the development of pneumatic pop-up nets was the key to the success in catching a total of seven seals – five harbour seals and two grey seals.

The quality and quantity of the information from the GPS/GSM tags was very high – producing an average of 90 precise GPS locations per day. In addition, each produced an average of 88 haul-out records and 5333 dive records over an average longevity of 165 days. The fine granularity (temporal and spatial) of the movement data from the GPS/GSM tags allowed us to infer feeding areas and thence preferred habitats.

The more compact, but less sophisticated, Argos Spot tag was deployed on the juvenile harbour seal because of its smaller size, but this still provided valuable information of its gross movements.

3.3.4.1. Harbour seals

Regionally, the conservation status of the harbour seal population at the Rødsand Lagoon is of the highest importance. The well-being of this population depends upon both the maintenance of relatively undisturbed haul-out sites and the continued local availability of prey.

We have shown that, at least for the season monitored, adults forage within 50 km of the two main haul-out sites of Rødsand and Vitten-Skrollen. This observation concurs with the previous study of Dietz et al. (2003) which showed that harbour seals foraged within 50 km of the haul-out sites year-round (see Appendix 7.7.3). Studies elsewhere, such as those undertaken on harbour seals in Scotland (Cunningham et al., 2009; Sharples et al., 2009; Thompson et al*.,* 1998), also support the finding that harbour seals forage in a restricted range. For example, on the west coast of Scotland, results from 24 satellite tagged harbour seals showed that 50% of the animals restricted their foraging trips to within 25 km of their haul-out (Cunningham et al., 2009).

The usage map (Figure 3.3-16) is a model prediction of *relative* harbour seal densities per 1 km^2 grid and does not represent *absolute* densities of animals at sea. The prediction relates to the time when seals are on foraging trips, i.e. when they are not hauled out and when they are more than 1 km from their departure haul-out site. The map predicts seal usage in average hydrographic conditions during October 2009 – May 2010 and will be less accurate under other hydrographic conditions. However, the usage map does show that the adult harbour seals do not heavily utilise the planned area for the fixed link. Extrapolating to the population level we predict that, when adult harbour seals are not hauled out, only about 0.5% of the population would be within the planned area for the fixed link, and only 2% would be in this area or to the west of this area. We include this extended westward area to account for the hypothesis that, whilst there is little usage within the planned area for the fixed link itself, it could be used as a corridor to the west. However, our results show that this scenario is unlikely, or of little effect.

Our prediction of very low population usage within the planned area for the fixed link is subject to uncertainty. The spatial distribution of uncertainty is shown graphically in Figure 3.3-17. It is evident that there is regional variability in the uncertainty estimates. Generally, uncertainty is greater in areas where there are fewer data, or where there is a large degree in variability of animal movement patterns – the latter having a higher effect when the sample size is small. However, the relatively low mean coefficients of variation (within the 1x1 km cells) within the planned area for the fixed link provides confidence that our very low estimate of relative usage in that area is precise and robust. This method of estimating at sea population usage is based on the work of Matthiopoulos et al. (2004). However McConnell et al. (2009) recently used this method to update usage maps of grey seals on the southeast coast of Scotland.

There were many potentially important habitat variables (= potential proxies of prey abundance) that could influence the local seal distribution. The tagged seals travelled from their haul-out sites to forage in areas that were shallower (less than 20 metres deep) than nearby deeper areas (Figure 3.3-19). These areas also appeared to have somewhat weaker levels of stratification (Appendix, Figure 7.7-7) and less dense / saline bottom water (Appendix, Figure 7.7-8). In the study area, density of bottom water was almost solely determined by bottom salinity, and both were correlated with surface salinities and densities (Appendix, Figure 7.7-9). Foraging areas also appeared to be characterised by higher surface and bottom temperatures (Appendix, Figure 7.7-10). The areas may also have higher bottom current speeds (Appendix Figure 7.7-11), which may be a proxy for greater grain size (Appendix Figure 7.7-12), which is a characteristic of the sediment type found in areas of higher bottom currents. Grain size, in turn, might affect fish movements and therefore indirectly, the movement preferences of harbour seals in the area.

We were also able to identify putative feeding areas and we have characterised them by their high energy substrates. We made the reasonable assumption that feeding areas may be identified by slow travel rates at sea (for a discussion see Kuhn et al., 2010). Dive records indicate that most dives extended to the sea bed and thus we infer that a significant proportion of foraging was on epi-benthic prey similar to studies on Californian harbour seals (Grigg et al., 2009). This concurs with the diet studies that indicate that sandeels (*Ammodytes marinus*) and cod (*Gadus morhua*) form a significant proportion of diet (see Chapter 3.4). These species have habitat preferences for sand and rough boulder substrates respectively (Thedinga et al., 2008; Gregory et al., 1997). We have shown that the majority (96%) of feeding (= slow-travel rate) locations outside the Rødsand Lagoon were contained within either 'coarse sediment / boulders' or 'sand' substrate types. Within the Lagoon there were also several well-defined hot spots of slow travel rate locations. However the substrate data available indicate the lagoon as just one substrate type – ‘sand’. We were thus unable to characterise the Lagoon hot spots with regards to substrate type at any finer resolution.

‘Coarse sediment / boulders’ or ‘sand’ are referred to as high energy substrates and contain no mud. The distribution of feeding hot spots varied seasonally. Also, the haul-out behaviour indicated a change from day-time feeding trips in November / December to night-time feeding trips in spring. This may reflect seasonal changes in the diurnal availability of local prey availability. The results found here should be integrated with fish and hydrographic studies in order to explain and predict future changes in foraging behaviour in the Rødsand harbour seals. There was also seasonality in the amount of time spent hauled out, with a reduction from November to March. The lowest point corresponded with the period of highest ice cover in the Rødsand Lagoon.

All the adult harbour seals tracked hauled out at either Rødsand or Vitten-Skrollen. This suggests that the Rødsand Lagoon adult harbour seal population is a discrete unit. Thus, these two haul-out sites are the appropriate and sufficient sites to target regular aerial censuses of hauled out seals (see Chapter 3.2). However, the possible extended range of juveniles (see below) may not make this true for all age classes.

The single juvenile harbour seal (fitted with the Argos Spot tag) undertook much more extensive movements, and made two trips of over 100 km to the north of the capture site. It also transited the planned area for the fixed link. Whilst this is only data from a single individual, other studies have confirmed increased movement ranges of harbour seal pups/juveniles (Thompson et al., 1994; Lander et al., 2002; Small et al., 2005; SMRU, unpublished data). Thus this pattern of movement may not be atypical of harbour seal pups/juveniles born at Rødsand and the planned area for the fixed link may be used in their first year of exploration. A more recent study funded by the UK’s Crown Estate, show tracks from a sub-adult harbour seal making multiple transits through the Fehmarnbelt fixed link area (Appendix 7.7.4) which adds further support for the hypothesis that juvenile seals do travel more widely than adults. Juvenile seals might be, therefore, more vulnerable to disturbance from the fixed link than adults.

3.3.4.2. Grey seals

Population usage estimates were not attempted from the two grey seals studied here due to the small sample size (2) and the variability in their movement patterns. The six grey seals tracked from Rødsand in the Dietz et al. study (2003) (see Appendix 7.7.3 for maps of tracks from this study) were fitted with a type of Argos tag that did not sufficiently accurately identify haul-out bouts, and so trip classification (required for the Matthiopoulos (2004) usage method) could not be applied to them. Nevertheless, our study on grey seals was able to reveal some interesting and relevant patterns of individual movement.

Two juvenile grey seals were tagged with GPS/GSM tags. One seal, (28-04-09), behaved at a spatial / temporal scale similar to the relatively confined, at-sea home ranges of adult harbour seals in this study. However, its purported feeding area was more diffuse than those of the harbour seals and was not readily characterised by substrate type. None of the study harbour seals fed in there. However there was some overlap of feeding areas between harbour seals and this one grey seal in the area c. 10 km south of the Rødsand sandbank. The fact that 89% of the time the maximum dive depth extended to deeper than 90% of the local sea bed depth suggests epi-benthic foraging. However, the diet of grey seals is known to be variable with respect to individual, region and season. Lunstron et al. (2010) reported that herring (*Clupea harengus*) and European sprat (*Sprattus sprattus*,) dominated the diet of Baltic grey seals. The study on health assessment in seals (see Chapter 3.4) reports that hard part remains of large cod (*Gadus morhua*), whiting (*Merlangius merlangus*) and herring (*Clupea harengus*) were found in faecal samples collected at Rødsand, indicating that these species are an important part of seal diet in the area. As mentioned in the harbour seal discussion above, the movement and diet results found here should be integrated with fish and hydrographic studies in order to explain and predict future changes in foraging behaviour in the Rødsand grey seals.

Seal 28-04-09 transited the planned area for the fixed link once in its 118 days of tracking. One yearling grey seal fitted with an Argos tag by Dietz et al. (2003) (out of a total of six seals in their study, totalling 1002 seal-days of tracking) briefly entered the planned area for the fixed link twice. Whilst this cannot be considered high usage, it does suggest that the Fehmarnbelt may act as a movement corridor for grey seals. A more recent telemetry study funded by the UK's Crown Estate, shows grey seals tagged at the Rødsand haul-out making extensive passages through the Fehmarnbelt to haul-outs in the north-west of the region (Appendix 7.7.4)

The other juvenile tagged grey seal (28-02-09) moved at much greater geographic scales. It undertook a series of three trips, lasting between one and two weeks to an area to the south of the Øresund, each time returning to Rødsand. Finally, it undertook a 70 day trip to this region and then moved north to the south of Stockholm – 600 km from Rødsand.

It is important to consider that – as in the case of the tagged juvenile harbour seal – long-range movements might be a function of age. However, grey seal movement of this geographic scale was also reported by Dietz et al. (2003) where *adult* grey seals tagged at Rødsand travelled as far as eastern Sweden, Latvia and Estonia. Such movement patterns are also shown in the Baltic and Gulf of Bothnia (Sjoberg et al., 2000 and Eklöf, 2007), in the UK (McConnell et al., 1999) and Canada (Breed et al., 2006) where such large-scale movements were also observed in *adult* grey seals.

This potential for wide-ranging grey seal movement suggests that the population of grey seals that haul-out in the Rødsand Lagoon may be less dependent of local feeding areas and thus less vulnerable to local change. However, one of our study animals (plus one grey seal in the Dietz et al. (2003) study) did forage locally and it correspondingly spent more time hauled out locally. Thus a reduction in the local availability of prey may result in fewer grey seals seen within the Rødsand Lagoon.

3.4. Health assessment of seals

3.4.1. Introduction

There have been a limited number of studies published on the health of harbour seals in the Baltic, Kattegat and Skagerrak regions (Lunneryd, 1991; Olsson et al., 1994). The aim of this study was therefore to provide baseline information of the health status of seals before the onset of construction and operation of the Fehmarnbelt Fixed Link.

Seals in the region have previously been affected by disease; most notably phocine distemper virus or PDV. Two major epidemics have occurred in the area in 1988 and 2002 (Härkönen et al., 2006) but as with other morbillivirus outbreaks such as measles, the disease has not persisted in the population. Animals either die or survive infection with lifelong immunity. However, there may be a point in the future when the number of susceptible animals in the population increases to a level where the re-introduction of the virus will cause another outbreak (Hall et al., 2006).

Other viruses reported in this population include herpes, but this was associated with the 1988 PDV epidemic (Frey et al., 1989). PDV is immunosuppressive and other secondary infections such as the herpes viruses can then take hold. Other lesions found on examination of the carcasses from the PDV outbreak include lenticular lesions (disease in the eye lens) particularly malformations and cataracts in younger harbour seals (Schoon and Schoon 1992).

Studies of the health of grey seals have mostly focused on animals from the Baltic proper, rather than the western Baltic. Investigations in the 1960s/70s found that grey (and ringed) seals were suffering from a disease complex described as a primary lesion in the adrenals causing secondary reactions in various other organs (see Olsson et al., 1994). Studies on historical Baltic grey seal skull bone material showed that the prevalence of affected animals started to increase after World War II. The disease complex explains the dramatic decrease in the Baltic grey (and ringed) seal populations during the 1960s and 1970s and is believed to be caused by environmental pollutants (Olsson et al., 1994). An improvement in Baltic grey seal gynaecological health was seen from the 1970s/early 80s to the late 1980s/90s, with a decreasing prevalence of uterine obstructions and tumours (leiomyomas) and an increasing prevalence of pregnancies (Bergman 1999). Also found, however, was an increased prevalence of colonic ulcers in young seals (which indicates that the food consumed may have contained new or increased amounts of hitherto unidentified toxic factors which affect their immune system; Bergman, 1999). There have also been isolated cases of conditions such as septicaemia (Krovacek et al., 1998) in Baltic grey seals.

Dietary information from seals in the southern Kattegat/western Baltic is scarce. The most relevant study was carried out by (Andersen et al., 2007) who processed 26 harbour seal scats and digestive tracts collected in the Rødsand area over a five year period. Evidence of 20 different prey species was found. The diet was mainly made up of cod (*Gadus morhua*), herring (*Clupea harengus*), sandeel (*Ammodytes tobianus*), flounder (*Platichthys flesus*), plaice (*Pleuronectes platessa*) and dab (*Limanda limanda*).

In this study a number of different physiological parameters were measured in individual seals to indicate their current general health status (Hall et al., 2010).

3.4.2. Methods

Once captured (see section 3.3.2), the seals were anaesthetised with Zoletil. Standard morphogenetic measures were taken and samples were taken for health parameters. Blood samples were collected using the Vacutainer system (Becton Dickenson, Oxford, UK) into plain (serum) and heparinized (plasma) blood tubes. Samples were processed immediately on return from the field. Mass, standard nose-tail length and maximum axillary girth was measured using spring balance scales and tape measure respectively. Any faecal samples found on the haul-out were collected into individual plastic bags and stored at -20^{o}C on return from the field until analysis.

3.4.2.1. Haematology, immunology and clinical blood chemistry

Total white blood cells were counted manually in the field. Whole blood was diluted 1:21 with Baar’s fluid to ensure red cell lysis. White cells were counted microscopically with a haemocytometer counting chamber under x40 magnification. Counts were duplicated and mean counts calculated. Blood smears were made in the field and stained with Leishmann’s stain on return to the laboratory. Differential white cell counts were carried out by classifying 200 cells by subtype (neutrophils, lymphocytes, monocytes and eosinophils). Following the capture and blood sampling of animals, whole blood was centrifuged in the field (5,000 rpm for 10 min) and the serum separated and stored at -80^{o}C in a dry shipper until return. Clinical blood chemistries (total protein, urea, total bilirubin, direct bilirubin, alanine aminotransferase (ALT), glucose, globulin, total immunoglobulin G (IgG), alkaline phosphatase (ALP), aspartate aminotransferase (AST), albumin, creatinine, cholesterol, triglycerides, and iron) were measured in the serum samples using standard colourimetric methods and enzymatic determinations by UV spectrophotometry at the appropriate wavelengths (Randox Laboratories, Belfast). These assays are usually carried out automatically in a clinical chemistry analyser but samples collected remotely must be assayed manually after separation of the plasma or serum and freezing at -80^{o}C. All assays are carried out in duplicate and the mean of two measurements used in the analysis (Hall, 1998). Total IgG was measured using a Protein A ELISA that has been optimized for use in many different seal species and followed the protocol of Ross et al. (1994). 100 µl serum diluted to 1:400 in sodium bicarbonate and the standard (dog reference serum) was added to wells of a high-binding microtite plate and incubated at 37^{o}C for 1 hour then washed twice with Tris-buffered saline Tween solution (TBS-Tween, 0.05M). 200 µl gelatin solution (20 µg/ml) was added to each well (to block the plate) and it was incubated at 37^{o}C for 30 minutes. The plate was then washed twice and100 µl Protein A horseradish peroxidase diluted in TBS Tween (1:2000) added and incubated again. The plate was washed five times with TBS Tween then100 µl of chromogen was added and after 10 min the reaction was stopped by addition of 100 µl oxalic acid (2%) and the plate read at 570 nm.

3.4.2.2. Phocine distemper virus serology

Serum samples were screened for the presence of distemper virus antibodies. However, the assay for determining anti-PDV antibodies is not yet widely available as it requires specialized dog-SLAM cells to grow the virus for the visualization of a cytopathic effect (Saliki et al., 2002). Therefore, since it has been widely demonstrated that there is good cross reactivity between canine distemper and phocine distemper virus antibodies (Cornwell et al., 1992), the use of the CDV-virus neutralization assay (CDV-VNT) to determine antibody status has been widely used as a surrogate for determining the presence and level of anti-PDV antibodies in seal samples (Pomeroy et al., 2005). Dilutions of sera were incubated with a fixed amount of CDV and inoculated into Vero cells (African green monkey kidney cells). Following incubation for up to a week at 37^0C the wells were examined for the viral cytopathogenic effect (CPE), which occurs with the absence of neutralising antibody. The maximum titre is reported as the dilution (or its reciprocal) at which the proportion of wells infected is reduced from four to two. This assay was carried out in a commercial laboratory, Biobest Ltd., Edinburgh UK.

3.4.2.3. Polyaromatic hydrocarbons in plasma

The concentration of polyaromatic hydrocarbons in plasma samples was determined using an immunoassay (cRaPID PAH Test kit, Strategic Diagnostics Inc. Newark, USA). Since this is a more cost effective method that has been optimized for use in plasma samples from seabirds (Troisi and Borjesson, 2005), this approach was used for the seal plasma samples in this study. The modified method optimized and tested by Troisi and Borjesson (2005) was used as follows. A calibration curve of triplicate BaP (benzo[*a*]pyrene) standards for PAH concentrations of 0.1 – 5 ppb (ng/g) was determined. PAHs were extracted from 200 µl seal plasma with the addition of 400 µl methanol and 400 µl phosphate buffered saline (pH 7.4) followed by centrifugation at 4000 rpm for 10 min. The clear supernatant was retained for PAH analysis. 50 µl sample or BaP standard (in triplicate) was added to the wells of a microtitre plate and 65 µl enzyme conjugate was added and mixed. 100 µl polyclonal PAH antibody-coupled paramagnetic beads were added and the plate incubated with gentle shaking at room temperature for 30 min. The plate was then placed on a magnetic separator for 5 min to sediment the anti-PAH antibody complex. The solution was removed and the plate washed twice with 200 µl wash solution. Finally 100 µl chromogen was added to the wells and the plate was incubated with gentle shaking at room temperature for 20 min. The reaction was stopped with 100 µl 2 M H_2SO_4 and the absorbance read within 2 min at 450 nm. Total PAH concentrations in the samples were calculated by fitting a log parameterized four parameter logistic regression fit to the standard curve using the package Calib in program R 2.11.0 (R Development Core Team, 2004).

3.4.2.4. Heavy metals in plasma

In general the concentrations of heavy metals (or trace elements) in marine mammals are monitored in kidney, liver or muscle samples as these appear to be the most important target organs for these contaminants. However, since it is not possible to collect these tissues from live-captured seals, the concentration of heavy metals in blood plasma was determined as a useful alternative. All analyses were carried out by the Cefas laboratory in Lowestoft, UK, which is among the UK leaders in analytical chemistry focussing on the determination of contaminants in various environmental and particularly marine samples. They have the accreditations to carry out monitoring in a wide variety of matrices, including biota such as fish, shellfish and marine mammal tissues (Law et al., 2006).

Using plasma levels as an alternative monitoring matrix is much more widely used in human biomonitoring studies (Goulle et al., 2005; Clark et al., 2007) with a move towards analysis using inductively coupled plasma-mass spectrometry (ICP-MS) rather that atomic absorption spectroscopy (Nunes et al., 2010). ICP-MS has been validated and used widely for analysing trace elements in various marine samples (Jones and Laslett, 1994) but required slight modification for the plasma samples. The samples were digested in a mixture of nitric acid and hydrogen peroxide using enclosed vessels in a microwave. The digested solutions were further diluted prior analysis by ICP-MS and by inductively coupled plasma-atomic emission spectroscopy (ICP-AES) depending on the element. A method blank and two certified references (Seronorm Trace Elements L-1 and Seronorm Trace Elements L-2) were included in the batch to indicate recovery. Quantification was done by external calibration and the results were in mg/kg of plasma. Levels of chromium (Cr), nickel (Ni), copper, (Cu), zinc (Zn), arsenic (As), lead (Pb), selenium (Se), mercury (Hg), manganese (Mn) and iron (Fe) were determined. Although this method has not been externally validated for use in marine mammal plasma samples, the method is entirely internally consistent and so future samples analysed using the same method and standards in the same laboratory will be reliably comparable to the results presented here.

3.4.2.5. Faecal and serum cortisol and progesterone concentrations

Faecal samples collected at haul-out sites were sub-sampled for the determination of cortisol, cortisol metabolites and progesterone levels. Steroid hormones were extracted from faeces and concentrations measured using standard immunoassay methods (enzyme linked immunosorbent or ELISA assays). Steroid extraction methods followed those of Palme et al. (2000)as validated by Mateo and Cavigelli (2005), which have also been validated for seals at SMRU (Hall, unpublished results). Samples were desiccated at 95^{o}C for 4-6 h to evaporate the water. Dried faeces were crushed and 0.2g weighed into a microcentrifuge tube. 1.5mL of 100% ethanol was added, vortexed and immediately centrifuged at 2,500*g* for 20 min. Supernatants were reserved and frozen until assayed. Serum samples were assayed directly as extraction of these hormones from the blood is not required.

Extracted samples were then assayed using ELISA kits (Fortress Diagnostics, Belfast) by dilution in assay buffer to ensure parallelism with the standard curve. Anti-human cortisol and progesterone antibodies have been shown to cross-react with seal steroid hormones (Gardiner et al., 1996). The methods are based on the principle of competitive binding between the steroids in the test specimen and a steroid-horseradish peroxidase (HRP) conjugate for a constant amount of rabbit anti-steroid. Goat anti-rabbit IgG-coated wells in a

96 well plate format were included with steroid standards, controls and the extracted samples. Steroid-HRP conjugate reagent and rabbit anti-steroid reagent were incubated in the wells at room temperature for 90min. During this reaction a fixed amount of HRP-labelled steroid competes with any steroid in the sample or standard for a fixed number of binding sites on the steroid-specific antibody. Thus, the amount of steroid-HRP conjugate bound progressively decreases as the concentration of steroid in the sample or standard increases. Unbound conjugate is removed by washing and a solution of a chromogen that reacts with the HRP is added and incubated at room temperature for 20 min resulting in the development of a blue colour. Hydrochloric acid (1N HCl) was added to stop the reaction and the absorbance measured spectrophotometrically at 450nm. The intensity of the colour is proportional to the amount of enzyme (HRP) present and is inversely related to the amount of unlabelled steroid in the sample. A standard curve is obtained by plotting the concentration of the standard against the absorbance and the quantity in the sample calculated from the standard curve. All assays are carried out in duplicate and the mean of two wells reported. Progesterone analysis was not performed on the harbour seal samples as they were collected too early in the seasonal cycle.

3.4.2.6. Faecal DNA to determine sex and species

Because the Rødsand haul-out sites can be shared by both species of seal, it is important to be able to identify the species (and sex) of the animal that produced the faecal sample being analysed. This was achieved using molecular genetic analysis whereby faecal DNA was amplified using polymerase chain reaction (PCR) and the presence of genetic microsatellite markers that are species and sex specific were investigated. DNA was extracted from the faeces using the methods of Matejusova et al. (2008) using a stool DNA extraction kit (QIAmp DNA Stool Mini Kit, Qaigen, Crawley, UK) and quantified by fluorometry (Quant-iT, PicGreen dsDNA assay kit, Invitrogen, Paisley, UK). A real-time or qPCR reaction contained 2.5 µl extracted genomic DNA, 900 nM each primer, 250 nM probe, 1 x Taqman master mix (Applied Biosystems, Warrington UK) and distilled water (Sigma, Gillingham, UK) in a final volume of 25 µl. Cycling conditions consisted of a single cycle to allow Uracil-*N*-glycosylase digestion of previously amplified potential contaminant products (50^{o}C for 2 min, 95^{o}C for 10 min) followed by 45 cycles of denaturation and annealing/extension (95^{o}C for 15 s, 60^{o}C for 1 min). To determine the species of seal that produced the scat, nucleic acid sequences encoding the interphotoreceptor retinoid-binding protein (IRBP) for both grey and harbour seal (Accession numbers DQ205902 and AB188519) were targeted. A pair of generic primers capable of amplifying a region of the target gene for both species of seal and two species-specific Taqman probes was used. The IRBP forward (5'-CAC AGT GGC CGA GGA TGA G-'3) and IRBP reverse (5'-ACG GAC ACC TGG AAC ATA GAG T-'3) primers were capable of amplifying a 63 bp fragment of the IRBP gene. The sequence of the IRBP gene Taqman MGB probe for harbour seal (PV assay) was 6-FAM-CTG TCC AGC AGG CCC T-MGB and was 6-FAM-TCC GGC GGG CGC TGG -MGB for grey seal (HG assay).

To determine the sex of seal that produced the scat, X and Y homologous fragments of the chromosomal gene zinc finger protein (ZFP) were required. Both the ZFX and ZFY loci were amplified reducing the risk of true female and failed male which occurs when using only a single sex (male only) test. Generic primers to amplify the ZFX and ZFY genes for both species of seal were designed using the Primer Express software as supplied by Applied Biosystems. Primer set ZFX forward (5'-AGA GCA ACC CTG TCA TAA AGA GAA C-'3) and ZFX reverse (5'-GGA CTG AGG TTG GTA CAA TCA GAC T-'3) was capable of amplifying a 71 bp fragment of the X homolog of ZFP from both species of seal. Sequence of the ZFX Taqman probe was (6FAM-CTG GTC TGA AAA CTT CAT T-MGB). Primer set ZFY forward (5'-GCA AGC TCC GAG ATT AAA CCA-'3) and ZFY reverse (5'-TGA TCT AGC AGC TAA ATT GCT ATC G-'3) amplified a fragment of 69 bp of the Y homolog of ZFP from both species of seal. The sequence of the ZFY Taqman probe was (6FAM-TGT ACC CAC AGA GGT GT-MGB).

3.4.2.7. Parasite egg counts

Parasite eggs in faecal samples collected from haul-out sites were conducted using a McMaster worm egg counting chamber (Cox, 1982). A 1-2g sample of faeces was diluted with saturated salt solution and floating eggs counted microscopically under x10 magnification. Counts were carried out in duplicate and the mean used in subsequent analyses.

3.4.2.8. Diet

The most widely used method for determining the diet of seals is to identify, count and measure the prey hard parts that remain in the faeces (Prime and Hammond, 1990). Scat samples were defrosted and prey hard parts (fish otoliths and cephalopod beaks) were extracted using a nest of sieves of mesh sizes 1 mm, 600 µm and 335 µm, running water and a soft brush. Otoliths were stored dry. Otoliths and beaks recovered from scats were identified to species using a reference collection and two identification guides (Härkönen, 1986; Leopold et al., 2001). Where they could not be identified to species with 100% certainty, they were recorded at order level (e.g. as “unidentified gadoid”) or as “unknown species”. Otolith lengths and widths were measured to the nearest 0.01 mm using digital callipers (Mitutoyo) under a binocular microscope (PZO MST130). The callipers were zeroed between measurements and were frequently cleaned. Broken otoliths and beaks were counted and measured only if the widest/longest part of the otolith, or the lower rostral length of the beak, was complete. Each recovered otolith was also examined to assess and record the amount by which it had been digested, which was classified based on its external morphological features. Pristine otoliths were classified as grade 1, moderately digested otoliths as grade 2 and considerably digested otoliths as grade 3 after Leopold et al. (2001).

All the results tables relating to the health and diet of the seals are given in Appendix 7.8.

3.4.3. Results

3.4.3.1. Harbour Seal Health

A total of 5 harbour seals were captured, sampled and released in October 2009 at the Rødsand haul-out site. Four animals were adult males and one a juvenile female (Table 7.8-1). None of the animals had ectoparasites, such as seal lice, or any external lesions.

Body condition

The relationship between mass and length for the 5 harbour seals is shown in Figure 3.4-1 (mass and length are listed in Table 7.8-1) together with auxiliary girth and body condition index measurements). The four males had higher condition indices (mass/length ratio, mean 0.676 kg/cm) than adult male harbour seals captured in UK waters between 1999 and 2007 during October (n=30, mean condition index=0.533 kg/cm, SMRU, unpublished). Thus, for each unit of body length the Rødsand seals were heavier, which is likely to be due to greater blubber rather than muscle mass since it is the size of this energy storage tissue that fluctuates during the year in response to energy uptake and utilisation.

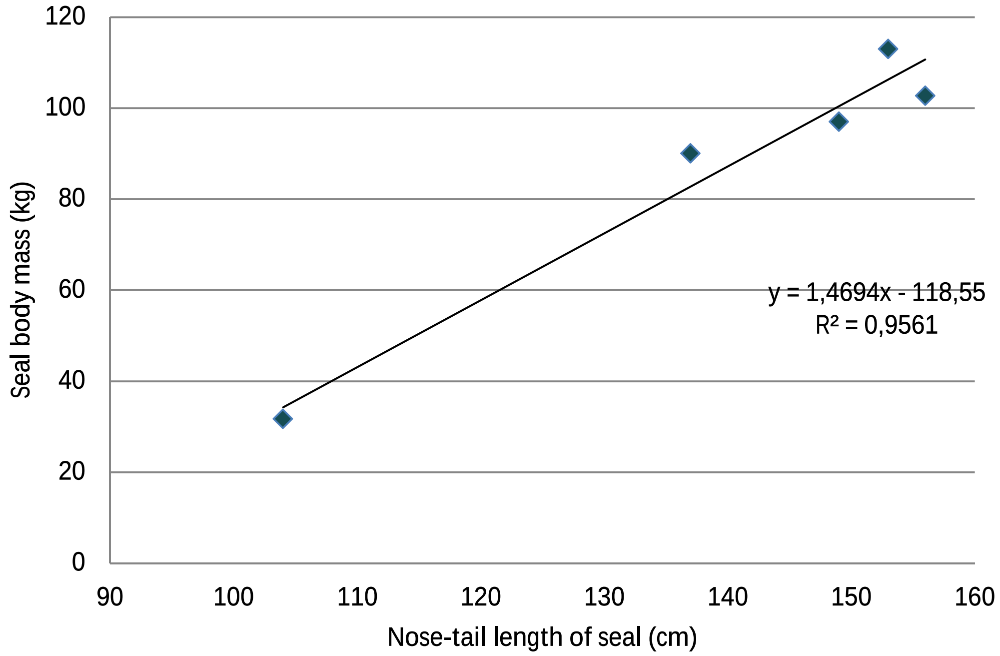


Figure 3.4-1 **The relationship of seal body mass and length of the five harbour seals tagged Rødsand Lagoon**

Haematology parameters

The haematology parameters (total white blood cells (TWBC)) and differential white cells (leukocytes) for the harbour seals are shown in Table 7.8-2. Although the objective of this study was to provide baseline data for future comparisons, it can often be helpful to compare haematology and clinical chemistry values with published ranges for the species. This can assist in determining whether there are any signs of disease in the individuals at the time of capture. However, it should be noted that these ranges can vary by analytical method, treatment of sample, species, age and sex as well as by geographic location (Schwacke et al., 2009) and unless these variables are comparable, the published ranges often provide just a general guide.

The juvenile animal had a slightly higher total white cell count than the adults but this would be expected as juveniles often have higher circulating leukocytes than adults (Hall, 1998). The median TWBC for all animals was 8.2 x 10^6/ml (range 6.1-10.6), which was within the best available published “normal” range for wild adult and juvenile harbour seals combined (5.6-18.0 x 10^6/ml (Greig et al., 2010). For the polymorphonuclear cells (also known as neutrophils) the median and maximum for all harbour seals were also within these normal limits (median 5.7 x 10^6/ml, range 2.9-6.2; normal range 1.5-10.3). The lymphocytes had a median value of 1.44 x 10^6/ml (range 1.23-2.15; normal range 1.1-5.9). The monocytes median was 0.68 x 10^6/ml (range 0.26-1.01; normal range 0.0-1.5) and the eosinophil median was 0.83 x 10^6/ml (range 0.34-1.94; normal range 0.04-3.4).

Total immunoglobulin G (IgG)

A simple additional measure of immune status is the assessment of total immunoglobulin G in the blood. This group of proteins are the antibodies produced in response to infection. High levels of IgG in the blood may therefore indicate recent or current exposure to a pathogen and low levels are indicative of immune dysfunction. Levels measured in the serum of the harbour seals are shown in Table 7.8-2 and they ranged from 36.11 to 42.10 mg/ml. All concentrations were within the range reported for harbour seals in Nova Scotia by Ross et al. (1993). In conjunction with the haematology results above this indicates that the animals were probably not immunologically challenged or infected at the time of sampling.

Clinical blood chemistries

A total of 13 clinical chemistry parameters were measured in the seal blood samples and the individual results are shown in Table 7.8-3. Six of these are useful indicators of nutritional status (glucose, cholesterol, alkaline phosphatase, urea, triglycerides and albumin; Hall et al., 2010) The published ranges for the wild adult and juvenile harbour seals combined (Greig et al., 2010) are also listed in Table 7.8-3. Although the methods used to establish the published ranges were slightly different (automatic clinical chemistry analyser compared to manual methods) and the study animals were Pacific harbour seals from the west coast of the US, in the absence of directly comparable data these ranges do provide some general diagnostic guidance of clinical perturbations that might be apparent in any individual. Some differences may also be due to the treatment of the samples. The published ranges are for samples analysed without freezing whereas the samples from Rødsand were frozen and thawed before analysis. This may have an effect on the glucose, protein and liver enzyme results. Indeed some of the glucose, ALP and albumin results were slightly higher than the published range. However, none of these were suggestive of nutritional perturbations or nutritional stress in the Rødsand harbour seals and although elevated levels of albumin can be indicative of dehydration or shock, the levels reported here are likely to be due to nutritional differences between the two groups of wild-caught animals. Similarly the protein levels in the Rødsand harbour seals were all slightly lower than those seen in the US harbour seals but the levels were not clinically relevant.

Other clinical parameters are indicative of the status of the hepatic system and these include the liver enzymes aspartate aminotransferase (AST) and alanine aminotransferase (ALT), creatinine, and total bilirubin although increases in some, such as ALT, may also be indicative of infection or parasitism. Creatinine concentrations were slightly higher in the Rødsand seals but again this is likely to be due to methodology differences since none of the other hepatic system indicators were elevated.

Finally total iron and globulin levels were measured. These parameters are indicators of infectious disease, immunity physiological stress and trauma. One animal had a slightly higher level of iron but again this was not clinically significant. Thus, from the clinical chemistry parameters monitored all the animals appeared to be in good general health with no evidence of nutritional stress or infection. However, the main purpose of measuring these parameters was to provide baseline data for this population for future comparative studies.

Phocine distemper virus serology

Antibody titres against CDV were used to indicate previous exposure and response to morbilliviruses such as PDV and the individual results are shown in Table 7.8-4. Two animals were negative (titres <1:5), one adult male and the juvenile female. Of the remaining three adult males all were seropositive with titres of 1:20, 1:56 and 1:113 respectively. This indicates that these individuals had been exposed to PDV or a similar related morbillivirus. It is highly likely that this represents exposure to PDV during the 2002 outbreak. These animals had titres that were sufficiently high to afford protection against future exposure to the virus (Thompson et al., 1992).

Blood cortisol concentrations and cortisol metabolites in faeces

Cortisol levels were measured both in the individual blood samples collected from the seals (Table 7.8-5.) and in the faecal samples collected from the haul-out sites. The concentrations provide baseline data for future comparisons to determine any stress effects on the animals. All the harbour seals captured had high levels of cortisol in their blood (range 480-2234 nmol/L). This indicates a normal response to capture and handling and concentrations were within the range reported for wild-caught harbour seals sampled in the UK (Gardiner and Hall, 1997). One individual had a very high level indicating a characteristic spike in response to the short term stress of handling.

Six of the faecal samples suitable for hormone analysis, all collected in October 2009, were identified from the DNA in the sample as having been produced by harbour seals. The levels of faecal cortisol metabolites measured are shown in Figure 3.4-2. All the samples were identified using DNA markers as being from males. This provides baseline data for future comparison.

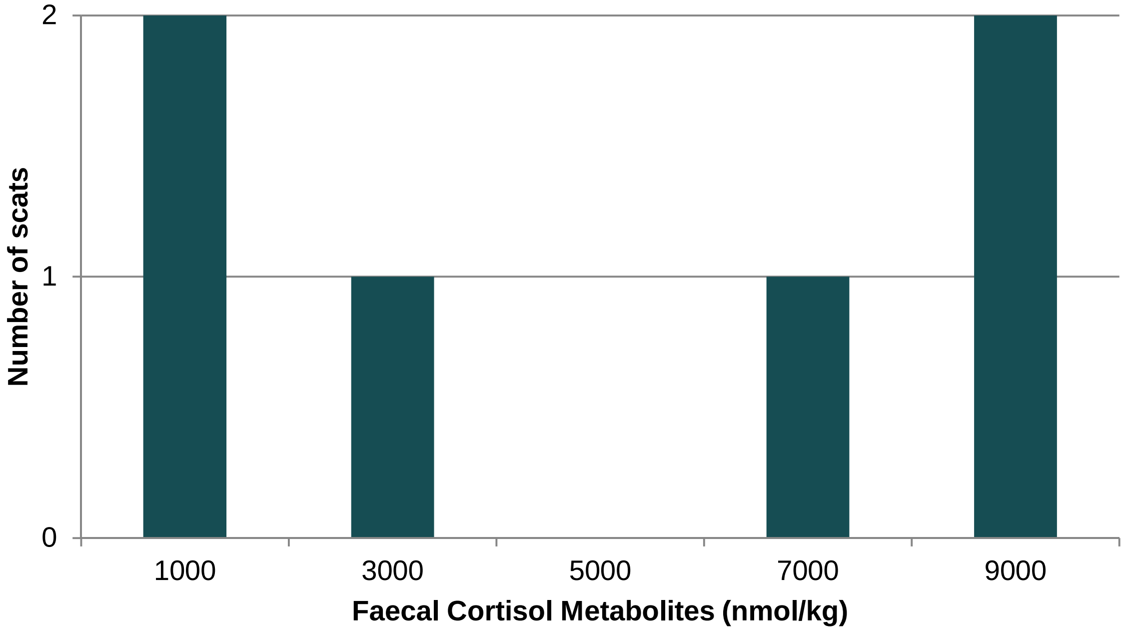


Figure 3.4-2 Faecal cortisol metabolites in a total of six harbour seal scats collected from Rødsand site (October 2009)

Progesterone concentrations in blood and faeces

Blood samples of the female juvenile showed a progesterone level of 8.6 nmol/l. The six faeces samples collected in October 2009 that were identified from DNA as having been produced by harbour seals were all males. These all had levels <150 nmol/l. Of the unknown species samples collected earlier, in April 2009, two had high levels of progesterone (599 and 543 nmol/l respectively). These were most likely produced by adult females (given the time of year, just prior to the harbour seal breeding season) but unfortunately this was not confirmed from the DNA as we were unable to extract sufficient amounts for confirmation from these samples.

Polyaromatic hydrocarbons

Plasma concentrations of total polyaromatic hydrocarbons (PAHs) were very low (Table 7.8-6). Two of the adult male harbour seals and the one juvenile female harbour seal had concentrations below the limit of detection (<0.5 ppb) and in the remaining two adults levels were 0.8 and 1.2 ppb respectively.

Heavy metals

The concentration of 11 heavy metals in plasma samples are given in Table 7.8-7 (mg/kg wet weight). The majority of elements measured were at or below the limit of detection. For three elements (copper, selenium and iron) concentrations were above these limits and showed more individual variability. However, there was no discernable pattern related to sex or age differences.

Faecal samples from the haul-out

A total of 23 faecal samples were collected from the Rødsand haul-out site, 13 in April 2009 and 10 in October 2009.

Parasite egg counts

The frequency distribution of parasite eggs counts (per gram of faeces) in 7/20 samples analysed (mean of duplicate counts) that were identified from the faecal DNA as having come from harbour seals are shown in Figure 3.4-3. The round eggs were identified microscopically as *Contracaecum*. The oval eggs were probably a liver fluke as an operculum was observed. These counts are not unusually high for seals (Gulland F.M.D., unpublished) and they followed the general pattern of overdispersion for parasite loads in mammals with most individuals having a small number of parasites and a few with much higher burdens. Marine mammals appear to be able to tolerate much higher parasite loads than most terrestrial species (Cox, 1982).

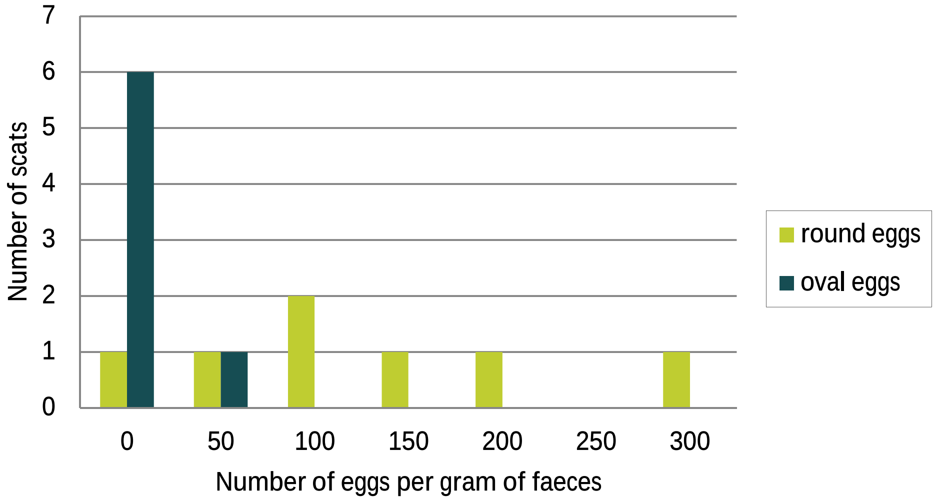


Figure 3.4-3 Parasite faecal egg counts in harbour seal scats collected at Rødsand Lagoon

Diet from fish otolith identification

Three of the faecal samples collected from the Rødsand haul-out site in October 2009 that were identified as harbour seal scats contained identifiable fish otoliths. The otolith measurements were corrected for digestion using the method and correction factors published by Grellier and Hammond (2006) for grey seals. The corrected values were then converted to fish lengths using the regression relationships published by Leopold et al. (2001) and Härkönen (1986). The results are shown in Table 7.8-8. The fish prey species identified included small cod (*Gadus morhua*) and herring (*Clupea harengus*) and small black gobies (*Gobius niger*). One sample also contained the distinctive green bones of the garfish (*Belone belone*).

3.4.3.2. Grey Seal Health

A total of 2 juvenile grey seals were captured, sampled and released in October 2009 at the Rødsand haul-out site, one male and one female (Table 7.8-1).

Body condition

The two juvenile grey seals were comparable in mass and size to yearling grey seals in the UK (Hall and McConnell, 2007). The morphometric data are shown in Table 7.8-1. Hall and McConnell (2007) investigated the relationship between body composition (total body fat and protein) and morphometric measurements in yearling grey seals and found that total body fat could be predicted from mass (TBF kg = 0.385*mass (kg) -11.31) and total body protein could be predicted from mass/length (TBP kg = 23.29* mass/length + 0.925). Using these equations both seals sampled at Rødsand were ~14% fat and ~22% protein. Both individuals were in slightly better condition than those sampled in the UK (mean condition index UK seals 0.37 n=6, mean condition index Rødsand seals 0.42 n=2).

Haematology parameters

The haematology results for the two grey seals are shown in Table 7.8-2. The total white cell counts (mean ±SD published 14.2 ±4.9 x10^6/ml) and differential white cell counts were within the range found for yearling grey seals (published polymorphonuclear cells 8.93 ±3.63 x10^6/ml; lymphocytes 3.89 ±1.85 x10^6/ml; monocytes 0.49 ±0.27 x10^6/ml; eosinophils 1.33 ±0.61 x10^6/ml; Hall 1998). From the basic haematology parameters there were no indications that the animals were suffering from infection or other diseases that affect circulating leukocytes.

Total immunoglobulin G (IgG)

The total IgG levels are also shown in Table 7.8-2. Unfortunately there are no published ranges for this species and age group but the levels were within those found for the adult harbour seals. Again, in conjunction with the above haematology values, these animals were probably not immunologically challenged or infected at the time of sampling.

Clinical blood chemistries

The clinical blood chemistry results for the two grey seals are shown in Table 7.8-3. Only a limited number of parameters have published ranges for this species and age class. However, these are directly comparable to the results presented here as they were carried out using the same methods and sample treatment (Hall, 1998). One animal had a slightly higher glucose level than the published range but this was not high enough to be clinically relevant. Of those that did not have comparable ranges for juvenile grey seals, one animal had a very high ALP level, outside the combined harbour seal range. However, ALP levels are generally much higher in developing juvenile animals as they are related to muscle growth as well as nutritional status (Engelhard et al., 2002). The other clinical chemistry parameters for this animal were not elevated.

Phocine distemper virus serology

The morbillivirus titres for the two juveniles indicated that they were seronegative (titres <5) and had thus not been exposed to PDV (Table 7.8-4). This fits with the epidemiology of this infection since it has not been seen in European seal populations since the 2002 outbreak. These animals were therefore too young to have been exposed.

Blood cortisol concentrations and cortisol metabolites in faeces

The serum cortisol concentrations measured in the two juvenile grey seals are given in Table 7.8-5. As with the harbour seals the levels were high in response to handling stress and were within the range found in other wild juvenile grey seals (Gardiner and Hall, 1997).

Of the anonymous faecal samples collected, all those found in April 2009 were identified using DNA as having been produced by grey seals. The frequency distribution of the cortisol metabolite concentrations in 7/10 are shown in Figure 3.4-4. These were an order of magnitude lower than those seen in the harbour seals.

The frequency distribution of the cortisol metabolites in all the faecal samples collected both in April and October for both species (n=23) are shown in Figure 3.4-5.

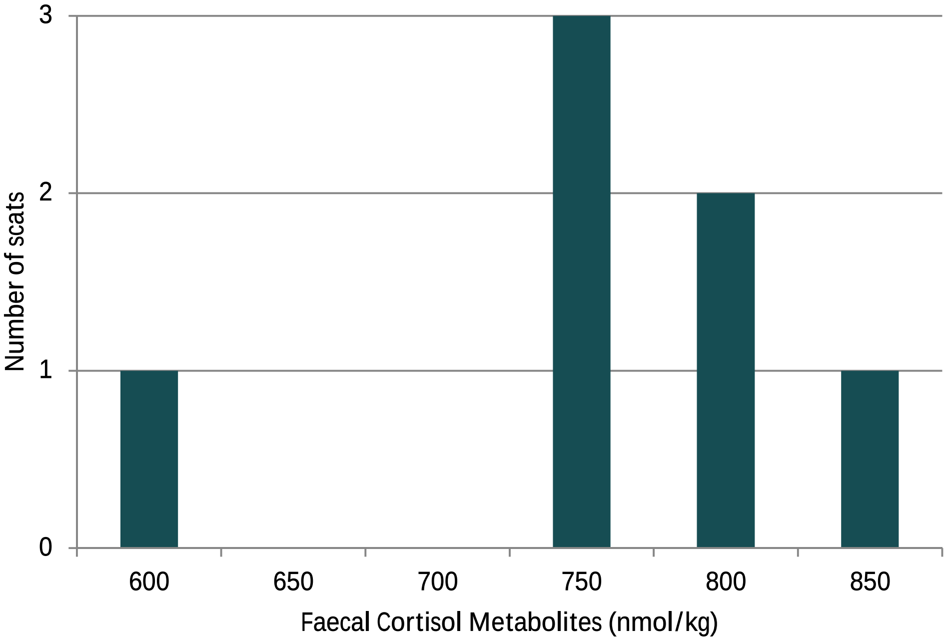


Figure 3.4-4 **Cortisol metabolites in scats identified as grey seals, collected from the Rødsand haul-out site (April 2009).**

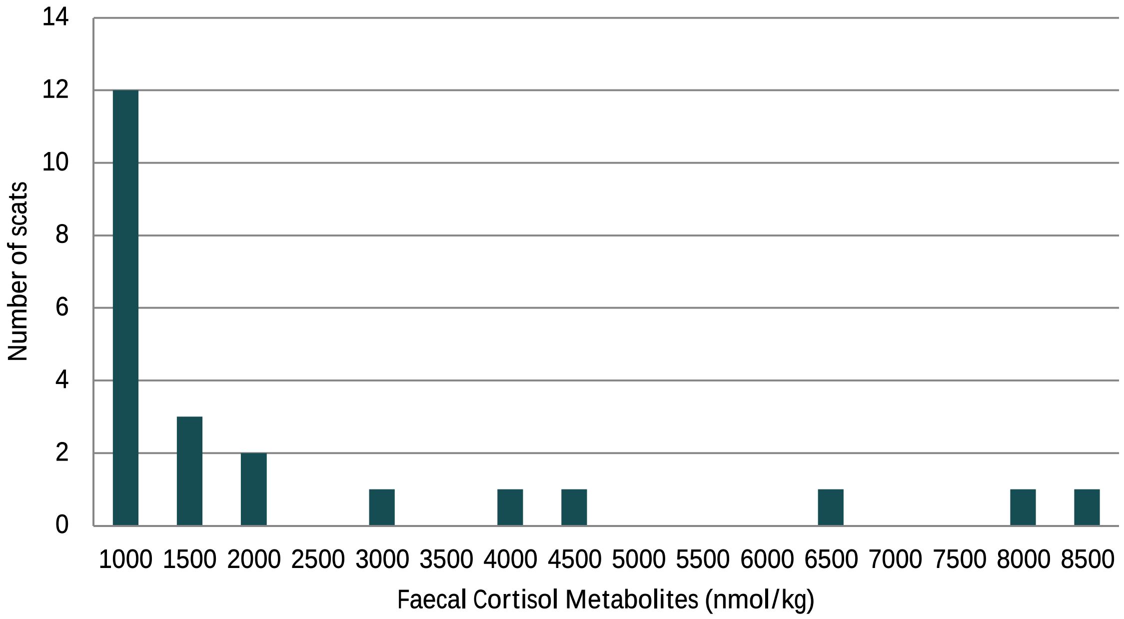


Figure 3.4-5 **Cortisol metabolites in all seal scats collected from the Rødsand haul-out site**

Progesterone concentrations in blood and faeces

Only one juvenile female grey seal was captured and blood sampled. Her blood progesterone level was 92.3 nmol/l, a level comparable to those found in immature seals and males (Gardiner et al., 1996).

The progesterone levels found in the scats identified as male grey seals (April 2009) were similarly low (n=7) (below the level of detection up to 120 nmol/l). The progesterone levels in all 15/23 samples collected are shown in Figure 3.4-6. The two samples with high levels are most likely to have been produced by pregnant female harbour seals (see section 3.1.8).

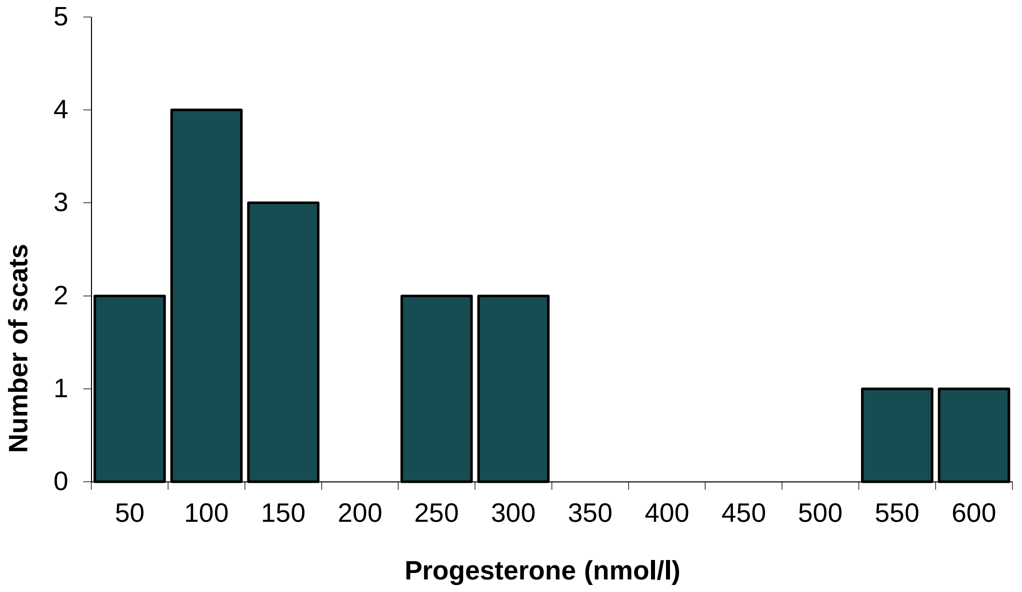


Figure 3.4-6 **Faecal progesterone levels in all seal scats collected from the Rødsand haul-out site (April 2009)**

Polyaromatic hydrocarbons

The PAH levels in the plasma of the two juvenile grey seals were below the limit of detection (Table 7.8-6).

Heavy metals

The results of the heavy metal analysis in plasma samples are given in Table 7.8-7 (mg/kg wet weight). As for the harbour seals the majority of elements measured were at or below the limit of detection but for copper, selenium and iron concentrations again were slightly more variable between the two individuals sampled. However, the iron levels were slightly lower in these two juvenile grey seals than they were in harbour seals.

Faecal samples from the haul-out

Parasite egg counts

The parasite egg counts were carried out in 6 of the anonymous scat samples identified as being from grey seals are shown in Figure 3.4-7. These followed a similar pattern to the harbour seals but one sample had quite a high count of 600 eggs/g faeces. The egg counts in all the scats collected from Rødsand in both April and October that were screened (n=20) are shown in Figure 3.4-8 and these also follow the expected pattern of overdispersion.

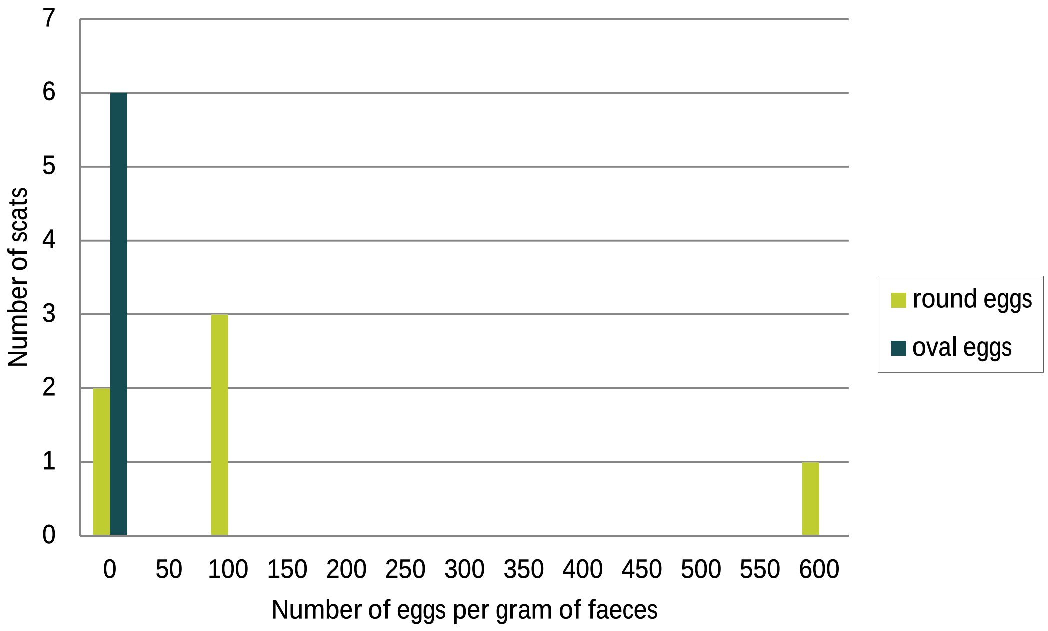


Figure 3.4-7 **Parasite egg counts in grey seal scats collected at Rødsand Lagoon**

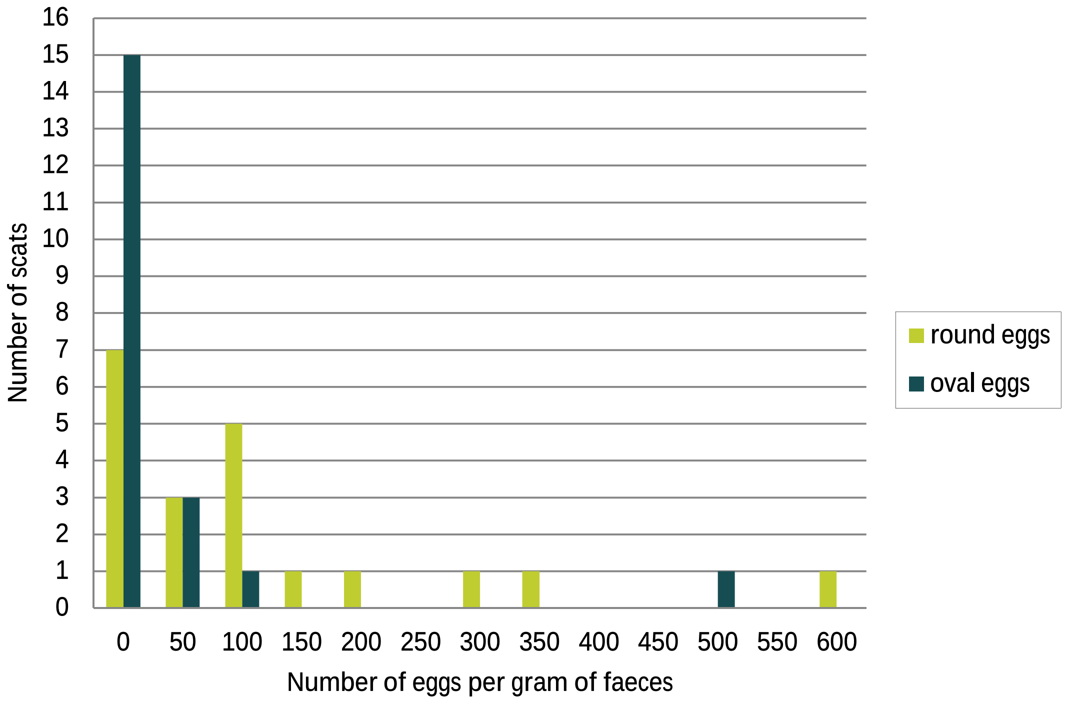


Figure 3.4-8 **Parasite egg counts in all seal scats collected from the Rødsand haul-out site**

Diet from fish otolith identification

Of the 7 anonymous faecal samples collected in April 2009 identified as grey seal scats 3 samples contained identifiable fish otoliths (Table 7.8-8.). These contained large cod (n=9), herring (n=3) and whiting (n=1). The length distribution of the cod (derived from otoliths) is shown in Figure 3.4-9 and ranged from approximately 35 to 66cm. Of some interest was the single common whitefish or lavaret (*Coregonus lavaretus)* otolith that was found in one sample.

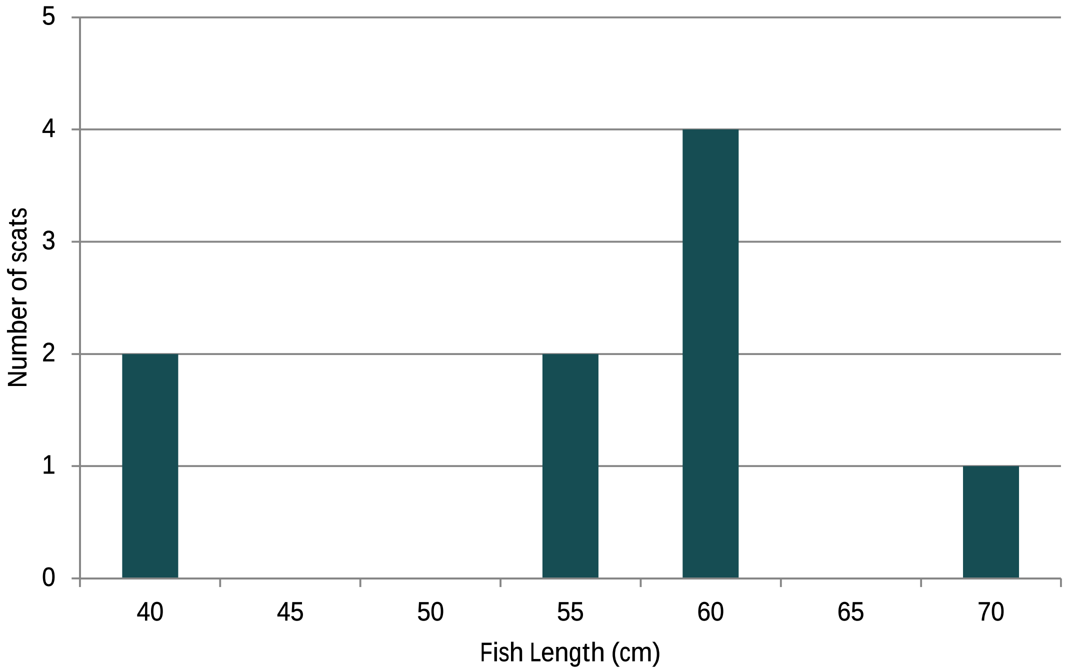


Figure 3.4-9 **Estimated size of cod from otoliths recovered in grey seal scats collected at Rødsand Lagoon (April 2009).**

3.4.4. Discussion

From the small sample of animals captured at the Rødsand haul-out site it appears that both species were in good general health and body condition. The data presented here provide a set of baseline health and dietary parameters which can be used to compare results obtained from animals captured and scats collected from the same haul-out during the construction phase of the Fehmarnbelt crossing.

3.4.4.1. Harbour seals

The results presented here indicate that the harbour seals captured at Rødsand in October 2009 were in good nutritional and physiological health with no signs of disease being detected using the various blood parameters and morphological measures as indicators. Some adult animals (3/4) had been exposed to a morbillivirus (probably PDV during the 2002 outbreak) and had protective levels of antibodies in their blood.

Levels of PAHs in the plasma were very low (<1.5 ppb in two individuals) as has been found in other seal species. Levels of PAHs in muscle tissue of harp seals (*Phoca groenlandica*) from Canada in the 1990s varied between 0.02 and 0.83 ppm, an order of magnitude higher than was found in the plasma samples analysed here. These compounds do not magnify through the food chain and if significant concentrations were found this would represent direct exposure to petroleum derived hydrocarbons. For example, oiled seabirds had mean plasma levels of 1.05±0.67 SD (Troisi and Borjesson, 2005). The results presented here provide baseline data for future comparisons.

The results obtained from anonymous faecal samples collected from the haul-outs for cortisol metabolite, progesterone, diet and parasite analysis again form a number of baselines for future comparative studies. The cortisol metabolites in the harbour seal scats were an order of magnitude higher than those in the grey seals. Studies of faecal cortisol metabolites in harbour seals have so far only been in relation to rehabilitated pups (where levels were between 200-3000 nmol/kg; Gulland et al., 1999) and although this is not a comparable group by age it indicates that the range of concentrations found can be very high. There may also be a difference in cortisol metabolism between the two species and previous studies have found circulating cortisol levels to be higher in harbour seals than grey seals (Gardiner and Hall, 1997). The prey found in the diet, although from a very limited number of samples, were comparable to the prey species identified in scats and digestive tracts of harbour seals from the Rødsand area collected between 2001 and 2005 (Andersen et al., 2007). During the autumn the diet was dominated (% by weight) by sandeels, black goby, cod and herring. Although no sandeels were recovered from the harbour seal samples analysed here, cod and herring were found as was long-spined sea scorpion. Sandeels were present in one unknown sample, collected during the autumn (Andersen et al., 2007). Interestingly, whiting otoliths were recovered, a species not previously reported in any season.

All the levels of heavy metals (also known as trace elements) in the plasma samples were low and for 8 of the 11 analytes measured concentrations were at or below the limit of detection. Concentrations of metals have been measured in whole blood samples in seals from the Wadden Sea (Griesel et al., 2008) but not in plasma. Whilst this matrix has been well established as useful for monitoring exposure levels and determining nutritionally important trace elements in humans (Iyengar and Woittiez 1988; Krachler and Irgolic 1999), plasma levels have not been investigated in marine mammals. Only copper, selenium and iron were at measureable concentrations and the levels found probably reflect the dietary intake of these animals (Elorriaga-Verplancken and Aurioles-Gamboa 2008). The fact that most metals (particularly the more toxic elements such as mercury and lead) were at very low levels in these samples indicates that their environment and foraging areas are not currently contaminated with these elements. In conclusion, these results provide a baseline for future comparison of heavy metal concentrations in seals from the Rødsand haul-out site.

3.4.4.2. Grey seals

The two juvenile grey seals captured, sampled and released at the Rødsand haul-out were both in good general health with no signs of infection or other diseases. They were nutritionally healthy with total body fat and protein levels higher than those seen in UK juvenile grey seals (Hall and McConnell, 2007). They had not been exposed to morbilliviruses, had plasma PAH levels below the limit of detection, had very low heavy metal concentrations in their plasma and displayed a normal cortisol response to handling.

The cortisol metabolite levels measured in faecal samples identified as having been produced by grey seals were an order of magnitude lower than in the harbour seal samples. The results presented here will provide baseline data for future studies.

The parasite egg counts also indicate that grey seals in this region do not have higher burdens than have been seen in this species elsewhere. Indeed the levels were lower than those reported in UK grey seals (Gulland, F.M.D unpublished).

Grey seal diet was assessed from the fish otoliths recovered in 3 samples identified as grey seal faeces from host DNA recovered from the samples. Some prey items were similar to those found in the harbour seal scats such as cod, whiting and herring. This overlap between the diet of grey and harbour seals has also been reported elsewhere. Thompson et al. (1996) found sandeels, gadoids, flatfish and cephalopods formed over 95% of the diet of both species in the Moray Firth, NE Scotland. However, they concluded that the dietary data, particularly for grey seals, may be biased toward those individuals which fed in more inshore areas. This may also be the case in this study as faecal samples deposited on the haul-out may represent only recent feeding.

3.5. Pressure analysis - Harbour and grey seals

3.5.1. Introduction

The purpose of the baseline pressure analysis is to identify pressures on local seal populations that already exist (i.e. prior to construction of a new fixed link). Rather than writing a solely generic description of pressures affecting seal populations, we have tried to identify pressures and conservation or management issues relevant to seals in the Baltic/Kattegat/Skaggerak region. Published literature of this kind is scarce, so in the following short document we have outlined the nature of current pressures and, where possible, the extent to which they are affecting the local grey and harbour seal populations. For this chapter, literature and internet searches were carried out (e.g. Web of Science) to find relevant information. In addition, relevant experts (for example, within SMRU) were consulted. Note that information on distribution and abundance of grey and harbour seals is presented elsewhere, in Chapters 3.2 and 3.3.

3.5.2. Results

3.5.2.1. Disturbance at haul-out sites

Unlike other areas in the Baltic (e.g. off the Danish coast), there are no organised seal watching trips in this area, however there is a considerable amount of recreational boat traffic, in addition to ferries and other commercial vessels. The Rødsand seal sanctuary (which was established in the late 1970s) is protected from public access (up to a distance of 500 m) from March to September, the main period when the site is used by seals. It is, therefore, unlikely that seals are regularly disturbed by boats when they are hauled out. However, during the aerial surveys disturbance by boats and people accessing the haul-out sites have occasionally been noticed. In the Fehmarnbelt area the Rødsand lagoon is the only area where remote sandbanks occur which are not frequented by humans. All beaches on the islands of Fehmarn and Lolland, as well as on the German mainland, are intensively used for recreational activities and it is assumed that the distribution of seals within the area is restricted by the availability of undisturbed haul-out sites.

3.5.2.2. Military activity

Off the Schleswig-Holstein coast, approximately 45 km to the west of the island of Fehmarn, 70 torpedo heads and sea mines (150-350kg TNT each) were discovered on the sea floor at a depth of 10 m (Koschinski, 2007). After 60 years the torpedo casings have corroded and disintegrated and TNT (trinitrotoluene) fragments are entering the environment. In October 2006 the Ministry of the Interior of the Federal State of Schleswig Holstein started to detonate the unexploded warheads without observing the requirements pursuant to the EC Habitats Directive. Underwater explosions represent the loudest point sources of anthropogenic noise in the sea (Koschinski, 2007), with the extremely short rise time of the noise signal posing a threat to marine mammals. Marine mammals exposed to such strong sounds can suffer deadly injuries, acoustic trauma, and permanent or temporary threshold shift (PTS or TTS; Southall et al., 2007). Further information on military activity can be found in Chapter 2.7.

3.5.2.3. Noise

The north east corner of the Nysted Offshore Wind farm (which consists of 72 turbines) is 4 km south-west of the Rødsand seal sanctuary. It was constructed between February 2002 and July 2003 and became fully operational in December 2003. During pile-driving of sheet piles in connection with one foundation there was a reduction in the number of seals hauled out compared to periods with no pile-driving (Edrén et al., 2010). It is unknown whether the seals reacted by leaving the general area or by remaining in the water. Either way the reaction appears to have been short-term as a concurrent series of aerial surveys did not show any decrease in the general abundance of seals during the construction period as a whole (Teilmann et al., 2004).

Harbour seals produce sounds down to 100Hz and have fairly good low-frequency hearing sensitivity (Southall et al., 2007). They are likely to be able to hear noise from operational wind farms (in the frequency range from 100Hz to 1 kHz at wind speeds of 5ms^{-1} and higher;

Madsen et al., 2006). In addition, masking cannot be ruled out as vocal signals of seals overlap with the frequency of offshore wind farm operational sounds. This may become important during the harbour seal mating season when males perform vocal displays (Van Parijs et al., 2000). One study examined the reactions of harbour seals to playbacks of simulated noise from an offshore turbine (Koschinski et al., 2003). This study showed that the responses occurred within a 60 to 200 m perimeter around the sound source. In other words, the impact zone for turbine noise would be small for harbour seals (see discussion in Madsen et al., 2006 on the limitation of the study undertaken by Koschinksi et al., 2003). Tougaard et al. (2009) estimated that harbour seals could detect sounds from operational wind farms (450 kW – 2 MW) from less than 100 m to several kilometres based on modelling exercises which assumed low to high transmission loss. However, they also concluded that behavioural reactions are not expected unless animals are in the immediate vicinity of the foundation. Further information on noise can be found in Chapter 2.7.

3.5.2.4. Contaminants

Marine mammals are generally exposed to a variety of anthropogenic contaminants. The main route for exposure is through their prey and because marine mammals are top predators they are at particular risk from contaminants which biomagnify[7] through the food chain. Most research has focused on two main groups of contaminants: the persistent organic pollutants (which have reproductive, immunosuppressive and disruptive endocrine effects; DeSwart et al., 1994; Ross et al., 1995) and the heavy metals (some of which bioaccumulate[8]). Although contaminant levels in the Baltic Sea ecosystem have decreased since the end of the 1970s, levels in Baltic seals are still high compared to seals in unpolluted waters (ICES, 2010). Additionally, there is evidence that grey seals have been suffering from pathological impairments, including reproductive disturbances, which have resulted in a depressed reproductive capacity (Nyman et al., 2003). There may be additional and unknown effects from novel or poorly known substances such as BCPS (Bis-(4chlorophenyl) sulfone) which has been shown to occur in grey seals and it is persistent in the Baltic (Olsson and Bergman, 1995). Few investigations on contaminants in marine mammals have been able to address effects at the population level. This is particularly important where contaminants or mixtures of contaminants are likely to affect survival or fecundity.

In addition, the Baltic Sea has the potential to be affected by 300,000 tons of chemical agents and 1.5 million tons of conventional weapons that were dumped there after the Second World War. The problem of the disintegrating munitions containers is becoming increasingly urgent (SCMM, 2007).

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[7] Biomagnification is a process by which concentrations of chemicals increases through the food chain, often through predator-prey interactions.

[8] Bioaccumulation is the initial transfer of a chemical from the environment to the first organism in a food chain.

3.5.2.5. Disease

The Skagerrak/Kattegat harbour seal population has been hit by three mass mortalities in recent times. In 1988 and 2002 outbreaks of phocine distemper virus (PDV) caused mass mortality in harbour seals. The 2002 outbreak resulted in lower moult counts at Rødsand and Vitten/Skrollen. The third epidemic (in 2007) killed fewer animals but was also caused by a virus, though not PDV (Härkönen et al., 2008). NERI moult counts from 2002 and 2007 reflect the local impact of these virus outbreaks. Because the harbour seals in the area are part of a small sub-population, mass mortality events (particularly if they increase in regularity) could have a significant long-term effect on abundance. It is worth noting however, that based on moult counts (harbour seals) and pup production (grey seals), populations of harbour and grey seals in the Baltic have increased in recent years (ICES, 2008).

3.5.2.6. By-catch

Seal by-catch has been recorded in three main types of fisheries in the area (1) fyke nets (fish traps), (2) bottom set gill nets (for cod, flatfish) and (3) salmon drift nets (e.g. Konigson et al., 2007). Much of the literature regarding the latter two is in relation to by-catch of harbour porpoises (*Phocoena phocoena*); yet, both grey and harbour seals are also bycaught. It should be mentioned, however, that some observers have noted that reports of seal by-catch are not as rigorous amongst the various European nations, compared to reporting of cetaceans (ICES, 2008). In the early 1990s, fyke nets started to be equipped with a retaining net, specifically to keep out seals. This retaining net is a large-meshed net at the entrance to the fyke through which eel and other fish, but not seals, can swim. Drowned seals are still found in areas where fykes unequipped with retaining nets are deployed. It is unclear whether retaining nets are primarily used to protect the catch from seals or to protect the seals from getting caught. Either way, retaining nets are a big step forward in mitigating seal by-catch in the fyke net fishery.

3.5.2.7. Eutrophication

The Baltic Sea is prone to eutrophication due to a very large catchment and the high influx of sewage. This results in regular algae blooms which in turn could result in lower oxygen levels at depth due to higher biodegradation (Lozan et al., 1996). Negative indirect consequences due to effects on prey species cannot be ruled out, although these are impossible to quantify as of yet.

3.5.2.8. Overfishing of prey species

Dietary information from seals in the southern Kattegat/western Baltic is scarce. Andersen et al. (2007) processed 26 faecal samples (scats) and digestive tracts collected in the Rødsand area over a five year period and found evidence of 20 different prey species. It appears that the diet was mainly made up of cod (*Gadus morhua*), herring (*Clupea harengus*), sandeel (*Ammodytes tobianus*), flounder (*Platichthys flesus*), plaice (*Pleuronectes platessa*) and dab (*Limanda limanda*). All of these species were caught in a study of fish communities in the Fehmarnbelt area (Dietrich et al., 2010). At least four of these species are commercially fished. Information on these commercially caught species (total stock biomass, recruitment, landings etc.) is available annually from ICES (http://www.ices.dk/). While the fish sizes taken by seals are likely to be smaller than those taken by the fisheries, competition between the two cannot be ruled out.

3.5.2.9. Licensed removal of seals

In various parts of the Baltic (including Rødsand), licences may be obtained to shoot seals in order to prevent damage to fishing gear (Edrén, 2009). The numbers of seals removed each year as a result of these licenses is low (in the order of between 10 and 18 animals in Denmark; see Edrén, 2009, and references therein) and is unlikely to have population-level consequences. However, seals at the haul-outs within Rødsand Lagoon are wary of human presence and suffer frequent disturbance from hunting activities (and vessel traffic). Repeated disturbance may cause stress to the animals in this region.

3.5.3. Conclusion

The baseline pressure analysis of seals in the Fehmarnbelt region is hampered by a lack of area-specific literature. Despite this, some general conclusions can be made. Disturbance through tourism or general boat-based activities should be limited and is controlled at the Rødsand seal sanctuary through regulations. Recent studies have shown little on-going (operational) effects of wind farms. Noise issues appear to relate more to short-term activities such as construction (pile-driving) or munitions explosions. Contaminants in Baltic seals are still at concerning levels, however linking this to population-level changes remains challenging. While by-catch occurs in at least some parts of the Baltic, it is difficult to assess this properly, as much of the by-catch literature focuses on harbour porpoise.

Against this backdrop of potential or actual pressures, moult counts (harbour seals) and pup production (grey seals) indicate that the Baltic populations of these species have increased in recent years (ICES, 2008). Historically, both harbour and grey seals were subject to intensive harvest at Rødsand with as many as 900 animals killed on single days in spring 1801. This figure indicates that seals were much more abundant in historic times than today. Grey seals were gradually driven from this area but the harbour seals persisted. However, this was to their detriment as by the 1970s only 30-40 animals remained (Olsen et al., *In press*). Harbour seals are recovering well and are thought to be approaching pre-hunting abundance (harbour seals were protected from 1967) and may even have reached carrying capacity within the region (Olsen et al., *In press*). Recent virus outbreaks have had a noticeable effect on count data (see Chapter 3.4); however these same data also indicate that numbers recover in subsequent years. The maintenance of this growing population in the future is dependent on the availability of resources, including suitable haul-out habitats and prey (Olsen et al., *In press*).

4. Synthesis and Baseline Evaluation Chapter

4.1. Synthesis and baseline evaluation

Three species of marine mammals occur regularly in the Fehmarnbelt: the grey seal, the harbour seal and the harbour porpoise. For all of these, Fehmarnbelt lies somewhat on the margin of their main range of distribution (see Bjørge and Tolley 2002; Burns 2009; Hall and Thompson, 2009). For harbour porpoise and harbour seal, areas of highest densities are found in the North Sea and the North Atlantic, where numbers are much higher compared to the Baltic Sea (Bjørge and Tolley, 2002; Hammond, 2006; SCOS, 2009). The grey seal occurs both in the North Sea and the Baltic Sea in high numbers (SCOS, 2009), although within the Baltic Sea, the main area of distribution is in the northern parts (SCOS, 2009). All three species occur, however, in important numbers in the wider Fehmarnbelt area and marine protected areas have been declared, both in Denmark and Germany, in order to protect these animals and their habitats (see, for example, www.bfn.de/habitatmare).

Marine mammals can be affected by various human activities (for reviews see Perrin et al., 2009; OSPAR, 2009b; Thomsen et al., 2011). In order to assess the baseline situation for harbour porpoises, harbour seals and grey seals in the context of an Environmental Impact Assessment for a large infrastructure project such as the Fehmarnbelt fixed link, it is necessary to analyse baseline survey data in relation to environmental variables which may drive the temporal and spatial distribution of the three species. It will also be required to evaluate the findings in relation to historic population trends and existing pressures in the Fehmarnbelt. In late 2008 FEMM started extensive and state-of-the-art baseline investigations on harbour porpoises, harbour seals and grey seals including visual and acoustic surveys for mapping distribution, estimating abundance and studies on movements and behaviour using telemetry techniques. In this report, we present analysis and assessments of the data covering the whole study period (November 2008 – January 2011). The evaluation of the baseline will follow a four-scaled matrix (Table 4.1-1) which has been developed by the environmental consultants within the Fehmarnbelt Environmental Investigations. This matrix provides the framework for the baseline evaluation. Specific criteria matching the overall classification are developed for specific conservation targets; in the case of marine mammals they are for the two species (-groups) harbour porpoise and seals. The initial matrix refers primarily to the conservation status on an environmental component which applies well to habitats, however, for animal species the conservation status has to be balanced against abundance criteria, which have been developed by FEMM for marine mammals (see below).

Table 4.1-1 Assessment criteria for the evaluation of the importance of the area

Importance level	Description
Very high	Components protected by international legislation/conventions (Annex I, II and IV of the Habitats Directive, Annex I of the Birds Directive), or of international ecological importance
High	Components protected by national or local legislation, or adapted on national "Red Lists". Components of importance for far-reaching ecosystem functions.
Medium	Components with specific value for the Fehmarnbelt region, and of importance for local ecosystem functions.
Minor	Other components of no special value, or of negative value.

4.2. Harbour porpoise

The Fehmarnbelt defines almost the south-eastern range of harbour porpoises inhabiting the Inner Danish Waters. Porpoise abundance to the east of Fehmarnbelt is lower compared to the Inner Danish waters (Scheidat et al., 2004b; Hammond, 2006; Verfuß et al., 2007). Whether environmental factors or possible population constraints govern this uneven distribution pattern is not known. Although, historically, the harbour porpoise population in the Baltic has been strongly influenced by anthropogenic factors such as direct catch (e.g. Kinze, 1995) it is not clear whether, or to what extent, distribution and abundance of harbour porpoises in the Baltic in recent times have been directly influenced by human pressures. Despite generally poor knowledge on population development, an ongoing decline of harbour porpoises in the Baltic Sea has often been postulated (Jastarnia Plan; see ASCOBANS, 2002) and currently by-catch rates are thought to be above accepted threshold levels (Kock and Benke, 1996; Koschinski 2002; see Chapter 2.7.2). Taking into account that today's population levels are lower than historic ones, Fehmarnbelt, as situated near the margins of the species distribution range, might be more strongly affected than areas located in central parts of the distribution range, such as parts of the North Sea.

Recent genetic studies by Wiemann et al. (2010) indicate that at least two genetically distinct populations of porpoises occur in the Baltic Sea: one in the Skagerrak and another in the Belt Sea with seasonal overlaps in the Kattegat. Although some further differences between the Belt Sea and the Inner Baltic were found, this was not statistically significant and did not separate a third genetically distinct population for the Inner Baltic. Though there is still some debate about the interpretation of data on population genetics (see Chapter 2.1.3.3), the findings of separate populations in the Belt Sea and in the Skagerrak are also reflected in animal movements derived from satellite telemetry (Chapter 2.2, Sveegaard et al., 2010). Porpoises occurring in the wider Fehmarnbelt area would thus belong to the population of the Belt Sea and Kattegat.

Baseline studies conducted by FEMM since late 2008 provide detailed insights into seasonal abundance and distribution of harbour porpoises in the Fehmarnbelt and adjacent waters with a very high spatial and temporal resolution. Previous studies conducted in Denmark and Germany usually focused on snapshots undertaken in the summer months or where the coverage of the area was limited (e.g. Scheidat et al., 2004b; Verfuß et al., 2007). In general, the different studies undertaken during the baseline evaluation provide concurrent results on seasonal patterns in the abundance of harbour porpoises with relatively low numbers in late winter (January to March), and higher numbers between spring and the end of the year - the seasonal change being more pronounced to the east of the Darss sill as compared to Fehmarn waters. It has to be noted that aerial survey data indicate a much stronger seasonal pattern compared to ferry boat counts and acoustic surveys using C-PODs. The overall abundance estimated from aerial survey data was at its lowest in winter with less than 100 individuals for single surveys in a study area of about 4,875 km^2 and maximum numbers were reached in April 2009, with almost 2,900 individuals, and in May 2010, with 4,600 individuals in the study area between Kiel and Gedser. Maximum numbers in 2009 and 2010 may be influenced by animals migrating through the area. Modelled summer averages for 2009 and 2010 reached 1,500 and 2,000 porpoises respectively. The aerial survey results show that abundance fluctuated at high levels in the summer months but decreased after September and average winter levels were below 1,000 porpoises. By contrast, ferryboat counts and C-POD data did not record a marked decrease before the end of the year; numbers being especially low in early 2010 when ice covered Fehmarnbelt. These differences could be due to the methodology applied, as visual surveys can only provide a snapshot in time even if undertaken twice a month whereas acoustic monitoring has, in general, a very good temporal resolution, though animal numbers are not obtained with this method. It is noteworthy that all studies pointed to a marked increase in April/May and somewhat lower numbers thereafter. They also show a second slight peak in late autumn/early winter. We hypothesise that these peaks in sightings are a result of animals moving across the Belt at different times of the year with perhaps a movement of porpoises into the Eastern Baltic in spring and a migration back to the western Baltic in autumn/winter. This study, therefore, provides an indication of harbour porpoise movement through the Fehmarnbelt. This could be inferred from the seasonal pattern of previous acoustic surveys (Verfuß et al., 2007) but has not yet been documented in detail as here. Analysis of the data of porpoise tagged with satellite transmitters indicate that a substantial part of the subpopulation of the Belt Sea migrates in winter to the Skagerrak area providing further evidence of seasonal movements.

The results of our different methodological approaches show that harbour porpoise occur year-round in the Fehmarnbelt area. Aerial survey data and C-POD data both show a strong gradient and uneven distribution in porpoise abundance throughout the study area. During aerial surveys, highest densities were found in the northern parts close to the entrance to the great Belt and south of Gedser and lowest densities to the south towards the coast of Mecklenburg. C-POD data also indicate that as well as a north-south gradient, there is a clear west-east gradient with only a few recordings in the eastern part of the study area. Spatial distribution and areas of higher densities remained constant over seasons and over the two-year study period and are also in line with earlier analysis from tagged animals (Teilmann et al., 2008). The results from the C-POD study show a slightly different pattern compared with results from the aerial surveys. In general, the gradient, at least from northwest to southeast, reflects the overall distribution of harbour porpoises in its distribution range (see Verfuß et al., 2007, FTZ and DMM 2010).

In order to assess the possible impact of the planned fixed link through the Fehmarnbelt, likely impacts have to be considered relative to other factors that already govern the activity of porpoises in the area. Apart from documenting abundance and temporal dynamics in the occurrence and the acoustic activity of porpoises for various parts of the Fehmarnbelt, a further objective of the baseline evaluation was to establish possible drivers of existing patterns of porpoise distribution in the area. Therefore, both aerial surveys and acoustic data have been analysed in relation to environmental variables. We would expect the distribution of marine mammals to be linked, mainly indirectly, to variables like water depth or position to hydrographical parameters such as salinity, temperature, hydrographic fronts etc. which in turn are believed to be linked to the distribution and abundance of prey (see Reid et al., 2003; Johnston et al., 2005; Camphuysen et al., 2006; Fontaine et al., 2007; Skov and Thomsen, 2008, Edrén et al., 2010). However, all of these relationships either direct or indirect between porpoise distribution and environmental parameters are not well understood.

Our investigations clearly indicate that the distribution of harbour porpoises in the Fehmarnbelt is influenced, either primarily or secondarily, by environmental conditions, particularly static features. For all harbour porpoise datasets (aerial surveys, CPOD and telemetry), latitude, longitude and depth were common variables affecting porpoise distribution. Geo-data based variables have previously been shown to be important for porpoise distribution (Johnston et al., 2005; Edren et al., 2010). However, it remains unclear how to bring these geo-coordinate variables into an ecological context as they only show that the distribution of porpoises is not random and some areas or stations are of more importance for the animals than others. The relationships with depth from the aerial survey and CPOD data concurred that the occurrence of harbour porpoises is low in the shallowest waters close to the coast, shallower than 10m. They also confirm that porpoises do occur in deeper waters but are less numerous. The modelling of the harbour porpoise telemetry data also showed that predicted distribution was clearly governed by depth. However, the habitat usage model of these data show an increasing probability of porpoise presence with increasing depth; this modelling approach also takes into account the availability of the habitat type (in this case deeper waters) in the surveyed area. This relationship means that if there was more ‘suitable’ deep water in the Fehmarnbelt, then porpoise presence would be expected to be higher. Perhaps the most obvious factor limiting the use of the deeper water areas is the presence of a busy shipping lane. A recent study based on Individual based modelling comes to the conclusion that the existing ship traffic in the Kattegat area is likely to cause a reduction in the population size, assuming that porpoises react to noise from ships by turning away (Nabe-Nielsen et a. 2011). There was also some evidence in the POD analysis that distance to the shipping lane on the one side and background noise level on the other side had some predictive power on porpoise distribution, showing avoidance at the closest (= loudest) distances. Distance to shipping lane was not an important predictor variable in the other analyses using aerial and telemetry data; therefore, we must assume that whilst there may be some avoidance it is a relatively minor effect. It is likely that there are differences in the hydrodynamics of the deeper water habitats compared with the shallower water ones (10-20 m) that are less attractive to porpoises or their prey. This is further supported by the fact that distance to shipping lane and background noise was only significant when fitted in conjunction with other variables (static and dynamic).

The role of dynamic hydrographic variables was found limited in all datasets used in this study (aerial surveys, passive acoustic monitoring, and telemetry). The results from the models only partly support the hypothesis that the fine-scale hydrodynamic variables, which are closely connected to inflow/outflow dynamics, act as governing factors on the general distribution of harbour porpoises in the Fehmarnbelt area. This might be due to the relatively small temporal scales of some of those variables compared to the scales at which the data could be modelled. The speed of the currents at depth (aerial and POD data) and at the surface (POD and telemetry data) all have an effect on the distribution of porpoises in the area with a tendency for occurrence to be higher in areas of low-moderate current strength. Water temperature was a strong predictor of porpoise distribution for both POD and aerial survey data. In general, the results of the models explain the seasonal changes in porpoise distribution with a marked reduction of porpoise activity/density at low water temperatures (4-5°C) that typify winter. The peak in porpoise activity/density occurs when water temperature is between 5-10°C in the spring or autumn months, when the abundance of porpoises in the area was at its highest.

Porpoise calves have been observed during summer aerial surveys, mostly during the warmer months of July and August. This is consistent with typical calving trends for this species, with most calves born between April and August (Jefferson et al., 2008). The numbers of calves recorded during the various surveys in the area are, however, highly variable between years. Analysis of the movements of porpoises tagged with satellite transmitters revealed that porpoise calves show large-scale movements, similar to adult porpoises tagged without calves, providing no indication that calves (and their mothers) stay in smaller selected areas which could be attributed to be calving grounds.

4.2.1. Baseline evaluation harbour porpoise

The harbour porpoise is included in the regional Agreement on the Conservation of Small Cetaceans of the Baltic and North Sea (ASCOBANS) resulting from the Bonn Convention. Since the harbour porpoise is the only cetacean resident in the Baltic Sea it has become the flagship species of this Agreement. In 2002, under the aegis of the ASCOBANS Secretariat, a special working group composed of representatives of international conventions, government ministries, fishermen and environmental groups, has developed a recovery plan for the Baltic harbour porpoise (Jastarnia Plan; see ASCOBANS, 2002), which recommends a programme for by-catch reduction, research and monitoring, marine protected area establishment and an increase of public awareness. The overall aim is to restore the Baltic population of harbour porpoises.

The harbour porpoise is further listed in Annex IV of the EU Habitats Directive which demands strict protection for animal and plant species of community interest. It is also listed in Annex II whereby all relevant member states are legally obliged to protect the harbour porpoise by designating Marine Protected Areas, referred to as Special Areas of Conservation (SAC).

The designation of marine SACs in the EU is scheduled to be completed by 2012 (European Commission, 2007). In the Fehmarnbelt, both bordering states have already declared marine areas as SACs in order to protect harbour porpoises. The declaration of these SACs was based on the findings of German and Danish research projects (see Scheidat et al., 2004a; Teilmann et al., 2008) which investigated population and behaviour of harbour porpoises in the Baltic Sea.

In evaluating the importance of the Fehmarnbelt for harbour porpoise these legal requirements have to be taken into account. Numerical criteria are commonly used to evaluate the importance of a given area for an animal species. However, in addition to criteria referring to abundance, the function an area may serve for different purposes during the annual cycle of a species should, if possible, be considered. Thus, the Fehmarnbelt or sub regions have to be evaluated for such functions as (1) staging area, (2) nursing ground and (3) migration corridor. The latter is an important consideration given the possibility that an eastern population exists. In the following section we will provide an initial assessment of the three functions based on preliminary criteria shown in Table 4.2-1.

Table 4.2-1 Preliminary criteria for the evaluation of the importance of the area for harbour porpoise

Importance level	Description	Staging	Nursing	Migration corridor
Very high	Components protected by international legislation/conventions (Annex I, II and IV of the Habitats Directive, Annex I of the Birds Directive), or of international ecological importance. Components of critical importance for wider ecosystem functions.	$>1/km^2$	Exceptional high calf ratio, highest abundance during nursing time	Essential corridor between important staging or nursing areas, connection between subpopulations
High	Components protected by national or local legislation, or adapted on national “Red Lists”. Components of importance for far-reaching ecosystem functions.	$>0.5/km^2$	High calf ratio, High abundance during nursing time	One of more corridors between important staging or nursing areas, connection between subpopulations
Medium	Components with specific value for the Fehmarnbelt region, and of importance for local ecosystem functions.	$>0.25/km^2$	Medium calf ratio, no special function as nursing ground	Corridor between medium important staging or nursing areas
Minor	Other components of no special value, or of negative value.	$<0.25/km^2$	Lower calf ration than average, lower numbers in the nursing period	Minor function as corridor between medium important staging or nursing areas

4.2.1.1. Importance as staging area

According to the available data on porpoise abundance from the cited studies and our own investigation, we applied the following criteria for the evaluation of the function of Fehmarnbelt as a staging area based on animal densities as obtained from visual surveys (see Table 4.2-1). Our values range from, $<0.25 / km^2$ (minor) to $>1 / km^2$ (very high). These criteria are specifically developed for the situation in the western Baltic where porpoise densities are relatively low (see for example Scheidat et al., 2004a). In the North Sea, densities in SACs and other areas reach values of 3 to 5 animals / km^2 (Scheidat et al., 2004a; Thomsen et al., 2006; Gilles et al., 2007; Diederichs et al., 2008).

The importance as staging area, which covers the function for all other aspects in the lifecycle of a harbour porpoise other than nursing ground and migration corridor (which are treated separately), is evaluated on the basis of the modelled abundance of porpoises as derived from aerial survey data. It has to be mentioned that, in this respect, the spatial distribution as obtained from the model applied to aerial survey data differs from model results using telemetry data (chapter 2.2) or POD data (chapter 2.6). Telemetry data in this study have been modelled to estimate predicted habitat use of harbour porpoises in the Fehmarnbelt area. A similar approach was used by Teilmann et al. (2008) to define important areas for porpoises in Denmark. However, in this study we did not use the telemetry data set directly for the baseline evaluation to estimate absolute densities because of limitations on the sample size of such data set in the Fehmarnbelt area. Results of the POD study and the analysis of the telemetry data will however, be considered as supplementary information for the Impact Assessment.

Within our study area, maximum densities of single surveys reached a value of about 0.6 to 0.9 porpoise / km^2 and mean densities during summer reached 0.43 porpoise / km^2 thus the whole area reached a level of medium importance during surveys in spring and early summer. The uneven distribution of porpoises in the Fehmarnbelt further leads to the conclusion that subareas may be ranked as higher importance and the results of the spatial modelling allows identifying of subareas of higher importance levels. As shown in Figure 4.2-1 extensive subareas reach medium importance levels during spring and summer and further areas exceed densities of 1 or 1.5 porpoise / km^2 thus reflecting subareas of high and very high importance. These areas have partly been included into Marine Protected Areas under the Natura 2000 network.

Importance levels for the winter months, Figure 4.2-2, are generally lower and only small subareas reach a level of medium importance. It is worth noting, however, that these areas are similarly located to those of higher importance during summer.

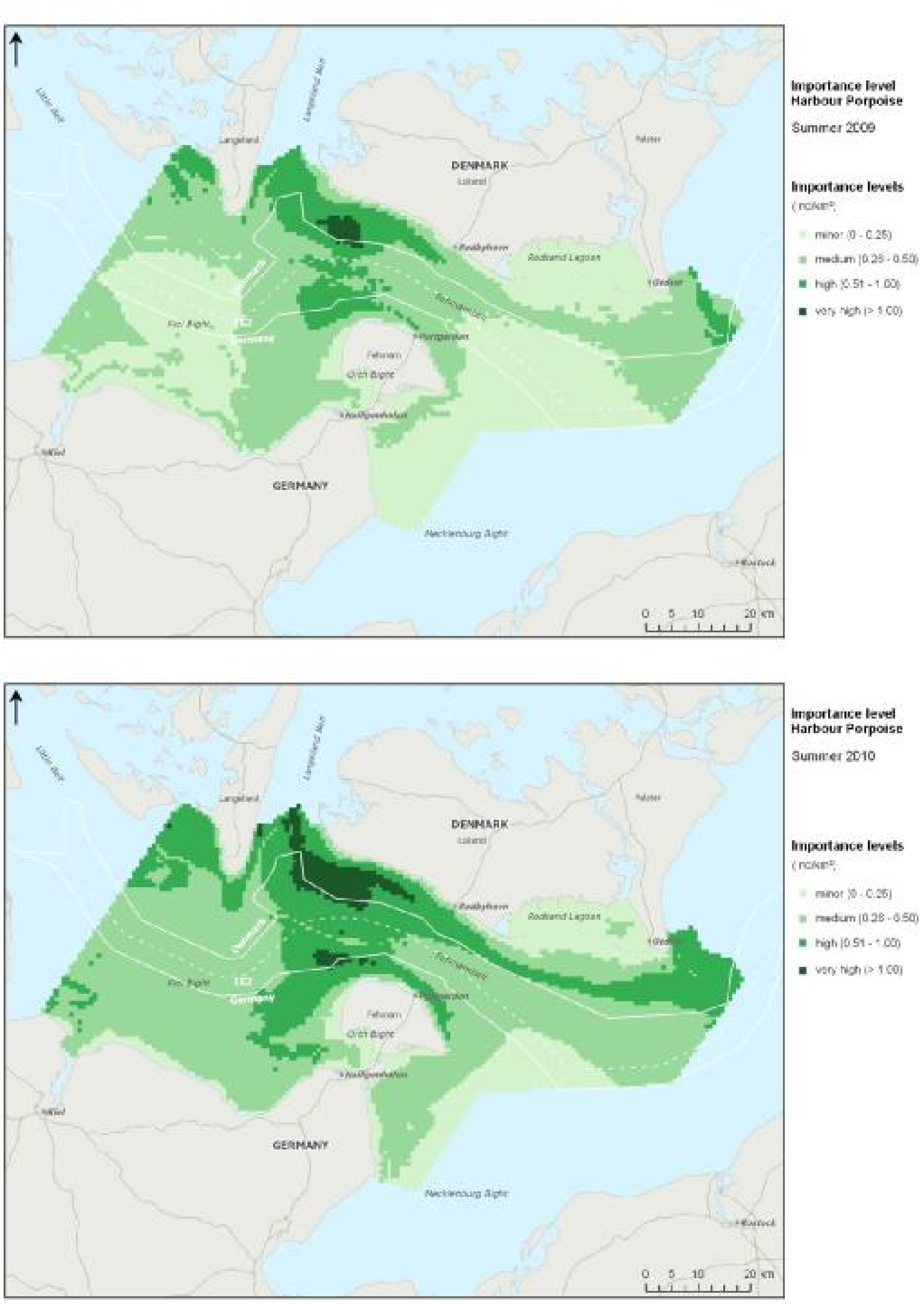

Figure 4.2-1 Classification of the importance of Fehmarnbelt for harbour porpoises during summer, based on modelled densities derived from aerial surveys (chapter 2.3) according to criteria of Table 4.2-1

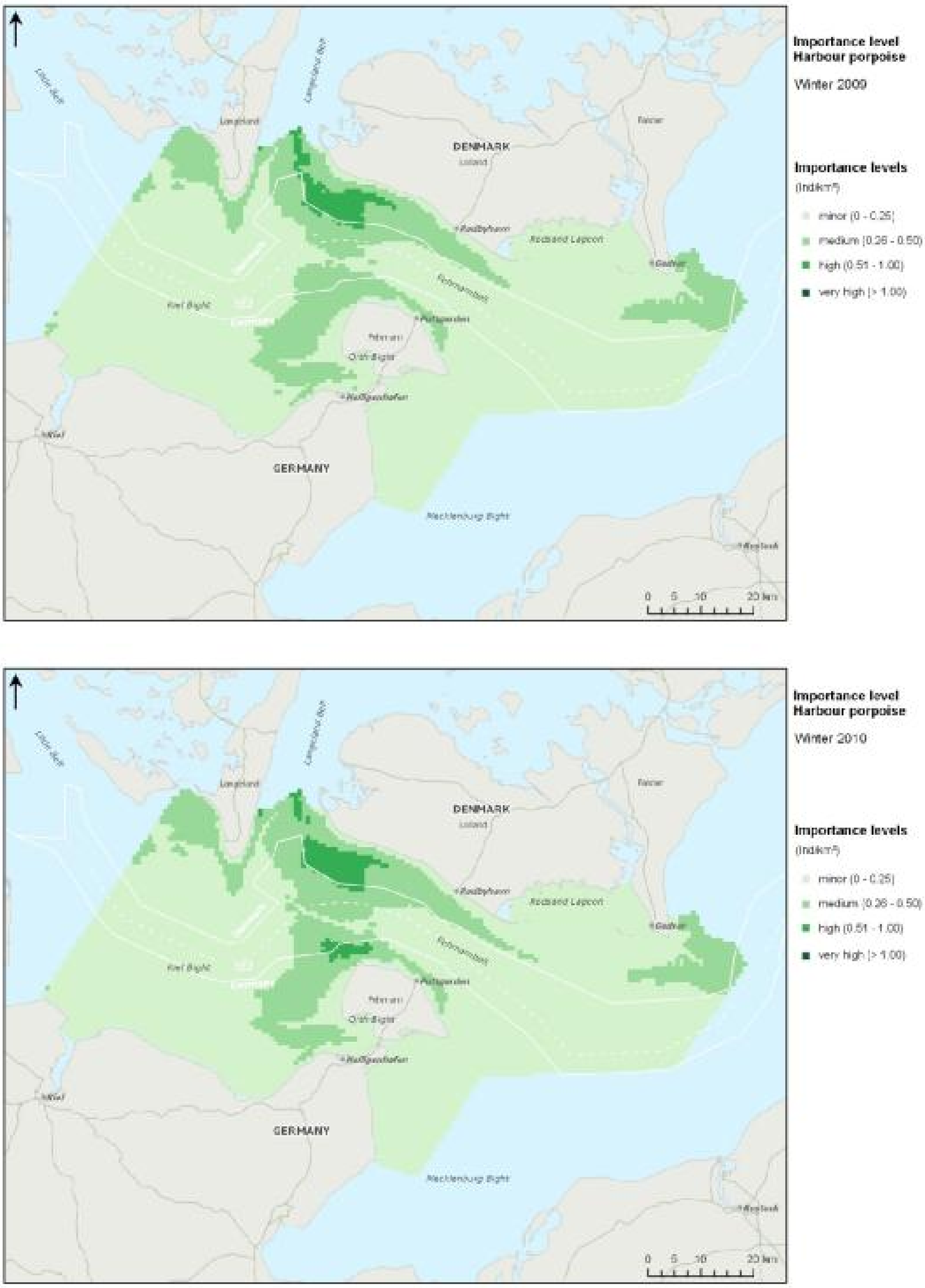

Figure 4.2-2 **Classification of the importance of Fehmarnbelt for harbour porpoises during winter, based on modelled densities derived from aerial surveys (chapter 2.3) according to criteria of Table 4.2-1**

4.2.1.2. Importance as nursing area

It should be noted here that while many baleen whales (e.g. humpback whale, gray whale) travel between special nursing and feeding areas throughout the annual cycle, nursing areas are so far not described for any odontocete species (see species overviews in Perrin et al., 2009). Most odontocetes don't undertake migrations between nursing and feeding grounds; they occupy one home range throughout the year in which movements are most likely governed by the distribution and abundance of prey (see Perrin et al., 2009). Yet, due to some seasonal movements, the existence of special calving grounds or nursing areas for harbour porpoises – for example off northern Frisia – has been postulated by some authors (e.g. Scheidat et al., 2004a). The available data are not sufficient to evaluate whether an area is functioning as a calving ground based solely on calf ratio data. From the available data it is clear that harbour porpoises calve in early summer wherever they are during that time, means that they calve and nurse calves also in the Fehmarnbelt region during the summer months but the calving rates we found are well within the limits described by other investigations and varied between the two-years of baseline studies. The function as a specific nursing area is thus preliminary evaluated as being medium at best.

4.2.1.3. Migration corridor

Several data sources give a clear indication of seasonality of the occurrence of harbour porpoises in the Fehmarnbelt and especially in the areas to the east of the Fehmarnbelt. Some of our results, for example, the spring and autumn peaks in porpoise abundance and acoustic activity, indicate that Fehmarnbelt has the function of a migration corridor for porpoise movements between the Eastern and Western Baltic. However, it is unclear how many porpoise would move across the alignment at these times; certainly porpoise abundance to the east of Fehmarnbelt is low compared to other areas of the distribution range of this population. The Fehmarnbelt is also not the only channel that provides a connection between the Western and Eastern Baltic as there are four more waterways connecting the eastern areas with the Inner Danish waters. The limited numbers of animals that are moving across the alignment are certainly not indicative of the Fehmarnbelt being a vital connection between important nursing areas, as calving rates fall within the variation described by other studies. It is further unlikely that the Belt connects important staging areas, as at most times of the year porpoise densities east of the alignment could be regarded as medium or even low. As porpoise numbers to the west were also comparably low, the function of Fehmarnbelt as a migration corridor is evaluated as medium. This evaluation is based on the present state of knowledge that no discrete population in the eastern part of the Baltic Sea is dependent on migration through the Fehmarnbelt.

4.3. Harbour and grey seal

The occurrence of both species in the Fehmarnbelt area is focused on the haul-out sites in the Rødsand lagoon. The distribution of harbour and grey seals is dictated to a large extent by their need to haul-out on the shoreline. This haul-out pattern makes seals vulnerable to human impacts, for example hunting and disturbance, and significantly restricts their distribution, though effects on overall population sizes have been difficult to discern (ICES, 2008). Both species of seals are currently increasing in numbers, although harbour seal numbers have been affected significantly by two outbreaks of Phocine Distemper Virus (Härkönen et al., 2008; ICES, 2008).

The occurrence of harbour seals in the Fehmarnbelt is largely restricted to the Rødsand lagoon where the only haul-out sites in the area are found. Previous surveys indicate that about 30-50% of all harbour seals found in Danish waters, and a third of the Baltic population of seals, occur in this area (SCOS, 2009; see also chapter 3.2). The telemetry data obtained in our study indicate that regular feeding areas are situated in the vicinity of the Rødsand lagoon. The importance of the Rødsand lagoon and adjacent feeding areas is evaluated as very high because a high proportion of Baltic seals occur in this area. In addition, the breeding and pupping ground at Rødsand is of importance for the whole Baltic population of harbour seals (Teilmann. J. and Heide-Jørgensen, 2001). The importance of the Fehmarnbelt outside the Rödsand area is ranked as low.

Similarly, the occurrence of grey seals in Fehmarnbelt concentrates at Rødsand lagoon. Grey seals extend their foraging trips to much wider areas than harbour seals but little movements into the Fehmarnbelt have been recorded during this study. On the other hand, grey seals apparently commute between haul-out sites and travelled on several occasions to the Øresund area where haul-out sites are found in Denmark and Sweden. The importance of the Rødsand area for grey seals is evaluated as high, as it holds a substantial part of all Danish grey seals, but total numbers are low compared to the whole Baltic population. The importance of the Fehmarnbelt outside the Rödsand area is ranked as low.

Table 4.3-1 Preliminary criteria for the evaluation of the importance of the area for harbour seal and grey seal

Importance Level	Description	Environmental component harbour seal and grey seal
Very high	Components protected by international legislation/conventions (Annex I, II and IV of the Habitats Directive, Annex I of the Birds Directive), or of international ecological importance. Components of critical importance for wider ecosystem functions.	Breeding or pupping ground of importance for the Baltic population
High	Components protected by national or local legislation, or adapted on national "Red Lists". Components of importance for far-reaching ecosystem functions.	Breeding or pupping ground of importance for the population in that area.
Medium	Components with specific value for the Fehmarnbelt region, and of importance for local ecosystem functions.	Breeding ground, but pupping rates not consistently higher than in other areas.
Minor	Other components of no special value, or of negative value.	Area is of minor importance for seals in the Western Baltic and beyond.

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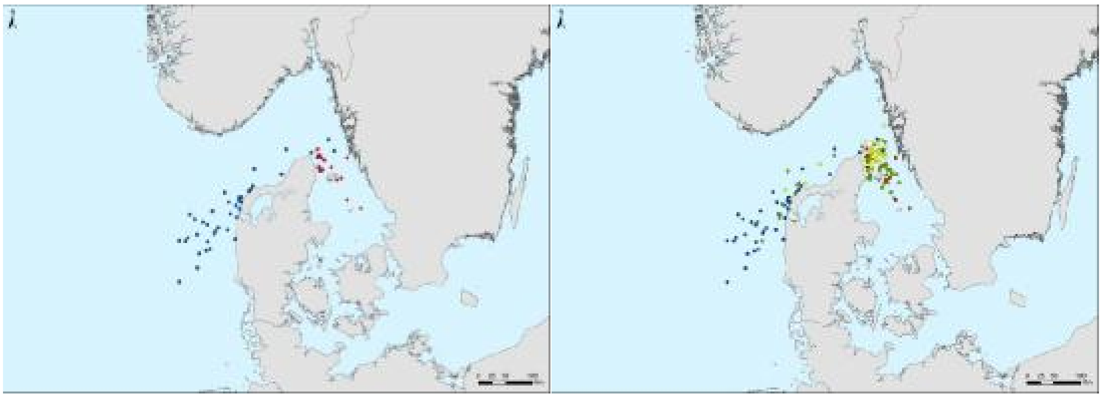
7. Appendices

7.1. Appendix 1 Harbour Porpoise Telemetry

A



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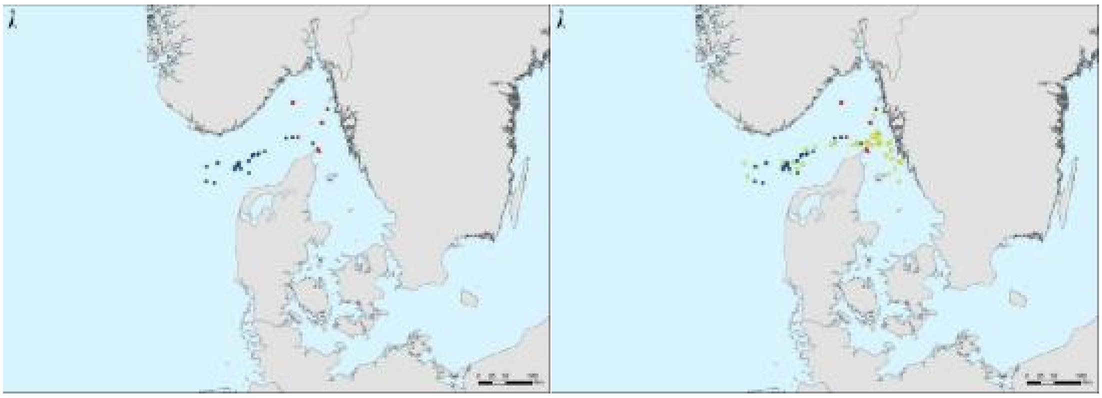

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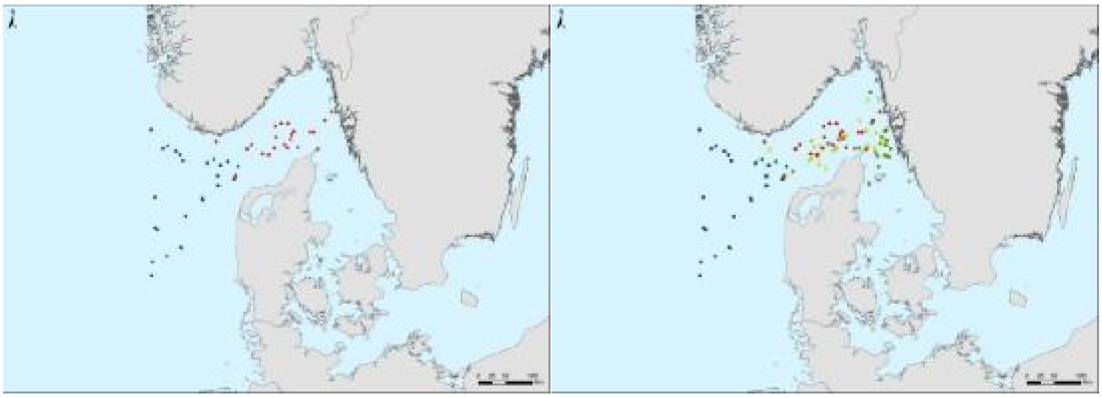

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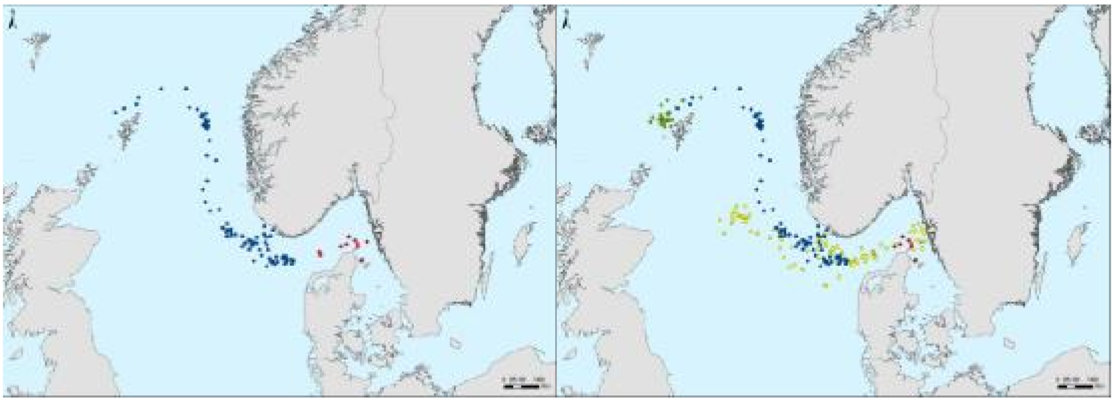

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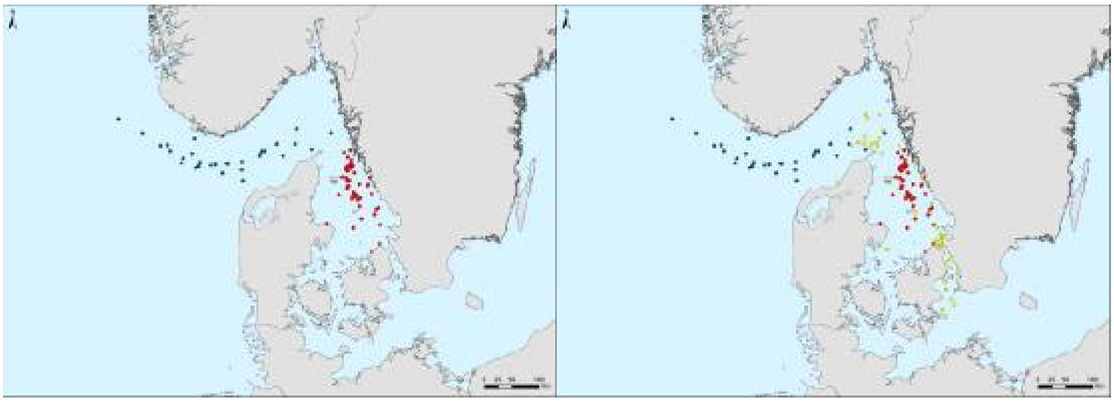

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B

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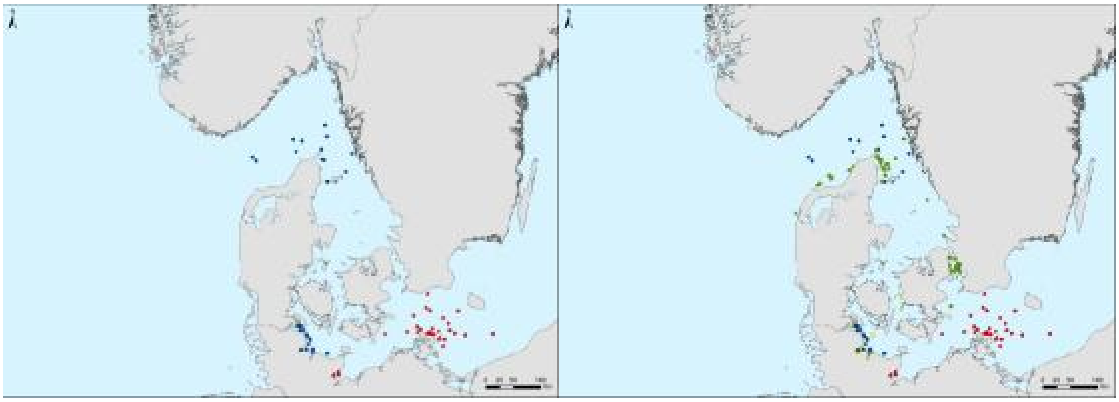

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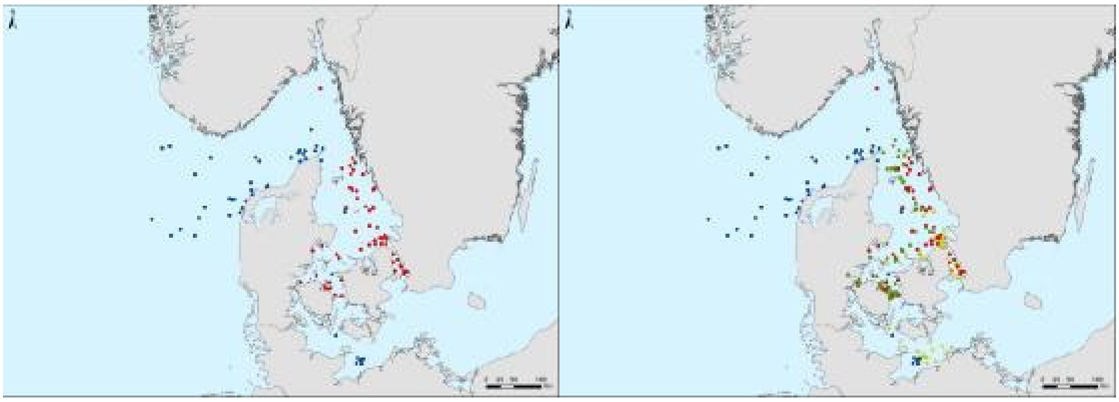

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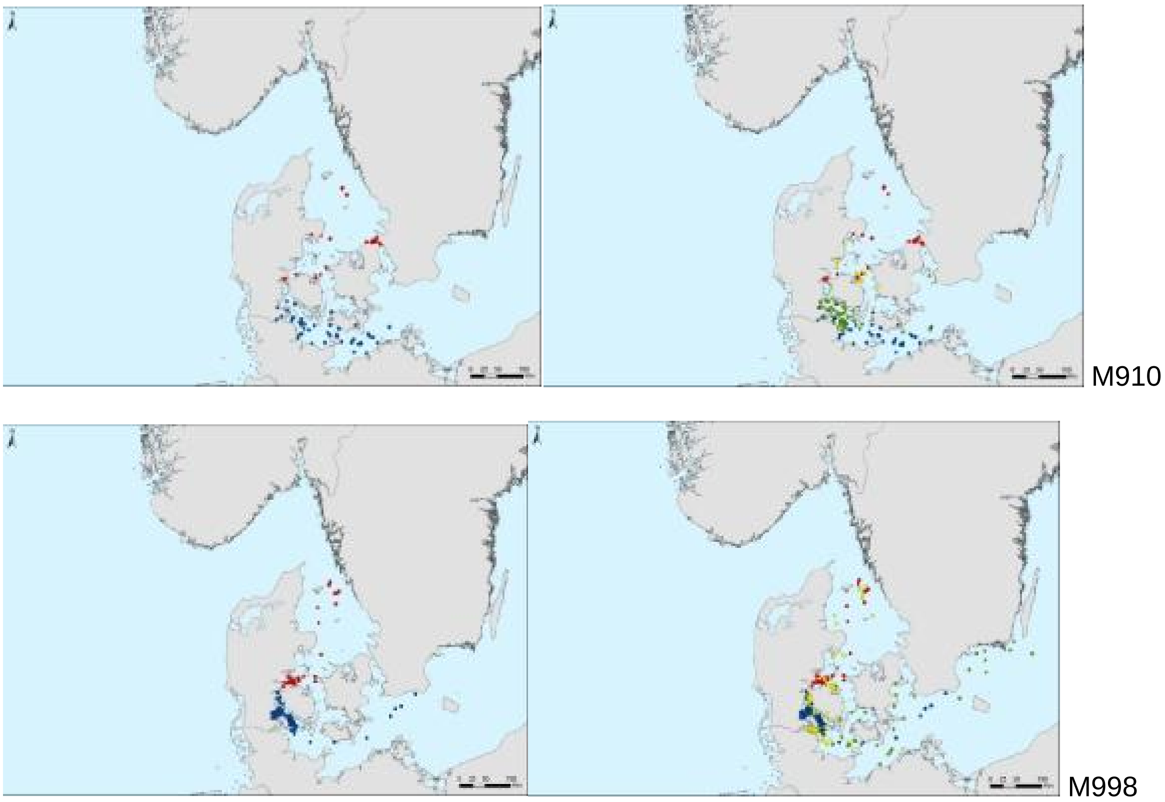

Figure 7.1-1 **Locations of 13 harbour porpoises tracked during both summer and winter. A. animals that spent the summer in the Kattegat and Skagerrak, B. animals that spent the summer in Inner Danish Waters (IDW) and moved north in winter, C. animals that spent the summer in IDW and moved south in winter. Each row represents one individual; the left hand maps show the locations of animals during summer and winter only, the right hand maps show locations during all four seasons (summer – red, autumn – yellow, winter – blue, spring – green). The legend to the right shows individual code.**

Table 7.1-1 **Number of locations recorded from each of the 82 tagged animals used in this study, and number of locations obtained within the Fehmarnbelt focal study area (Fehm). BELT = Belt Sea; FJEL = Fjellerup Strand; SKA = Skagen**

Animal	Tagging location	Total locations	Locations inside Fehm
m001	BELT	62	0
m007	BELT	124	26
m008	BELT	124	0
m011	BELT	50	0
m021	BELT	225	27
m022	BELT	59	0
m025	BELT	2	0
m026	BELT	116	4
m027	BELT	72	1
m028	BELT	72	20
m032	BELT	35	5
m034	BELT	20	0
m051	BELT	51	5
m061	BELT	102	0
m063	BELT	103	24
m072	BELT	26	0
m100	BELT	23	0
m200	BELT	94	14
m801	BELT	123	8
m802	BELT	7	0
m803	BELT	95	2
m804	BELT	47	11
m902	BELT	215	6
m905	BELT	25	12
m906	BELT	64	27
m907	BELT	69	13
m910	BELT	126	34
m971	BELT	26	0
m972	BELT	38	0
m973	BELT	37	0
m974	BELT	11	0
m981	BELT	66	39
m982	BELT	17	0
m983	BELT	45	19
m984	BELT	43	15
m985	BELT	57	0
m991	BELT	95	4
m992	BELT	98	0
m993	BELT	111	27
m994	BELT	113	0
m995	BELT	114	0
m996	BELT	101	3
m997	BELT	126	0
m998	BELT	243	20
m999	BELT	12	1
m012	FJEL	119	1
m024	FJEL	24	0
m031	FJEL	31	0
m062	FJEL	103	0
m064	FJEL	92	0
m071	FJEL	29	0
m300	FJEL	29	0
m401	FJEL	6	0
m402	FJEL	23	0
m500	FJEL	3	0
m901	FJEL	244	0
m903	FJEL	121	0
m904	FJEL	83	0
m002	SKA	20	0
m003	SKA	74	0
m004	SKA	12	0
m005	SKA	144	0
m006	SKA	67	0
m013	SKA	29	0
m014	SKA	103	0
m015	SKA	43	0
m016	SKA	49	0
m017	SKA	38	0
m018	SKA	99	0
m019	SKA	12	0
m023	SKA	28	0
m035	SKA	45	0
m036	SKA	81	0
m037	SKA	58	0
m038	SKA	52	0
m110	SKA	141	0
m111	SKA	45	0
m112	SKA	215	0
m113	SKA	27	0
m114	SKA	28	0
m115	SKA	5	0
m116	SKA	49	0

Table 7.1-2 NERI historic data (1997 – 2010), excluding the deployments made under the Fehmarnbelt project. The porpoise telemetry studies refer to NERI = work carried out by NERI-Aarhus University; FEHM = work carried out under the current project

Animal	PttID	Tagging location	Sex	Length	Weight (kg)	Deployment date	Contact period (any signal received)	Contact days	Transmission allowed and duty cycle	Transmitter type	Porpoise telemetry study
m001	200004178	Belt Sea	F	98	25	26.03.2000	26/3-13/8 2000	140	100upl/2dag	SDT-T16	NERI
m007	200002919	Belt Sea	M	121	36	01.09.2000	1/9 2000-6/1/2001	128	3t/dag	ST-18	NERI
m008	200004542	Belt Sea	F	116	28	08.11.2001	8/11/2000-4/9 2001	301	75upl/2dag	STR-T16	NERI
m011	200110343	Belt Sea	M	140	49	22.04.2001	22/4-20/7 2001	90	150upl/2dag	SP OT2	NERI
m021	200224296	Belt Sea	F	170	58	05.04.2002	5/4-25/11 2002	235	2t/dag	Kiwi101(C-cell)	NERI
m022	200224287	Belt Sea	F	129	39	05.04.2002	5/4 2002-bycaught 26/6 2002	84	2t/dag	Kiwi101	NERI
m025	200210340	Belt Sea	F	104	19	30.08.2002	30.08.2002-4.9 2002	6	75upl/dag	SDR-T16	NERI
m026	200206174	Belt Sea	M	131	29	26.09.2002	26.09 2002-23.5 2003	240	100upl/2dag	SPOT 2	NERI
m027	200206422	Belt Sea	F	105	21	27.09.2002	27.09.2002-27.2 2003	154	100upl/2dag	SPOT 2 (2xM1)	NERI
m028	200202919	Belt Sea	M	101	20	06.10.2002	06.10 2002-26.12 2002	82	90(2t/dag)	ST-10	NERI
m032	200310340	Belt Sea	M	153	47	17.04.2003	17.04 2003-31.7 2003	106	75upl/3days	SDR-T16	NERI
m034	200326634	Belt Sea	M	130	30	19.08.2003	19.08 2003-24.9 2003	37	2t/2d	ST-10	NERI
m051	200506420	Belt Sea	M	120	29.5	08.06.2005	08.06 2005-27.10 2005	142	250upl/3dag	SPOT4	NERI
m061	200606422	Belt Sea	M	149	53	23.04.2006	23.04-10.11 2006	202	250upl/2dag	SPOT4	NERI
m063	200606421	Belt Sea	M	125	29.5	02.05.2006	02.05-22.11 2006	205	250upl/2dag	SPOT4	NERI
m072	200717776	Belt Sea	M	146	46	08.10.2007	08.10-7.11 2007	31	100/dag	SPLASH	NERI
m100	201056573	Belt Sea	F	150	41	28.03.2010	28.03-20.4 2010	24	125/2dag	SPLASH	NERI
m200	201057102	Belt Sea	M	119	31.3	28.03.2010	28.03-12.9 2010	169	500/2dag	SPLASH	FEHM
m801	200806170	Belt Sea	M	122	29.5	30.10.2008	30.10 2008-30.7 2009	274	150/2dag	SPLASH	FEHM
m802	200806171	Belt Sea	M	122	31	14.11.2008	14.11-19.11 2008	6	150/2dag	SPLASH	FEHM
m803	200817758	Belt Sea	F	127	42	13.10.2008	13.10.2008-17.5 2009	217	150/2dag	SPLASH	FEHM
m804	200817764	Belt Sea	M	139	57	13.10.2008	13.10.2008-12.2 2009	123	150/2dag	SPLASH	FEHM

Animal	PttID	Tagging location	Sex	Length	Weight (kg)	Deployment date	Contact period (any signal received)	Contact days	Transmission allowed and duty cycle	Transmitter type	Porpoise telemetry study
m902	200906422	Belt Sea	M	139	41	09.04.2009	09.04.2009-6.9 2010	514	150/2dag	SPLASH	FEHM
m905	200956571	Belt Sea	M	104	21	25.09.2009	25.09.2009-4.11 2010	41	125/2dag	SPLASH	FEHM
m906	200957098	Belt Sea	F	160	51	25.09.2009	25.09.2009-21.1.2010	119	125/2dag	SPLASH	FEHM
m907	200957100	Belt Sea	F	129	31	10.10.2009	10.10.2009-18.2 2010	132	125/2dag	SPLASH	FEHM
m910	199904540	Belt Sea	F	109		02.11.1999	02.11.1999-3.9 2000	306	100upl/2dag	SDR-T16	NERI
m971	199706171	Belt Sea	F	110	26	14.04.1997	14.04-9.5 1997	26	500/dag	SDR-T10	NERI
m972	199706170	Belt Sea	F	164	62	16.04.1997	16.04-23.5 1997	38	500/dag	SDR-T10	NERI
m973	199706172	Belt Sea	M	138	37	27.10.1997	27.10-6.12 1997	41	400/dag	SDR-T10	NERI
m974	199706173	Belt Sea	M	114	24	01.11.1997	01.11 14.11 1997	14	400/dag	SDR-T10	NERI
m981	199806170	Belt Sea	M	135		04.04.1998	04.04-12.6 1998	70	360 (8t/dag)	ST-10	NERI
m982	199806174	Belt Sea	M	119	34	04.04.1998	04.04-20.4 1998	17	361 (8t/dag)	ST-10	NERI
m983	199806171	Belt Sea	F	166	58	11.05.1998	11.05-24.6 1998	45	250/dag	SDR-T10	NERI
m984	199806173	Belt Sea	F	110	26	11.05.1998	11.05-22.6 1998	43	250/dag	SDR-T10	NERI
m985	199806420	Belt Sea	M	116	32	19.05.1998	19.05-14.7 1998	57	250/dag	SDR-T10	NERI
m991	199906172	Belt Sea	F	138	45	30.03.1999	30.03-16.7 1999	109	100/dag	SDR-T10	NERI
m992	199906421	Belt Sea	M	127	37	13.04.1999	13.04-20.7 1999	99	100/dag	SDR-T10	NERI
m993	199906422	Belt Sea	F	120	31	13.04.1999	13.04-2.8 1999	112	100/dag	SDR-T10	NERI
m994	199906174	Belt Sea	F	112	31	25.04.1999	25.04-17.8 1999	115	100/dag	SDR-T10	NERI
m995	199906173	Belt Sea	F	144	65	25.04.1999	25.04-17.8 1999	115	100/dag	SDR-T10	NERI
m996	199906171	Belt Sea	F	116	30	26.04.1999	26.04-4.8 1999	101	100/dag	SDR-T10	NERI
m997	199906170	Belt Sea	M	118	37	27.04.1999	27.04-3.9 1999	130	100/dag	SDR-T10	NERI
m998	199906420	Belt Sea	M	107	18	28.07.1999	28.07.1999-7.4 2000	255	180 (4t/day)	ST-18	NERI
m999	199904108	Belt Sea	M	117	25	14.10.1999	14.10-7.11 1999	25	50/dag	SDR-T16	NERI
m012	2001103	Fjellerup	M	128	34	03.05.2001	03.05-29.8 2001	119	100upl/dag	SPOT2/VHF	NERI

Animal	PttID	Tagging location	Sex	Length	Weight (kg)	Deployment date	Contact period (any signal received)	Contact days	Transmission allowed and duty cycle	Transmitter type	Porpoise telemetry study
	36	strand									
m024	200210342	Fjellerup strand	M	140	43	10.05.2002	10.05-26.7 2002	78	100upl/dag	SPOT2	NERI
m031	200306170	Fjellerup strand	M	143	42	14.03.2002	14.03-15.5 2002	63	100upl/2dag	SDR-T10 (4xM1)	NERI
m062	200606172	Fjellerup strand	M	111		26.04.2006	26.04-12.11 2006	201	250upl/2dag	SPOT4	NERI
m064	200606171	Fjellerup strand	F	106		15.05.2006	15.05-15.11 2006	185	250upl/2dag	SPOT4	NERI
m071	200706170	Fjellerup strand	F	166	62	19.05.2007	19.05-15.6 2007	27	1000/dag	SPOT4	NERI
m300	201057101	Fjellerup strand	M	115	24	16.05.2010	16.05-6.10. 2010	>144	150/2days	SPLASH	NERI
m401	201056574	Fjellerup strand	M	107	22	19.05.2010	19.05-28.5 2010	10	150/2days	SPLASH	NERI

Table 7.1-3 **The number of crossings of straits and bridges by tagged harbour porpoises**

Animal ID	Æbeløgård	Little Belt bridge	Aerö	Sletterhage	Samsø	Great Belt bridge	Langeland	Helsingborg	Øresund bridge	Fehmarn Belt
Long tracks										
m998	8	1	12	1	1		2			2
m910	3		7		2	1	3			5
m904								2	2	
m903								4	2	
m902	8			1	13	2	2			2
m901				1	1			4		
m801						1	1	1	1	
m012										
m110										
m018					2	2		2		
m008	6									
m006										
m005										
Short tracks										
m001								1		
m002										
m003										
m004								1	1	
m007	1	1	2		2	1	1			3
m011					1			3	1	
m013										
m014										
m015										
m016										
m017										
m019										
m021			12		2	1	2			
m022				1	2					
m023										
m024										
m026	6		1	4	12	1	4			

Animal ID	Æbeløgård	Little Belt bridge	Aerö	Sletterhage	Samsø	Great Belt bridge	Langeland	Helsingborg	Øresund bridge	Fehmarn Belt
m027			2			12	1			1
m028			2			3	4			2
m031										
m032			5		2	1	1			
m034					3	2				
m035										
m036										
m037										
m038										
m051	1		9			1	1			
m061						1				
m062				2						
m063					2	1	1			3
m064										
m071										
m072										
m100					1					
m111										
m112										
m113										
m114										
m116										
m200				1	1	1	1			
m300										
m400_1										
m400_2										
m803					8	1	1			1
m804			1				2			5
m905										5
m906					3	5	9			6
m907	1	1	5							
m971	1				1					
m972					5					
m973	1				1					

Animal ID	**Æbeløgård**	**Little Belt bridge**	**Aerö**	**Sletterhage**	**Samsø**	**Great Belt bridge**	**Langeland**	**Helsingborg**	**Øresund bridge**	**Fehmarn Belt**
m981					2	1	10			4
m982					1					
m983					2	1	1	2		2
m984					2	1	1	2		2
m985	4			1	1					
m991			4	1	3	1	1	2		
m992					1					
m993	1		6			1	1			2
m994	12	2		2	2					
m995					7					
m996	3	1	1			1	1			2
m997				9						
m999			1							
number of crossings	56	6	70	24	86	43	51	24	7	47
n of animals	14	5	15	11	29	23	22	11	5	16
crossings per animal	4	1.2	4.7	2.2	3.0	1.9	2.3	2.2	1.4	2.9

7.2. Appendix 2

Harbour Porpoise sightings during aerial surveys

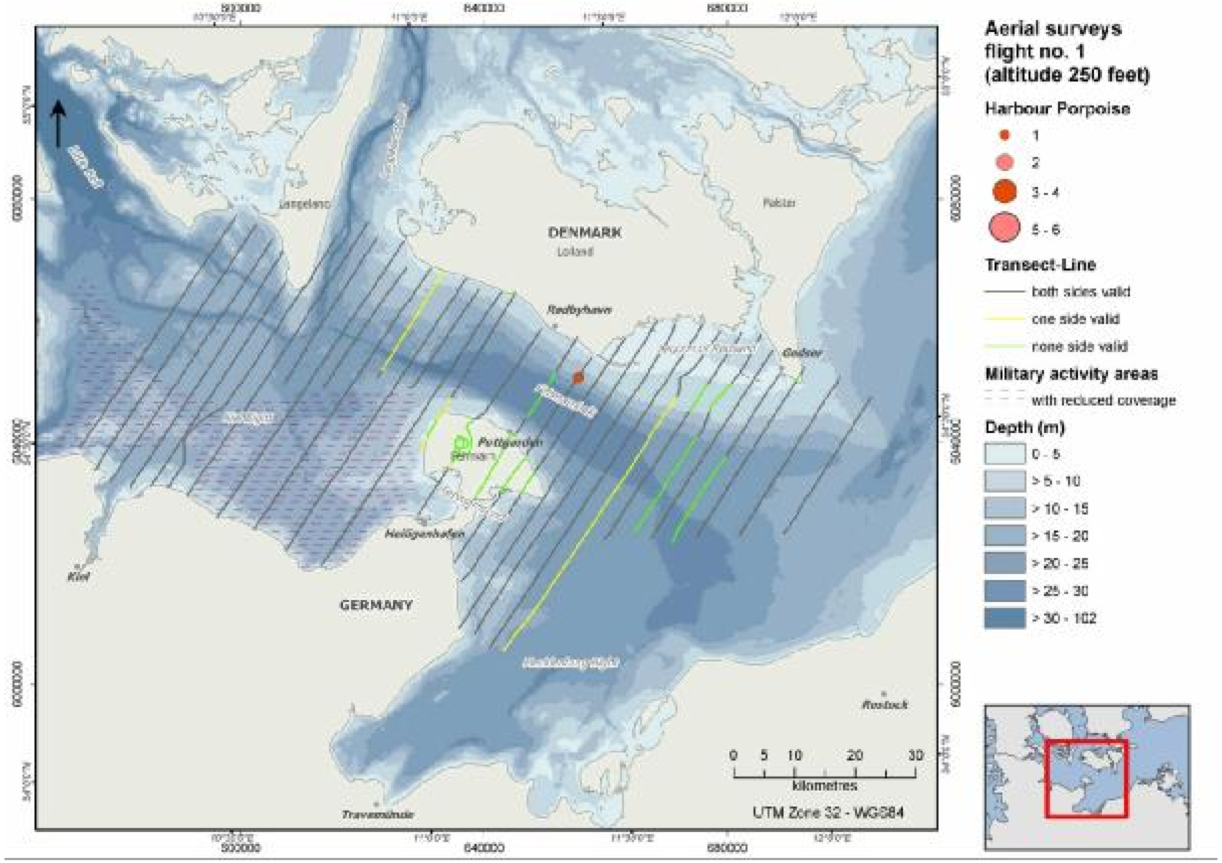

Figure 7.2-1 Locations of harbour porpoise sightings in flight No 1 (November 08 and 17 2008) in a flight altitude of 76 m.

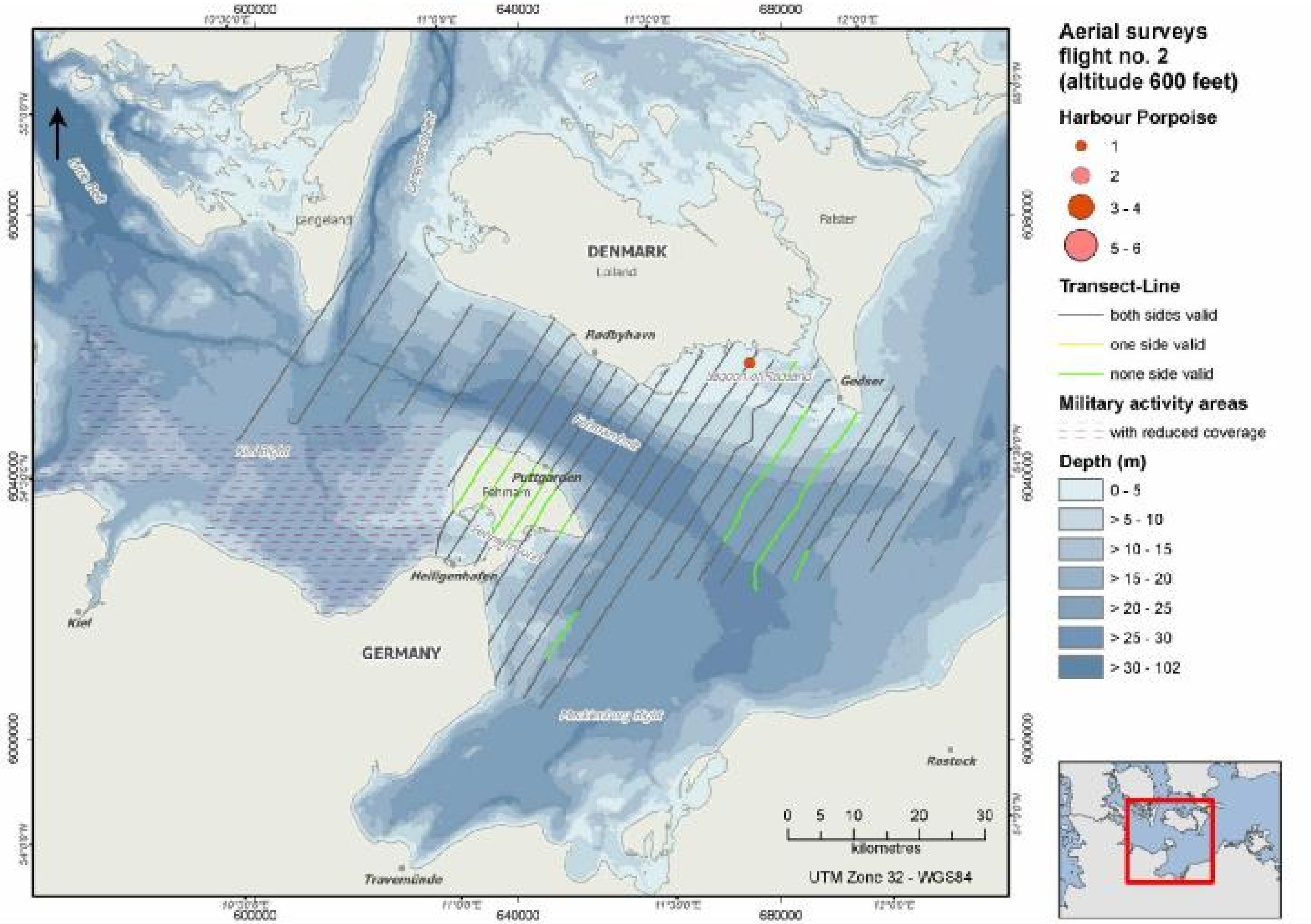

Figure 7.2-2 Locations of harbour porpoise sightings in flight No 2 (December 16 and 17 2008) in a flight altitude of 183 m.

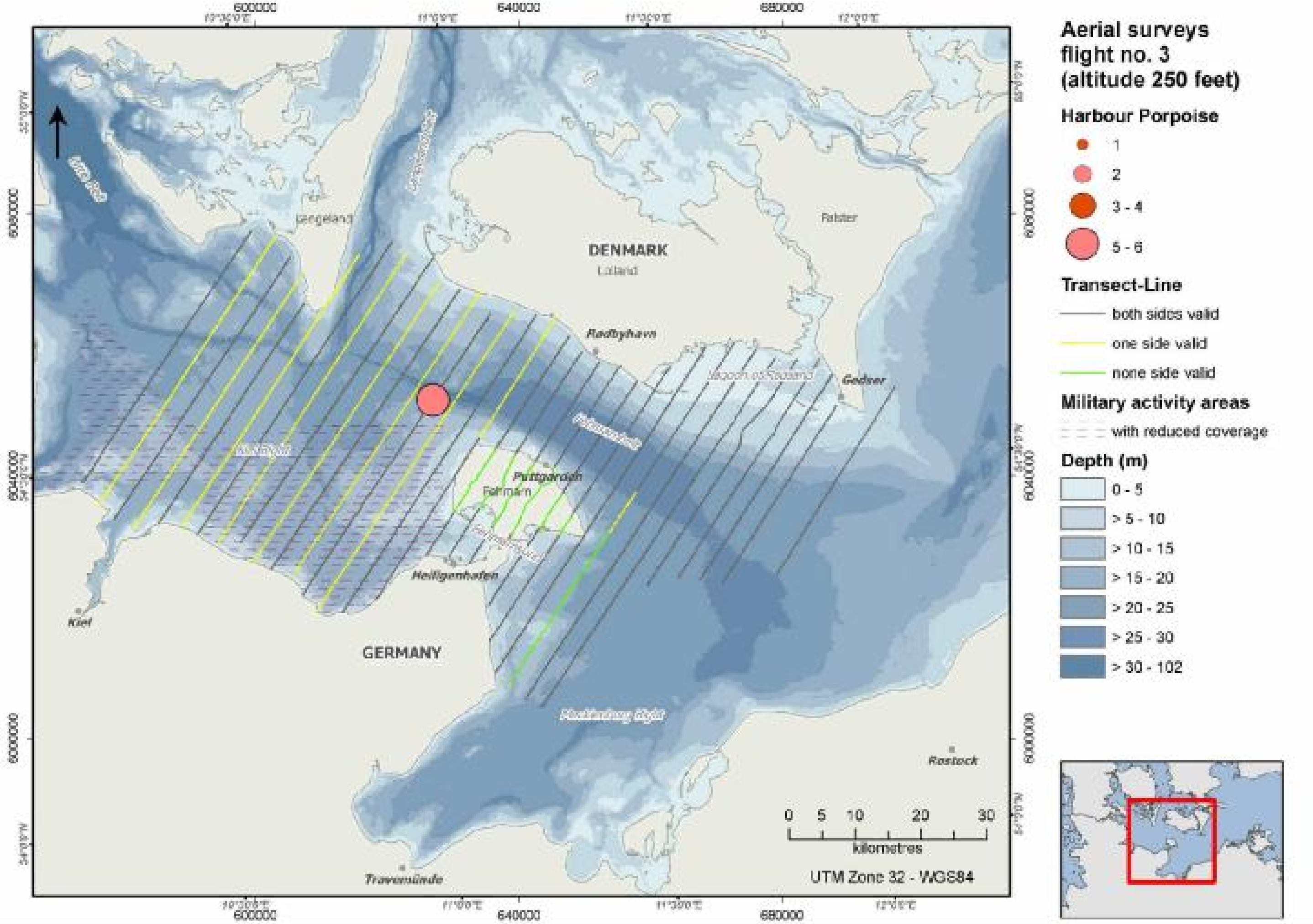

Figure 7.2-3 Locations of harbour porpoise sightings in flight No 3 (December 28 and 29 2008) in a flight altitude of 76 m.

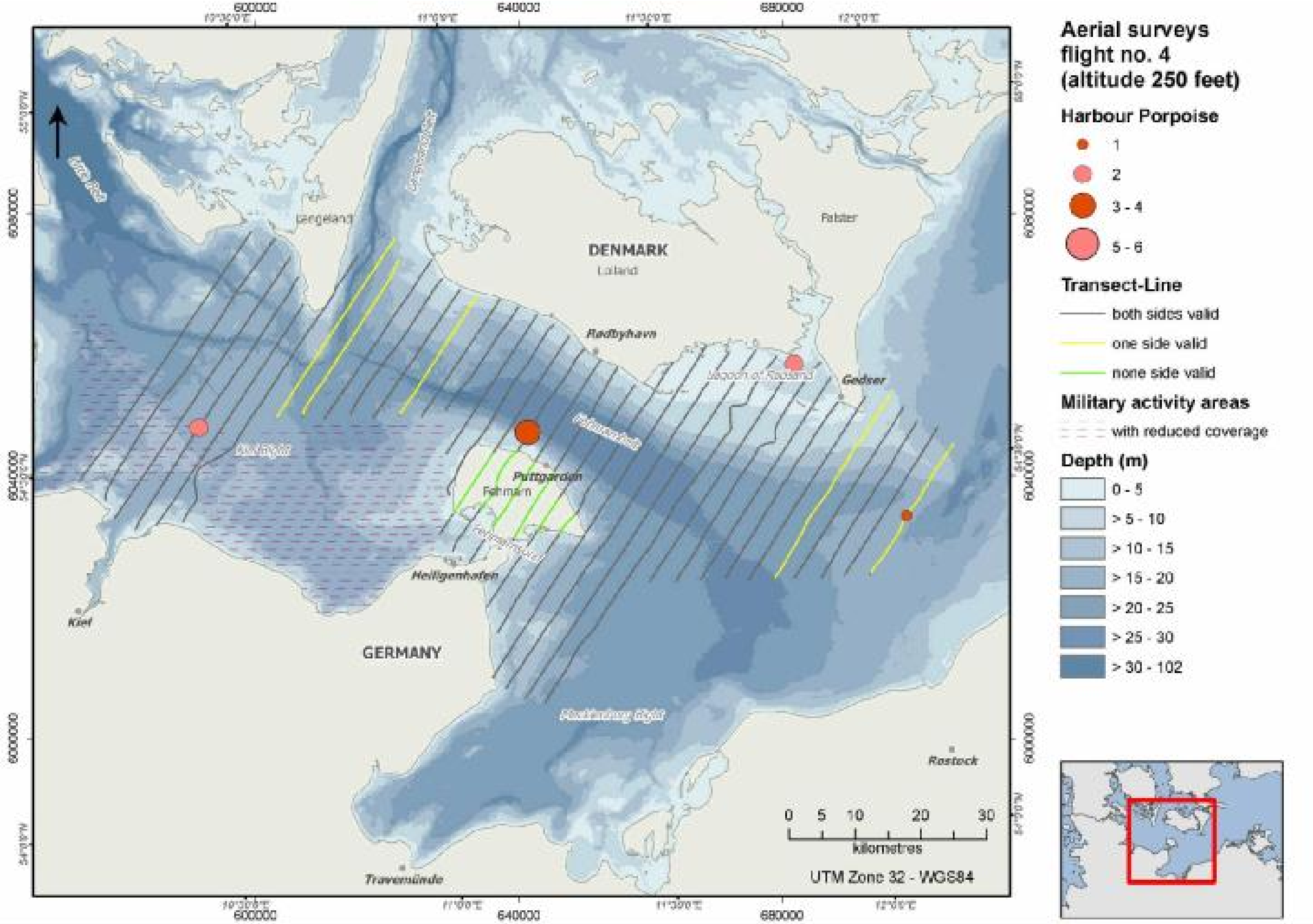

Figure 7.2-4 Locations of harbour porpoise sightings in flight No 4 (January 21 2009) in a flight altitude of 76 m.

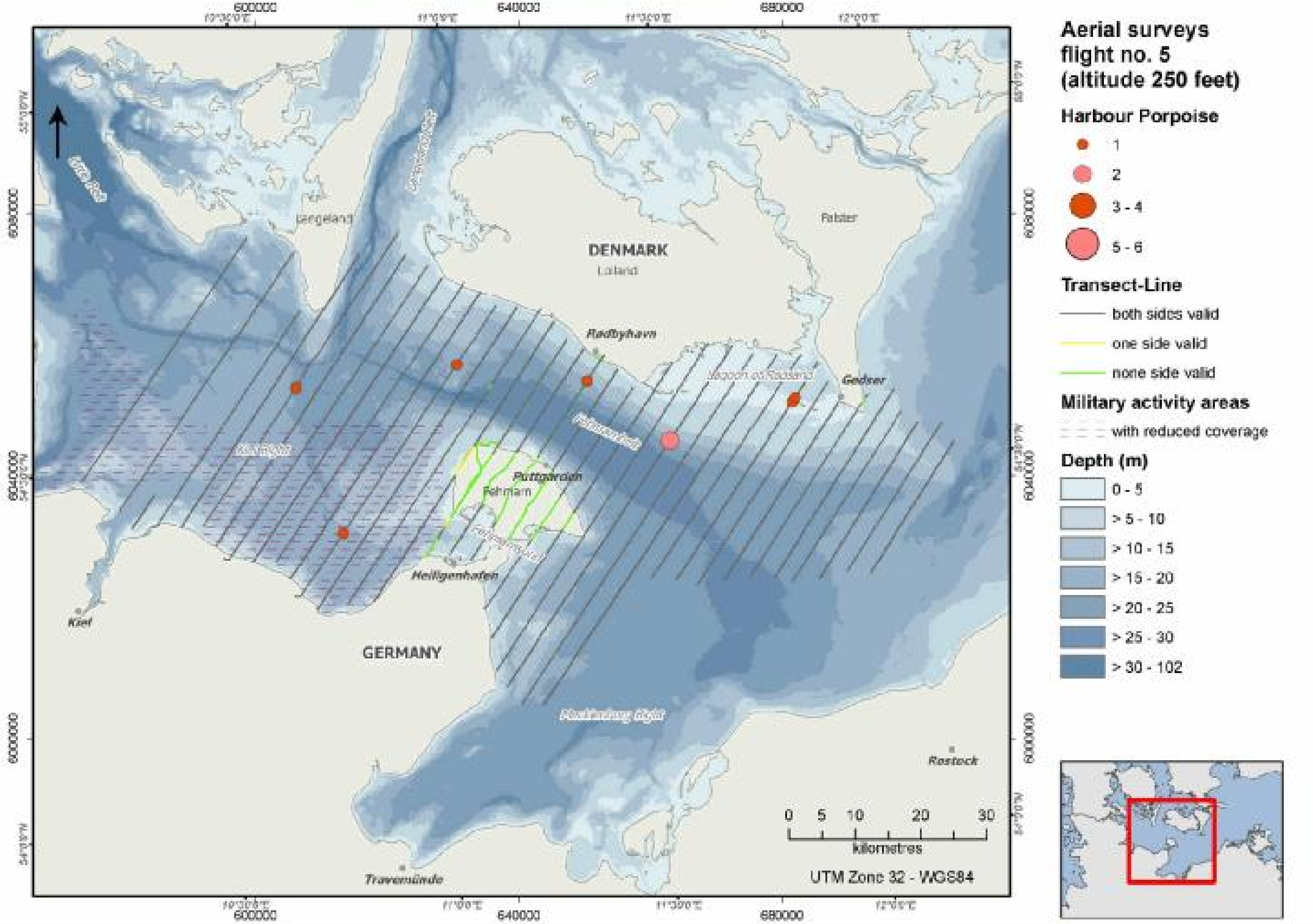

Figure 7.2-5 **Locations of harbour porpoise sightings in flight No 5 (February 07, 18 and 21 2009) in a flight altitude of 76 m.**

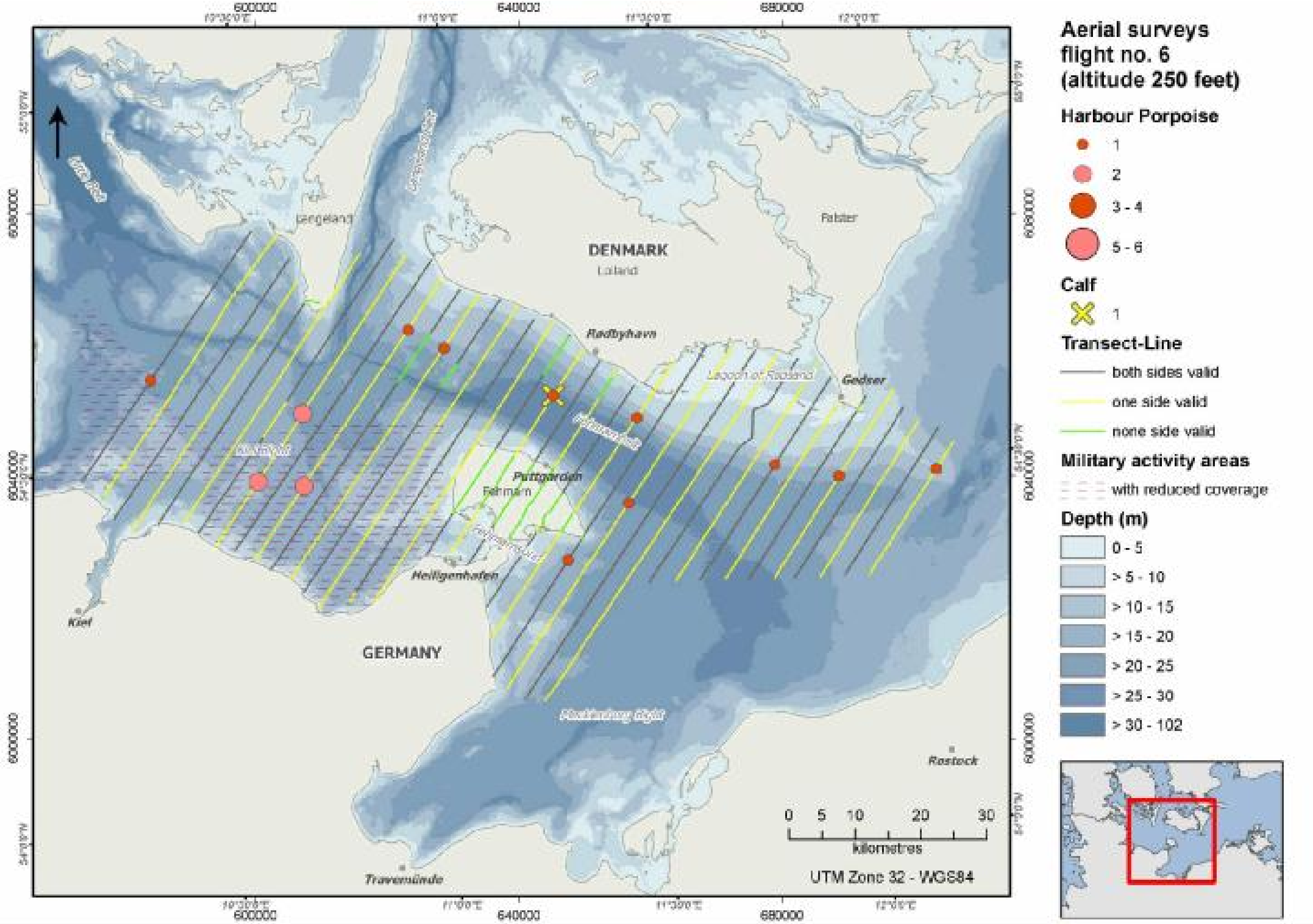

Figure 7.2-6 **Locations of harbour porpoise sightings in flight No 6 (March 07 and April 04 2009) in a flight altitude of 76 m.**

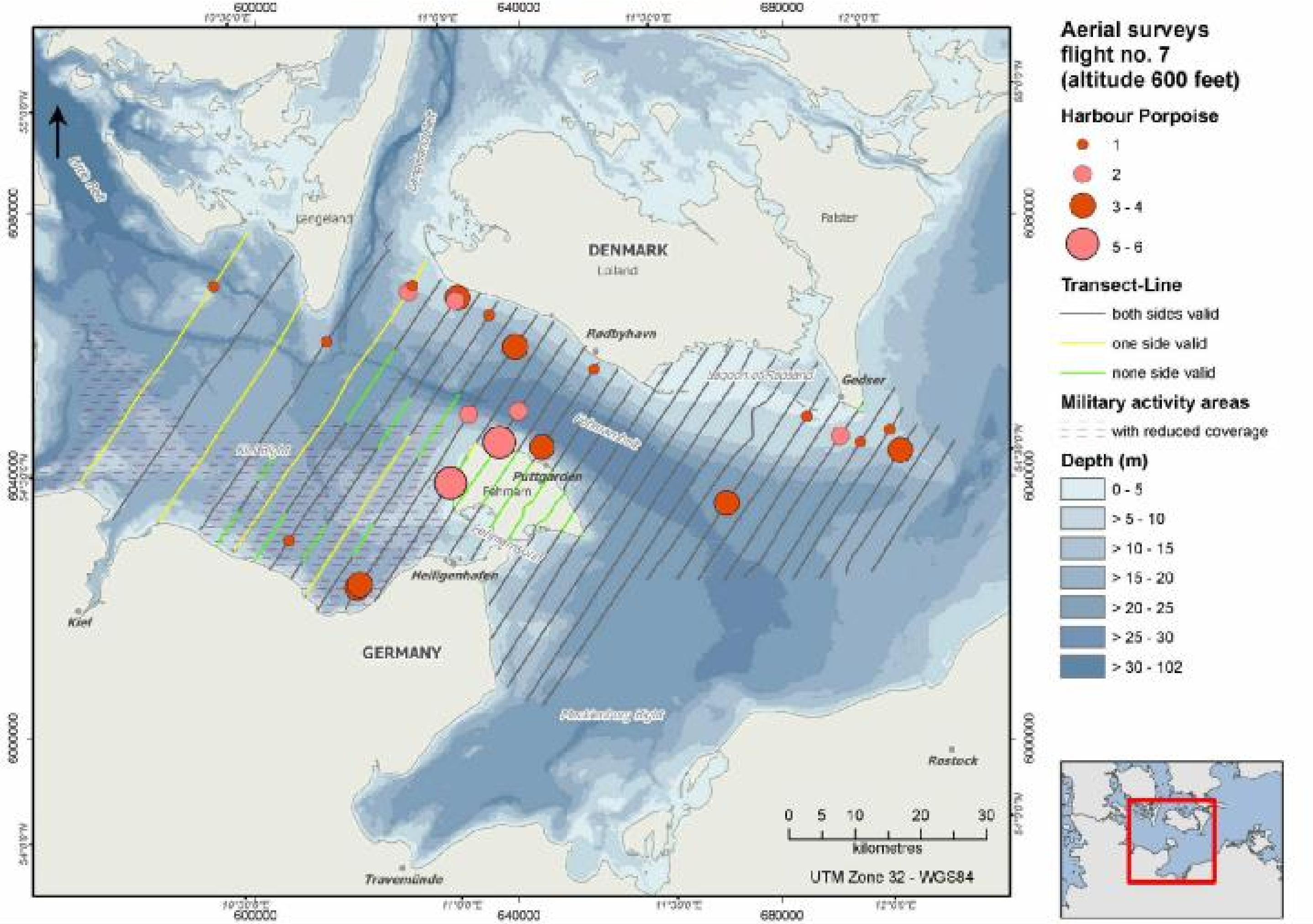

Figure 7.2-7 **Locations of harbour porpoise sightings in flight No 7 (April 03 and 06 2009) in a flight altitude of 183 m.**

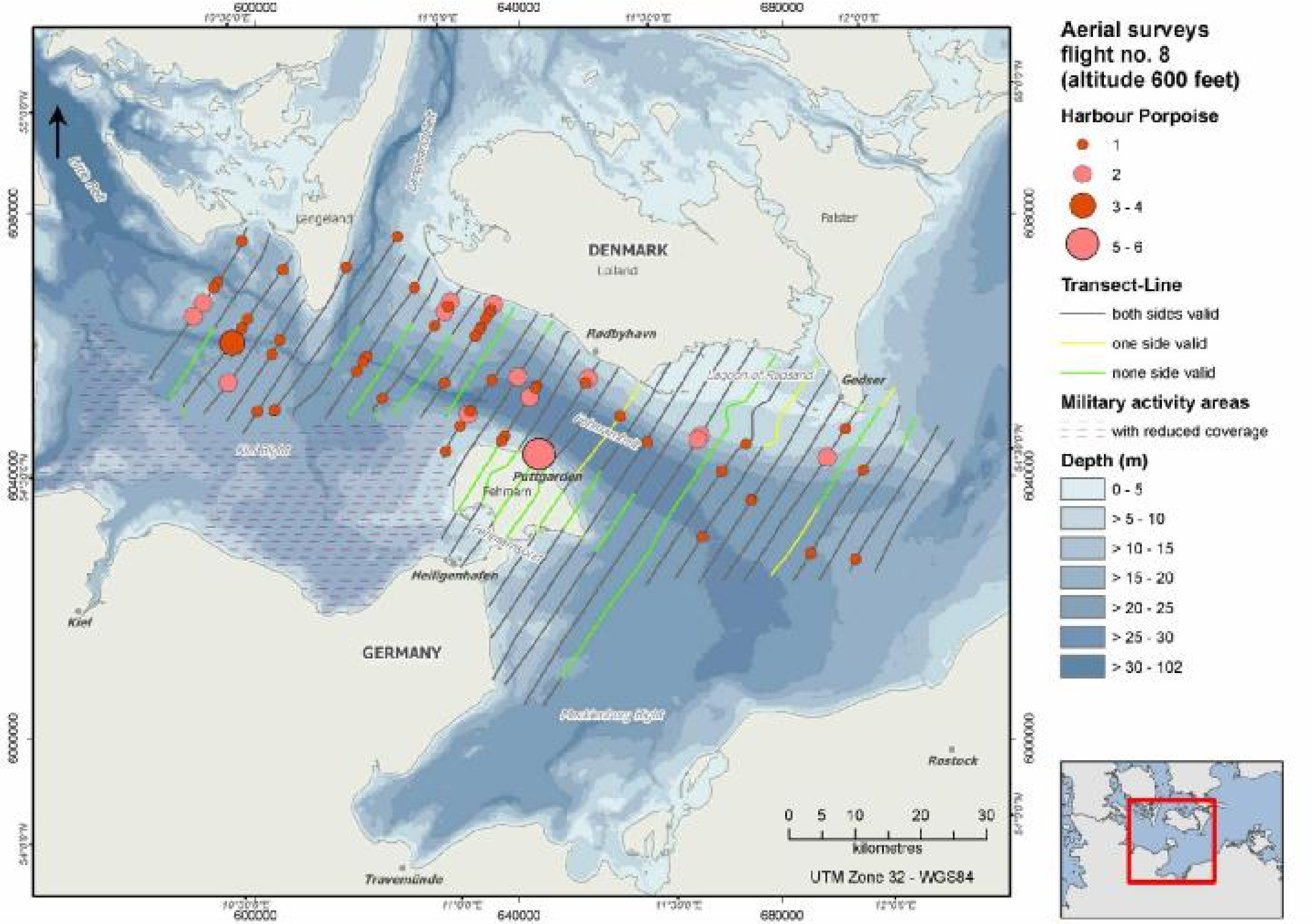

Figure 7.2-8 **Locations of harbour porpoise sightings in flight No 8 (April 20 and 21 2009) in a flight altitude of 183 m.**

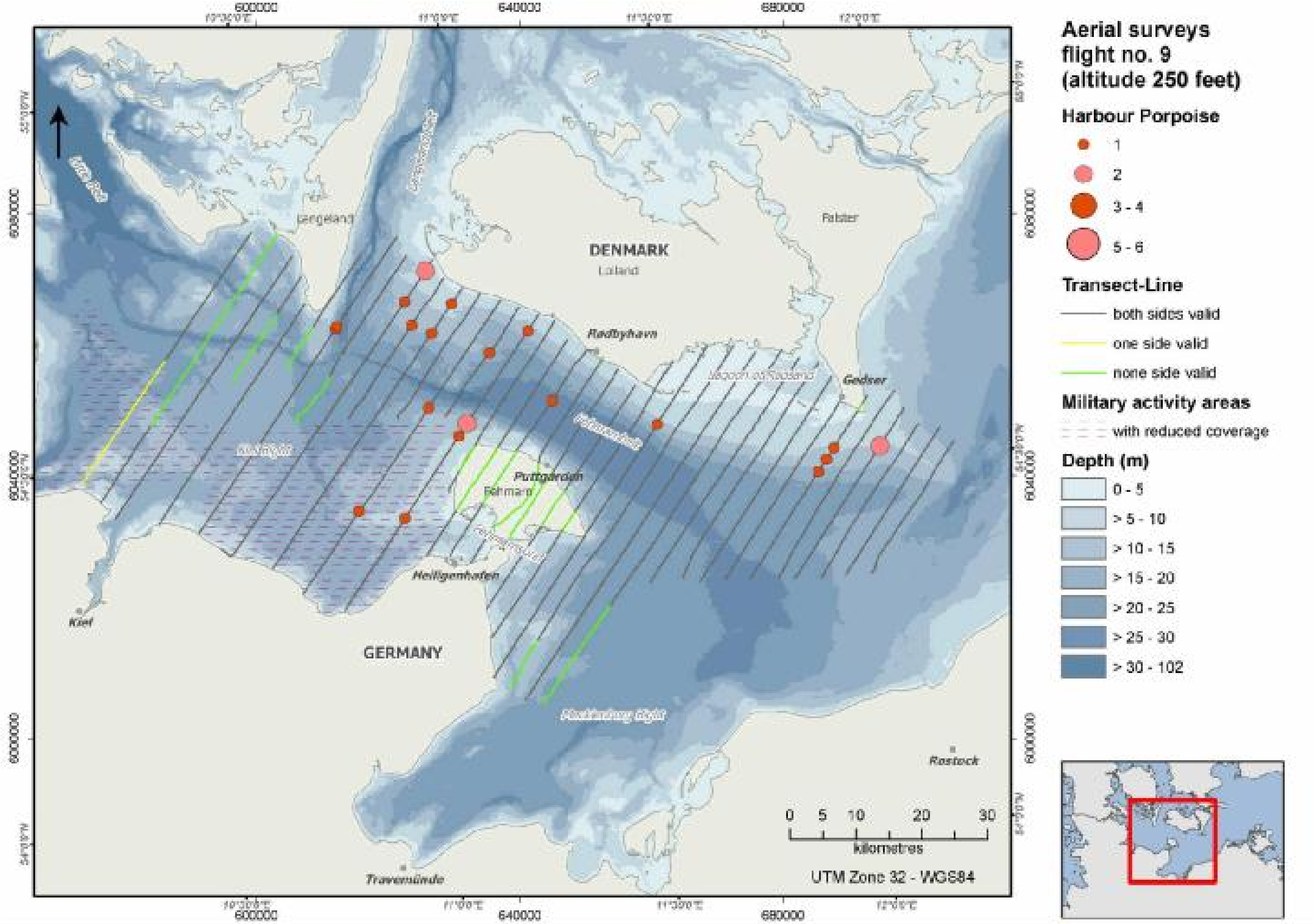

Figure 7.2-9 Locations of harbour porpoise sightings in flight No 9 (April 26 and May 11 2009) in a flight altitude of 76 m.

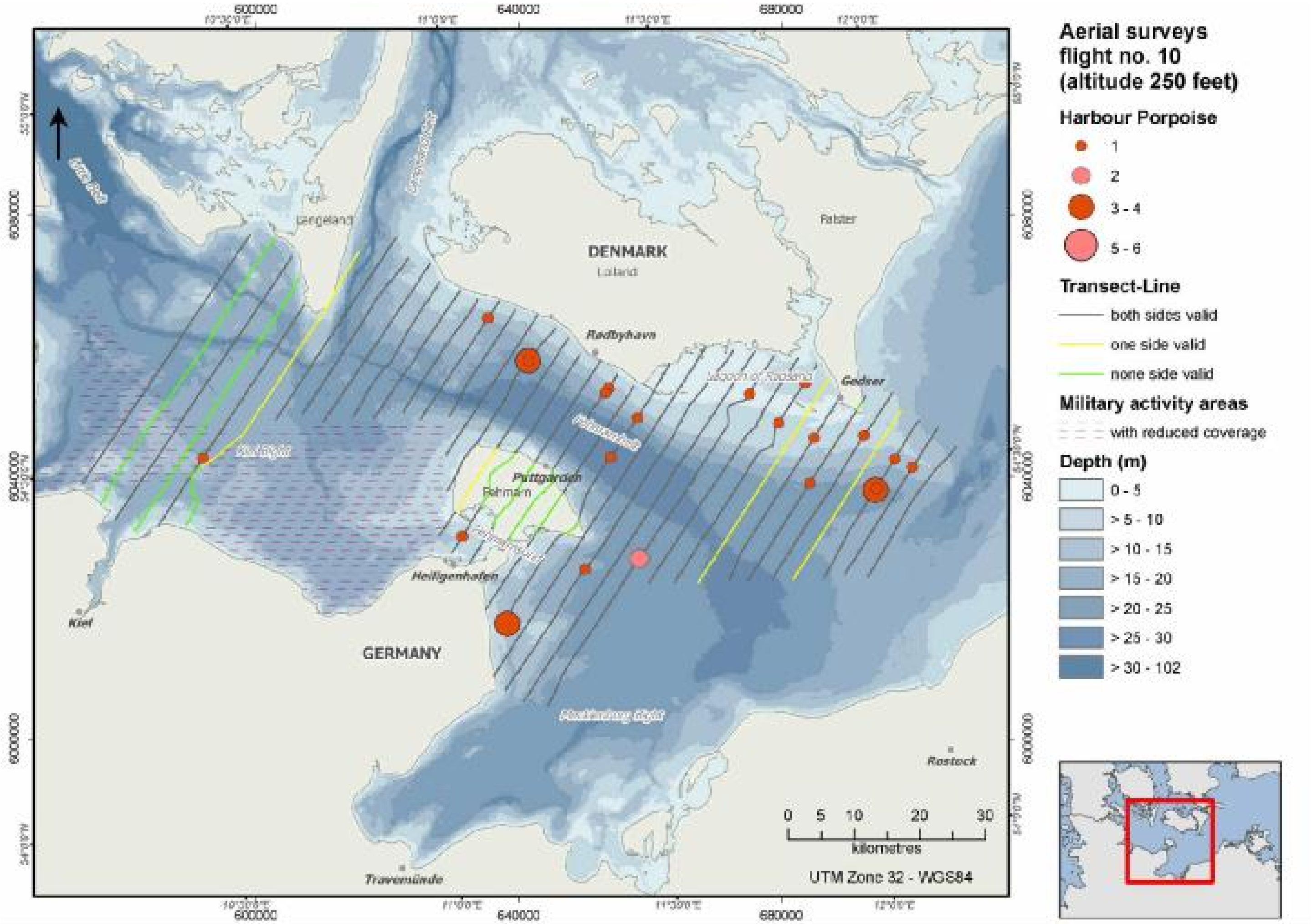

Figure 7.2-10 Locations of harbour porpoise sightings in flight No 10 (May 13 and 20 2009) in a flight altitude of 76 m.

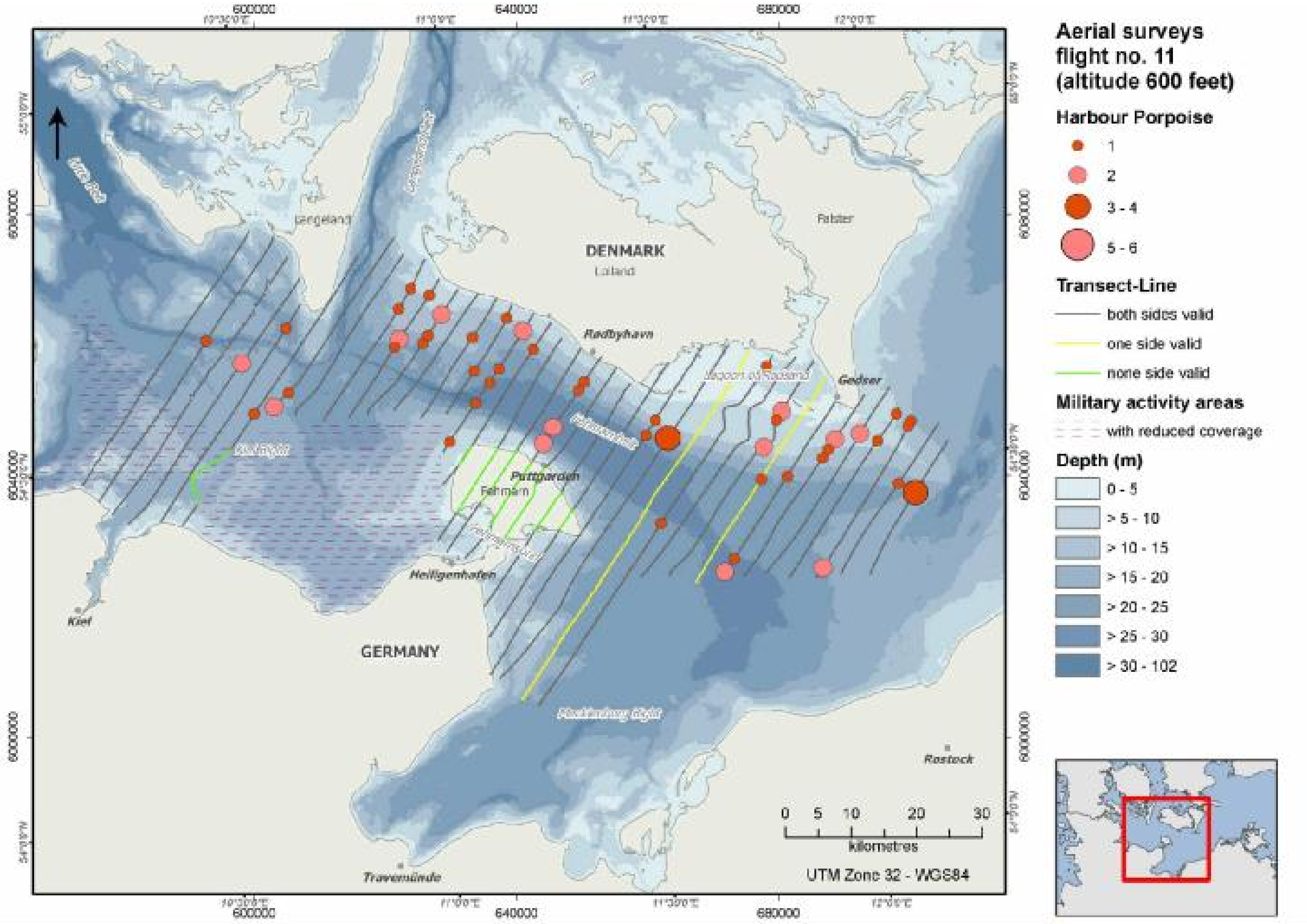

Figure 7.2-11 Locations of harbour porpoise sightings in flight No 11 (May 18 and 19 2009) in a flight altitude of 183 m.

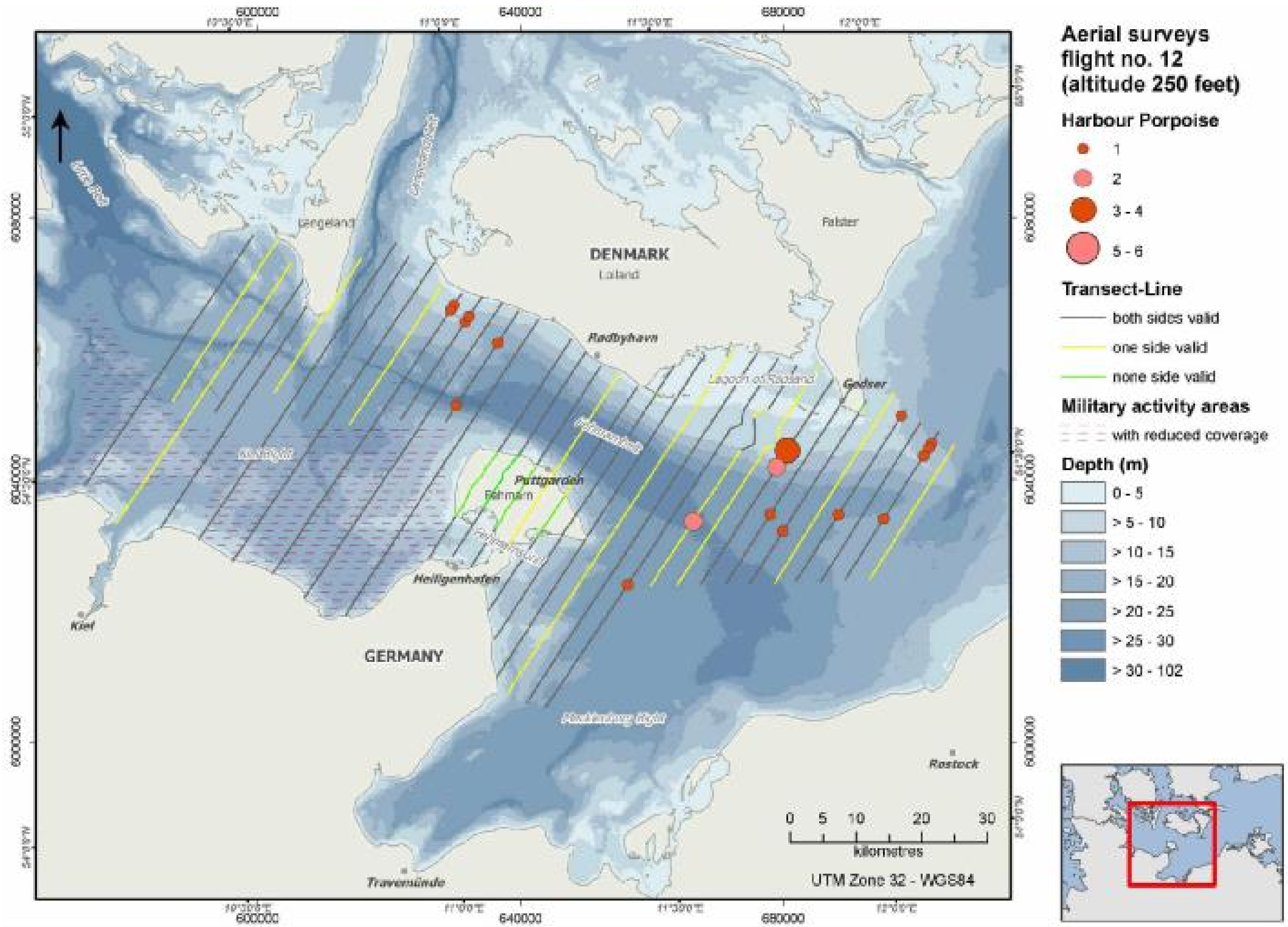

Figure 7.2-12 **Locations of harbour porpoise sightings in flight No 12 (June 01 and 17 2009) in a flight altitude of 76 m.**

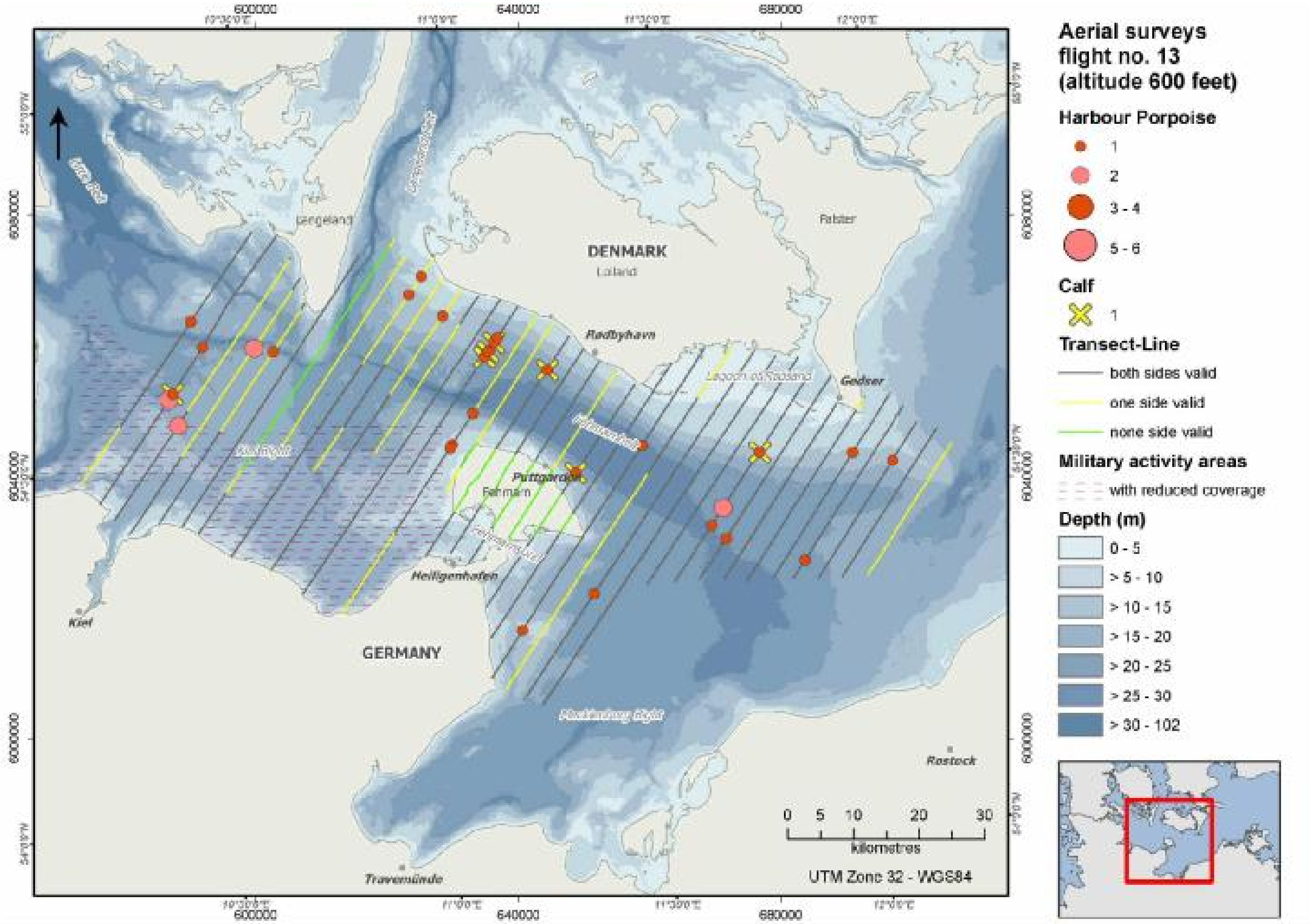

Figure 7.2-13 Locations of harbour porpoise sightings in flight No 13 (June 21 and 22 2009) in a flight altitude of 183 m.

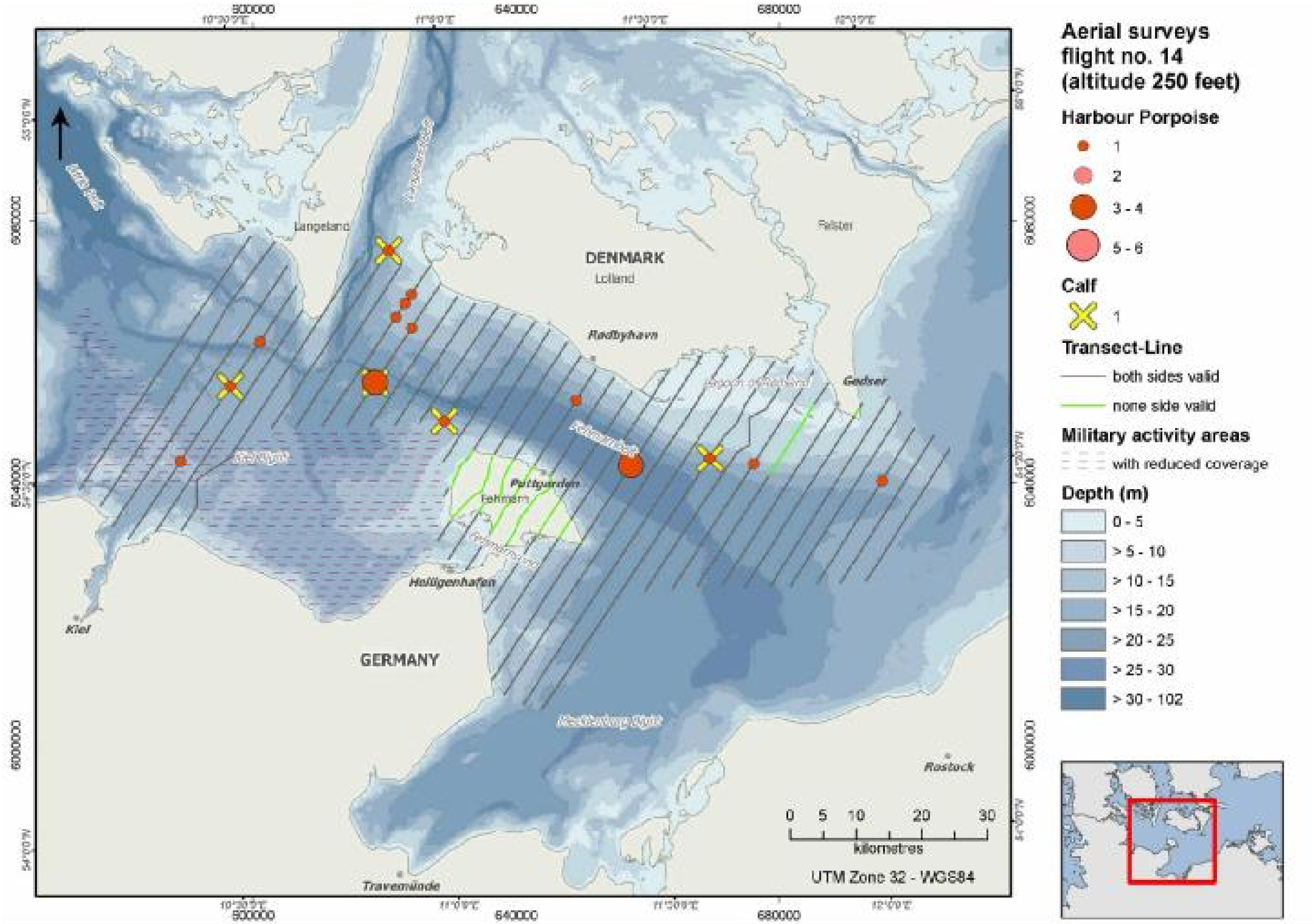

Figure 7.2-14 Locations of harbour porpoise sightings in flight No 14 (July 06 and 15 2009) in a flight altitude of 76 m.

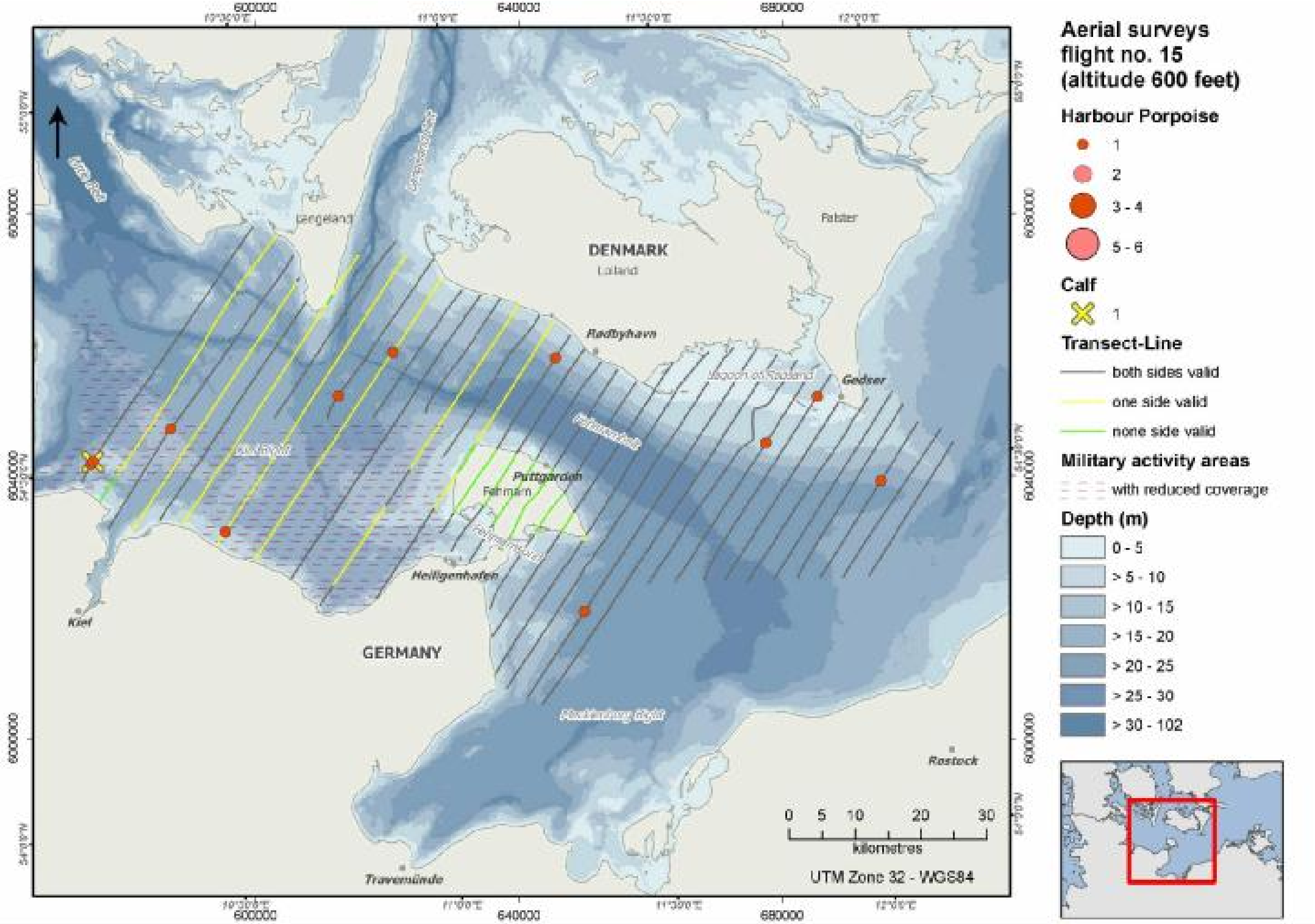

Figure 7.2-15 Locations of harbour porpoise sightings in flight No 15 (July 14 and August 01 2009) in a flight altitude of 183 m.

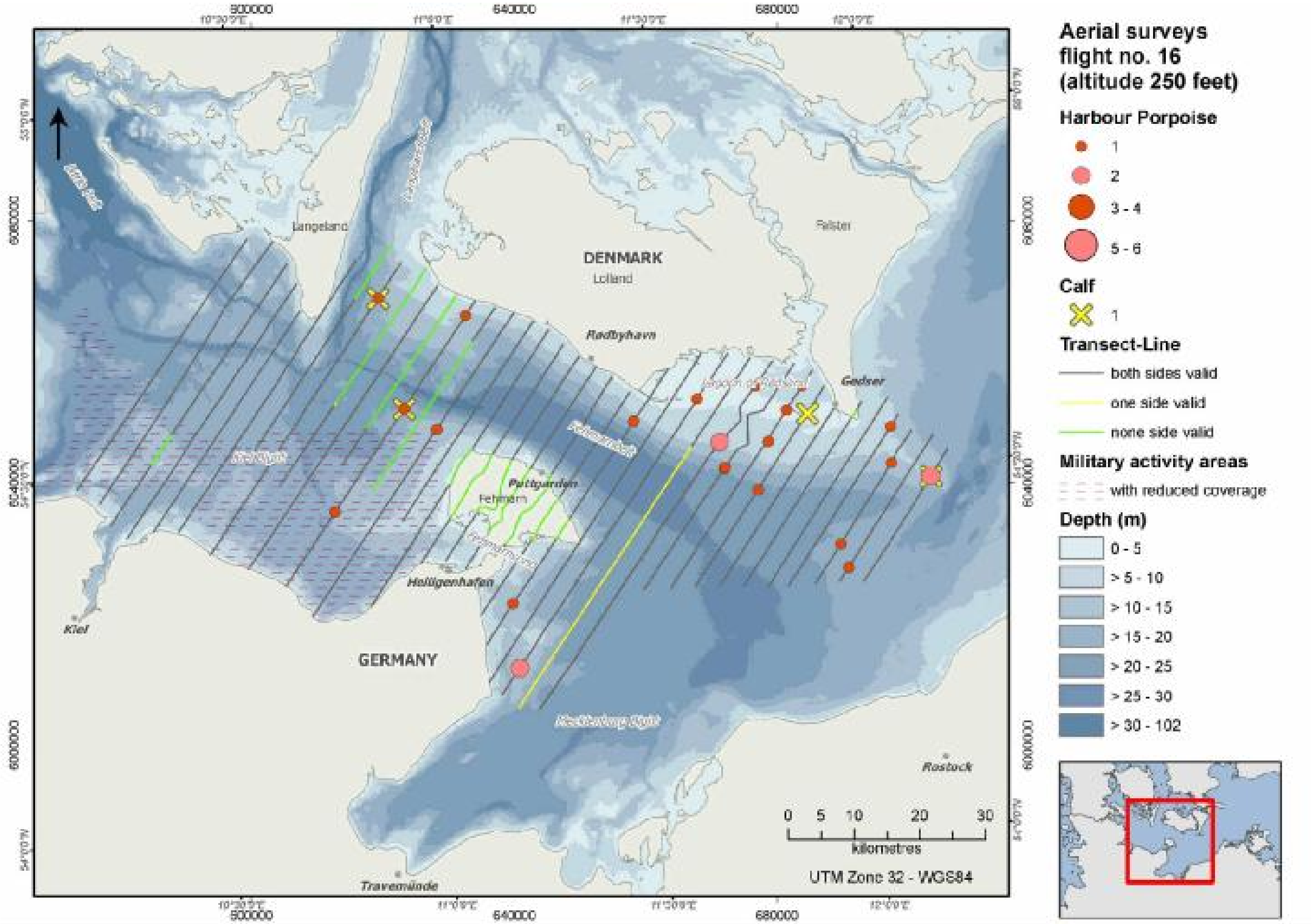

Figure 7.2-16 Locations of harbour porpoise sightings in flight No 16 (August 05 and September 09 2009) in a flight altitude of 76 m.

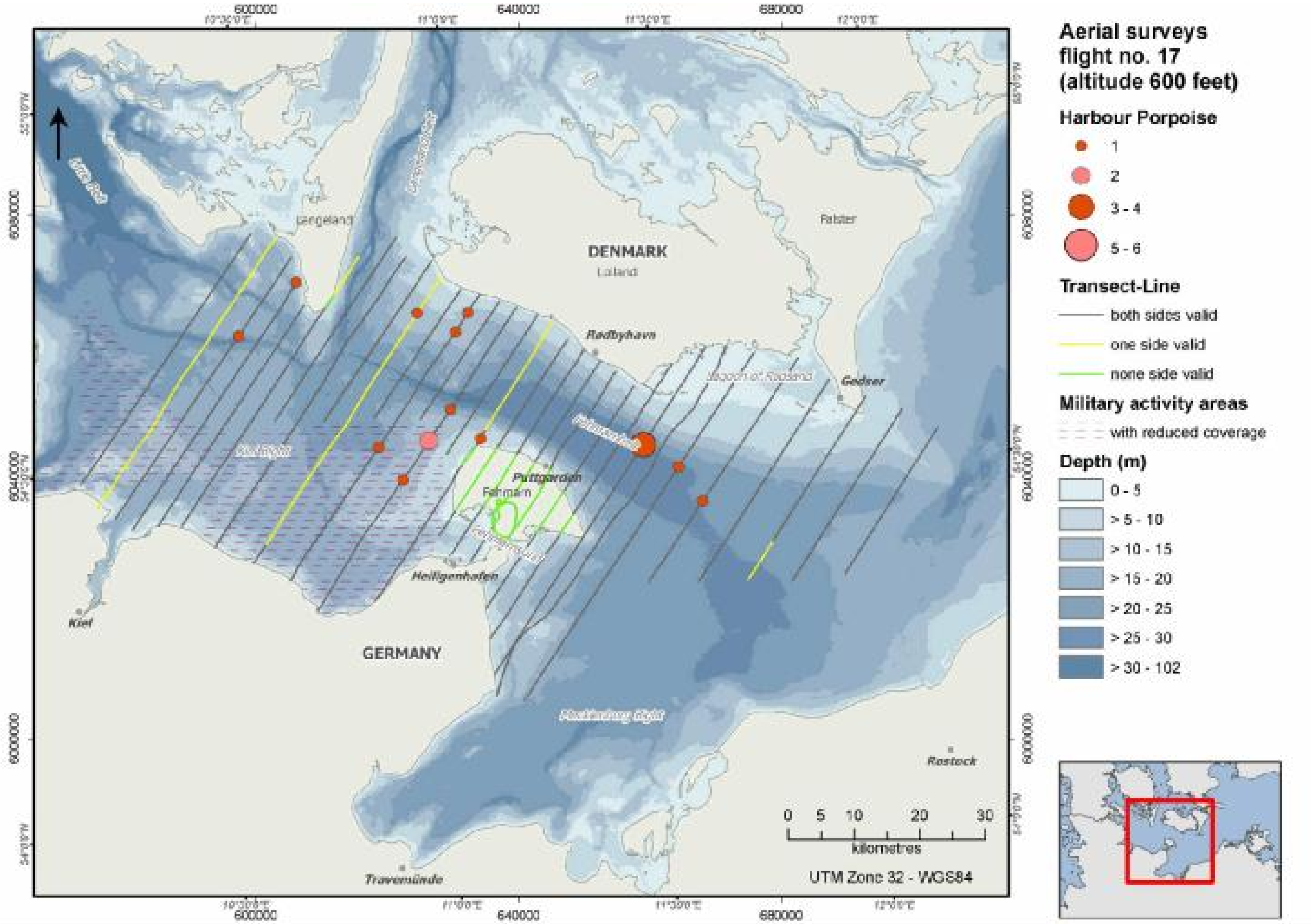

Figure 7.2-17 Locations of harbour porpoise sightings in flight No 17 (August 23 and 25 2009) in a flight altitude of 183 m.

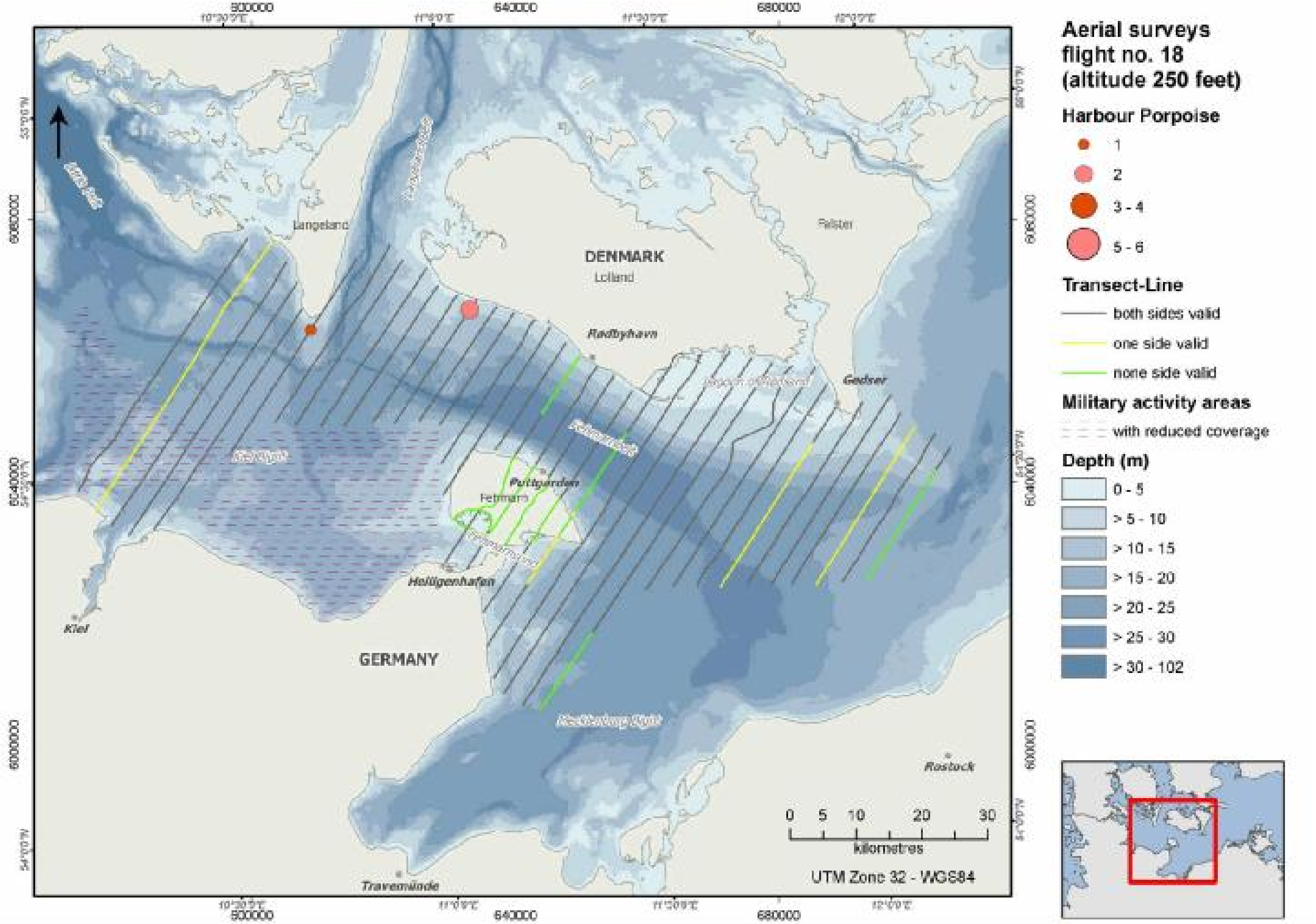

Figure 7.2-18 **Locations of harbour porpoise sightings in flight No 18 (September 11 and 21 2009) in a flight altitude of 76 m.**

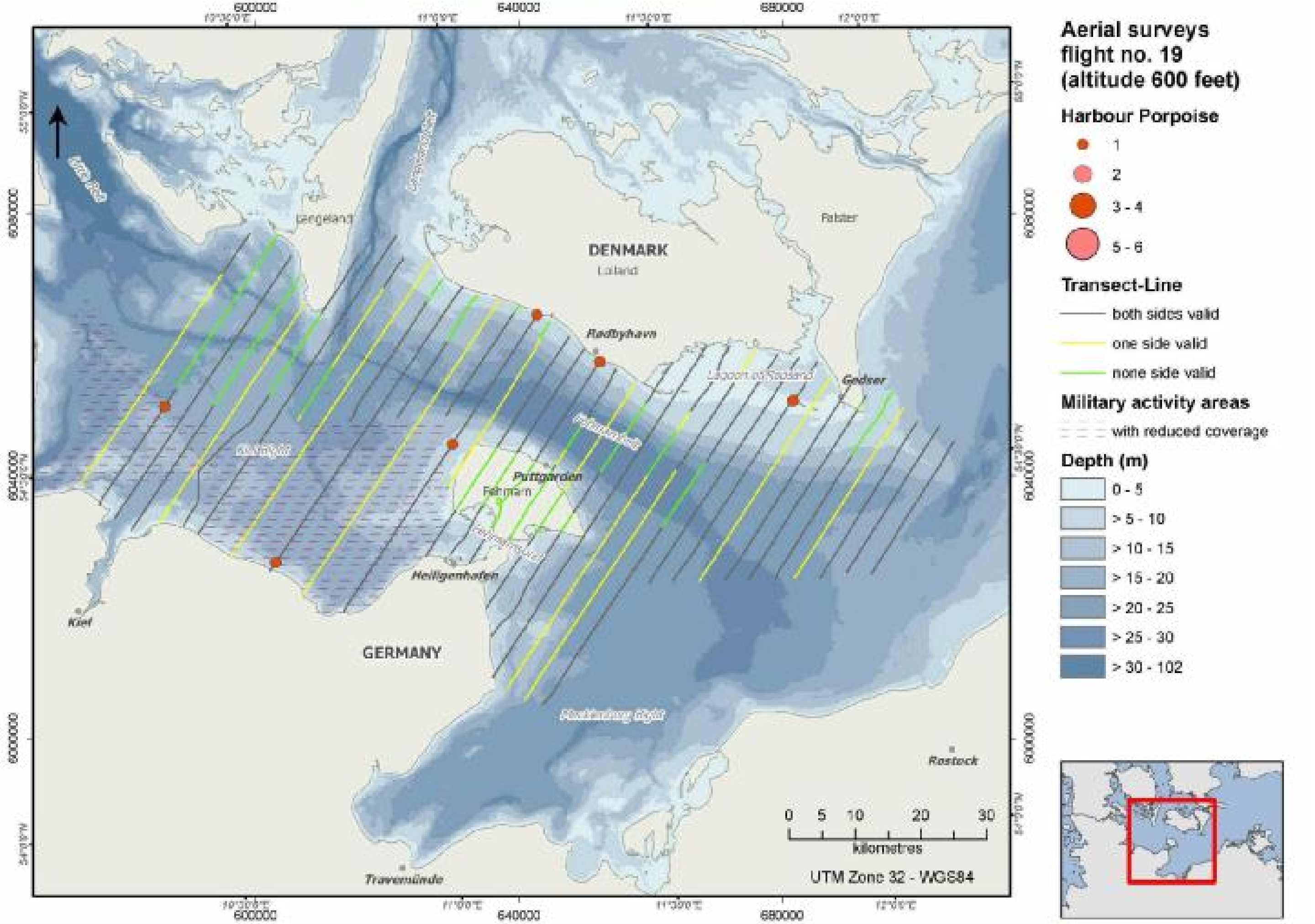

Figure 7.2-19 **Locations of harbour porpoise sightings in flight No 19 (September 16 and 21 2009) in a flight altitude of 183 m.**

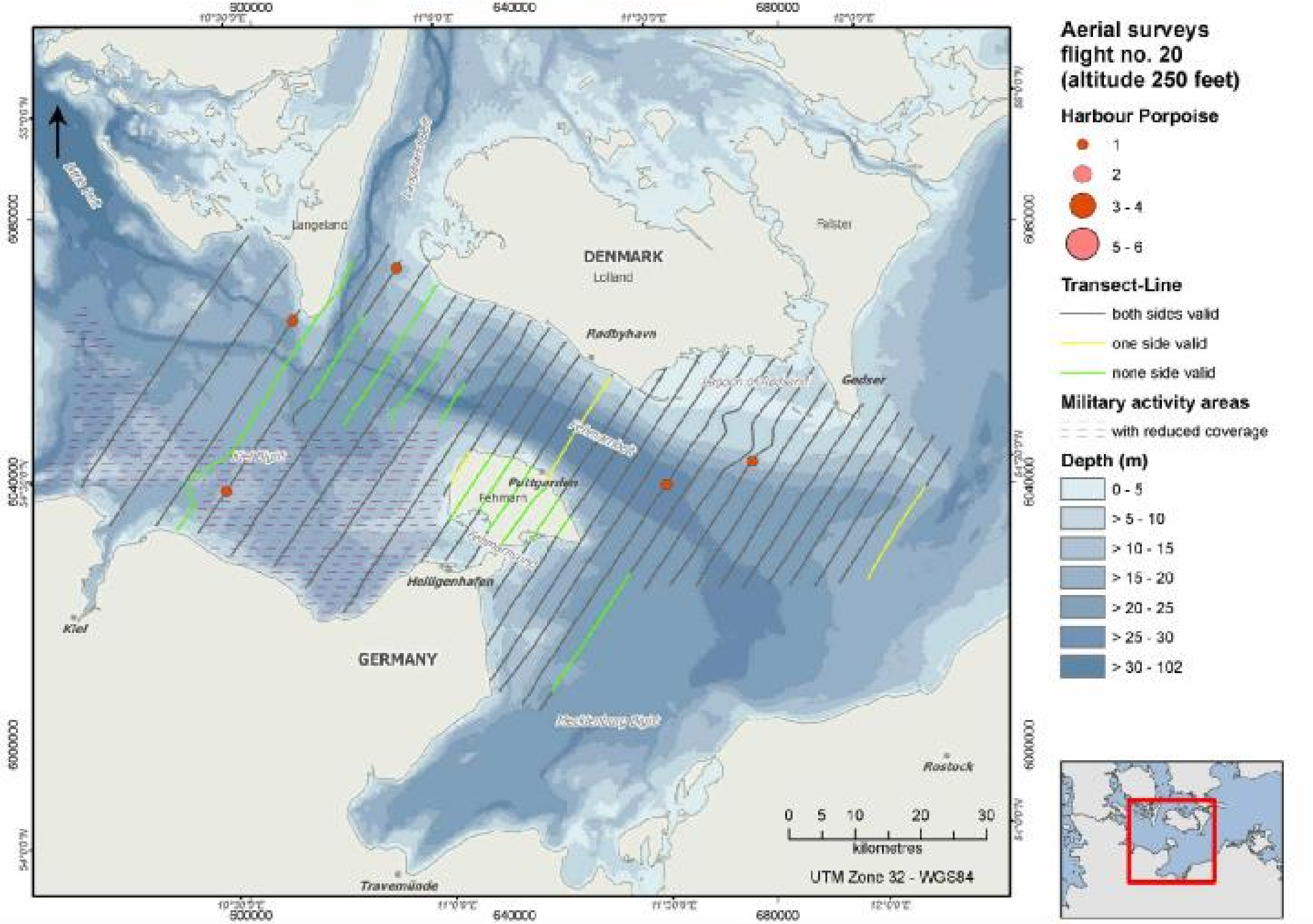

Figure 7.2-20 Locations of harbour porpoise sightings in flight No 20 (October 11 and 30 2009) in a flight altitude of 76 m.

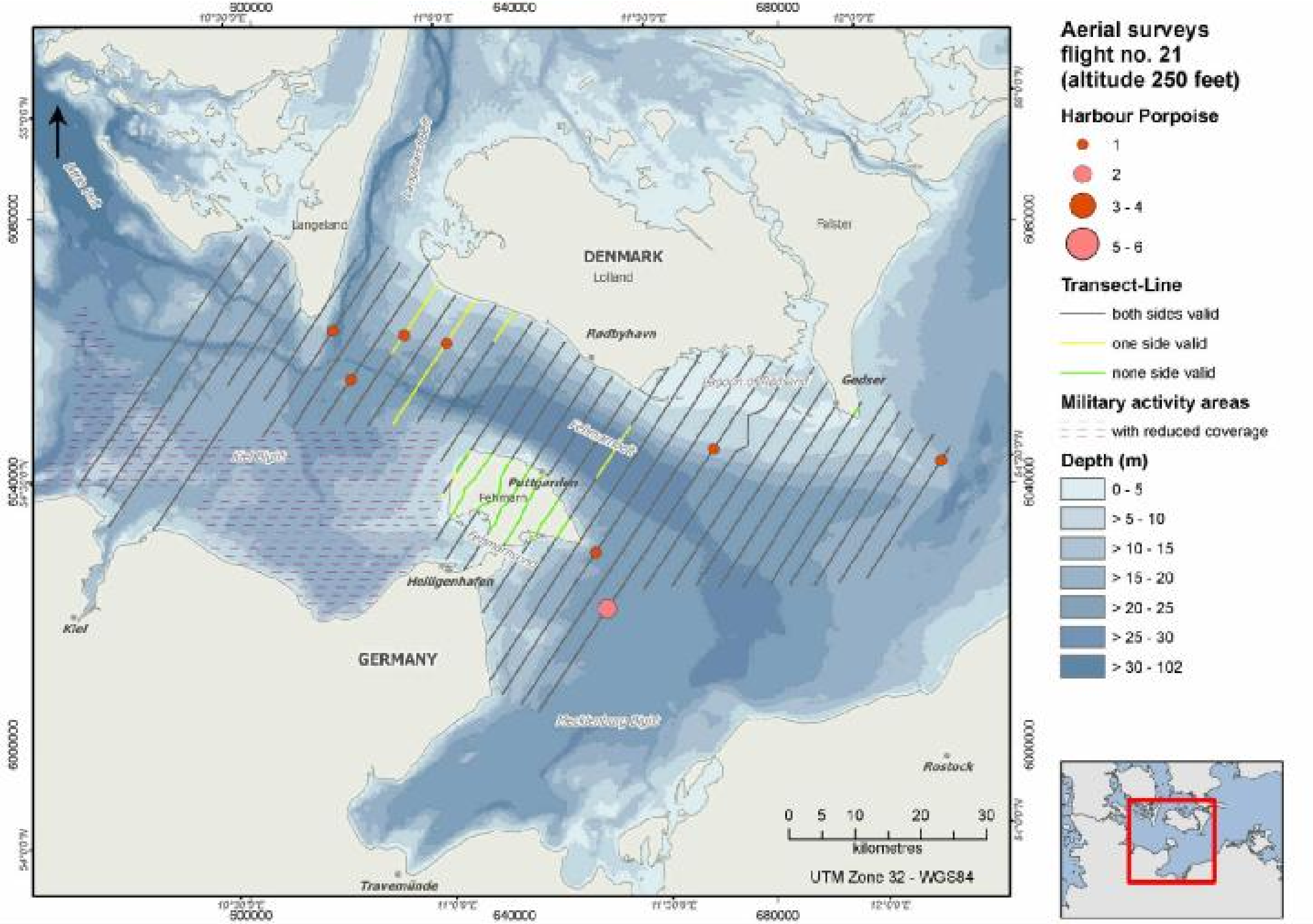

Figure 7.2-21 **Locations of harbour porpoise sightings in flight No 21 (November 30 and December 02 2009) in a flight altitude of 76 m.**

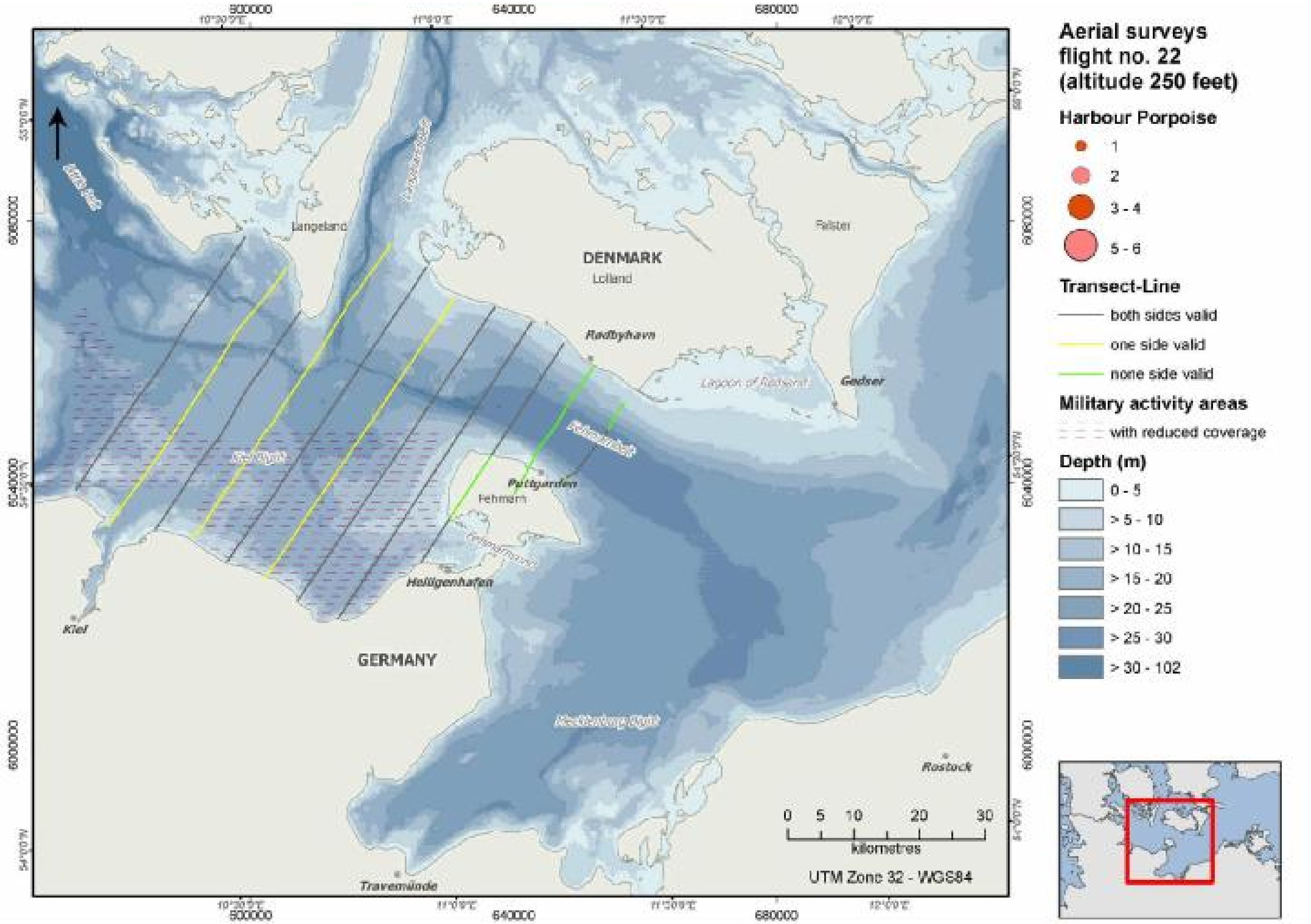

Figure 7.2-22 Locations of harbour porpoise sightings in flight No 22 (December 29 2009) in a flight altitude of 76 m. [no sightings]

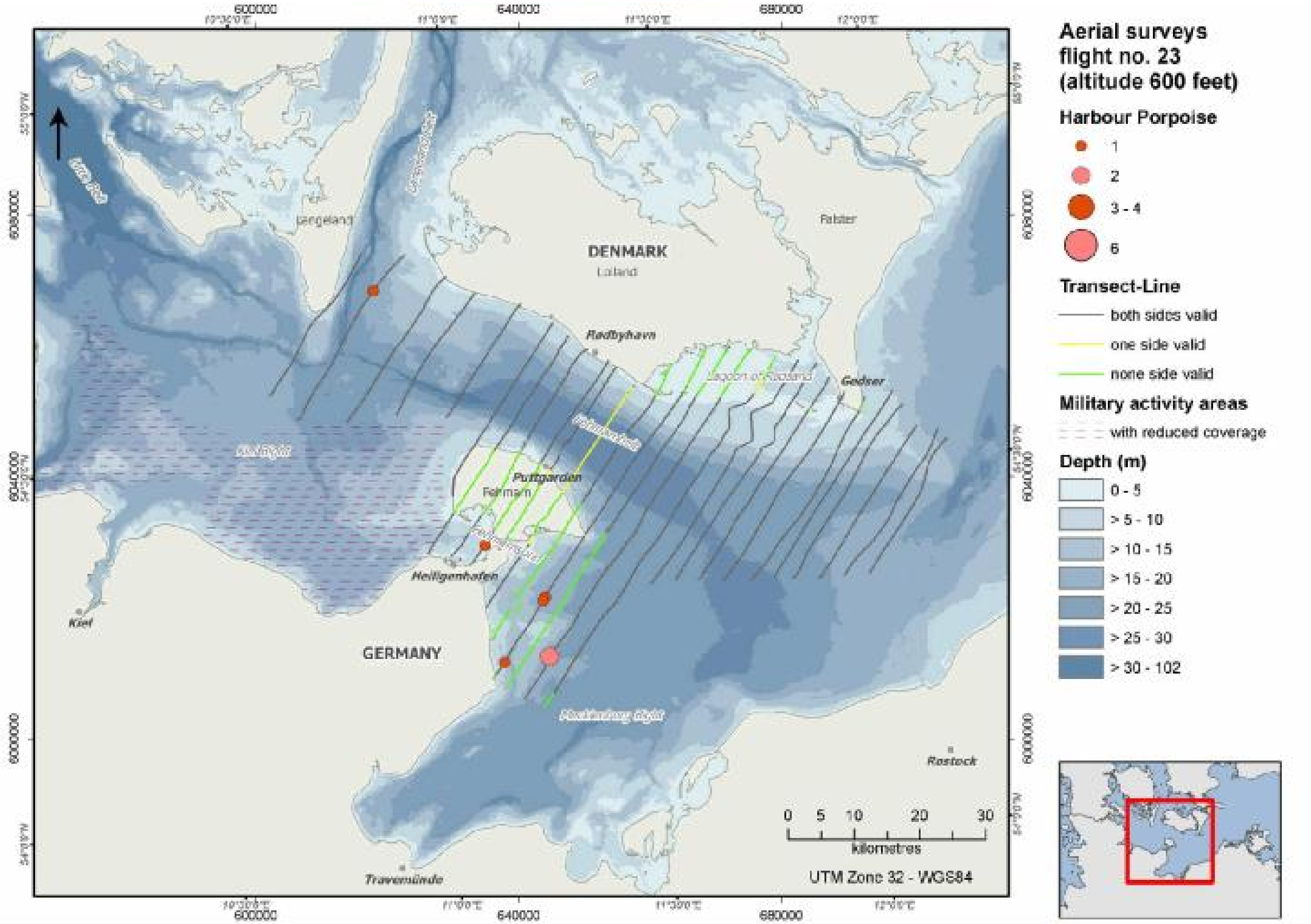

Figure 7.2-23 Locations of harbour porpoise sightings in flight No 23 (February 07 and 08 2010) in a flight altitude of 183 m.

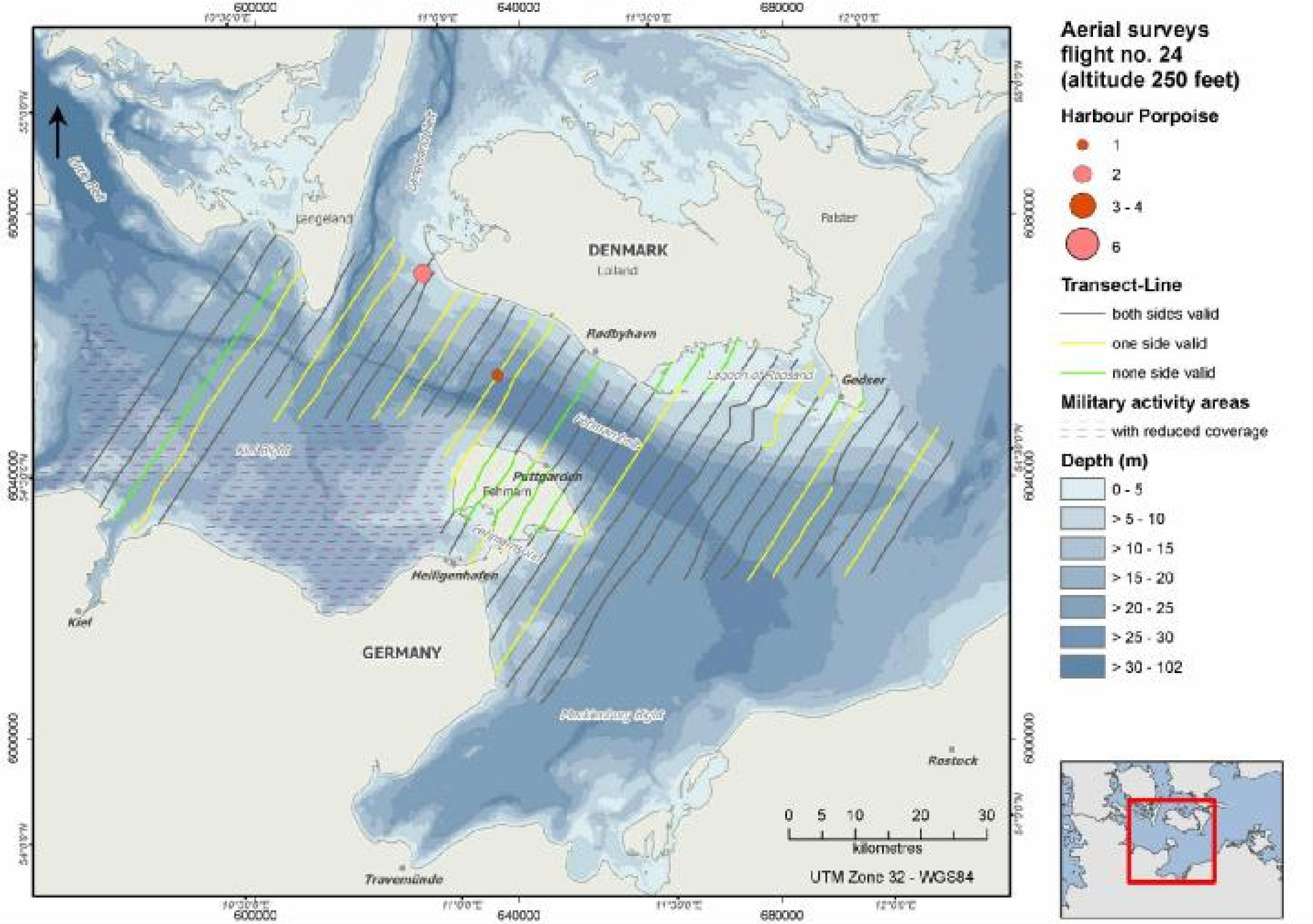

Figure 7.2-24 Locations of harbour porpoise sightings in flight No 24 (March 05 2010) in a flight altitude of 76 m.

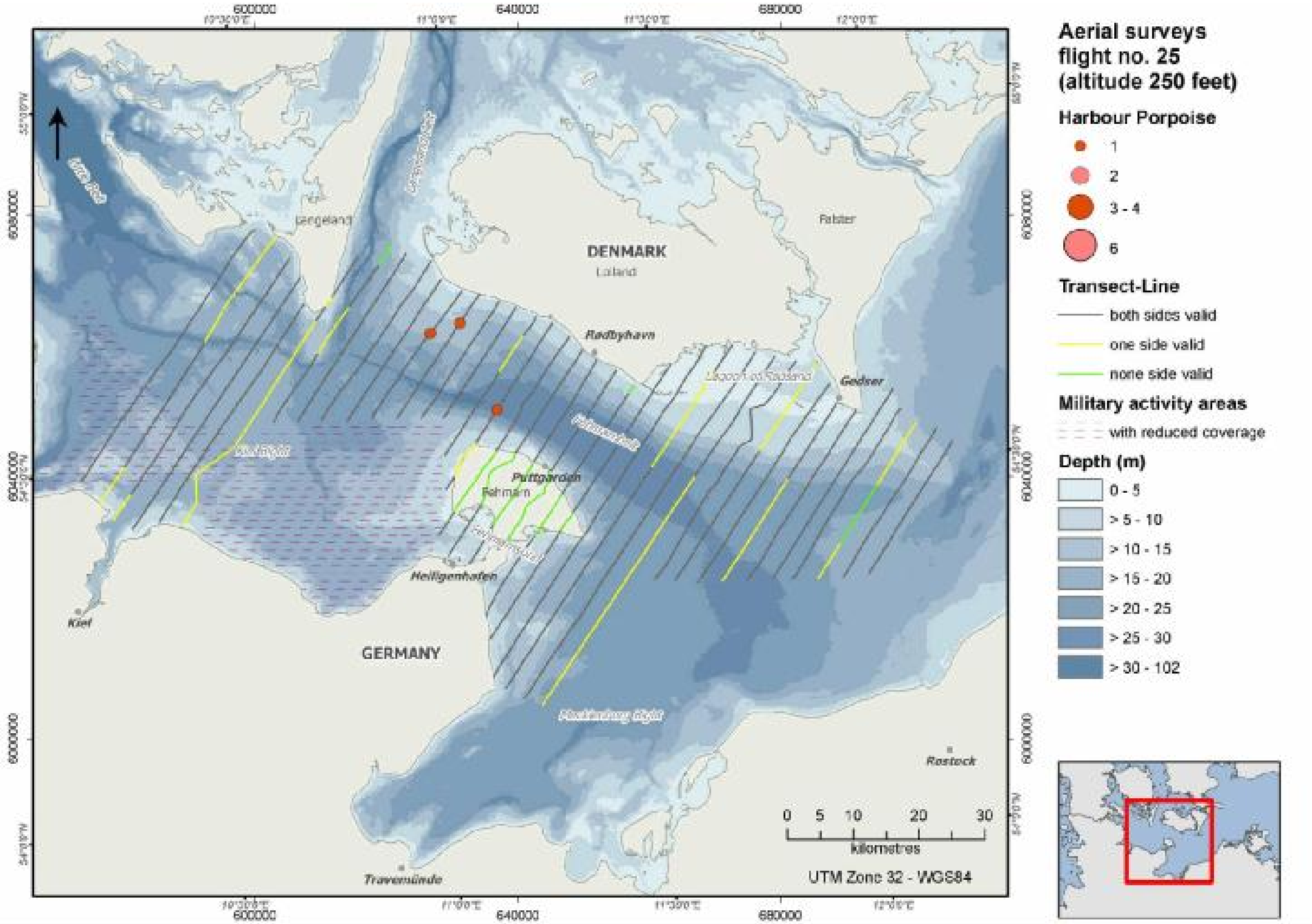

Figure 7.2-25 Locations of harbour porpoise sightings in flight No 25 (March 22 and 25 2010) in a flight altitude of 76 m.

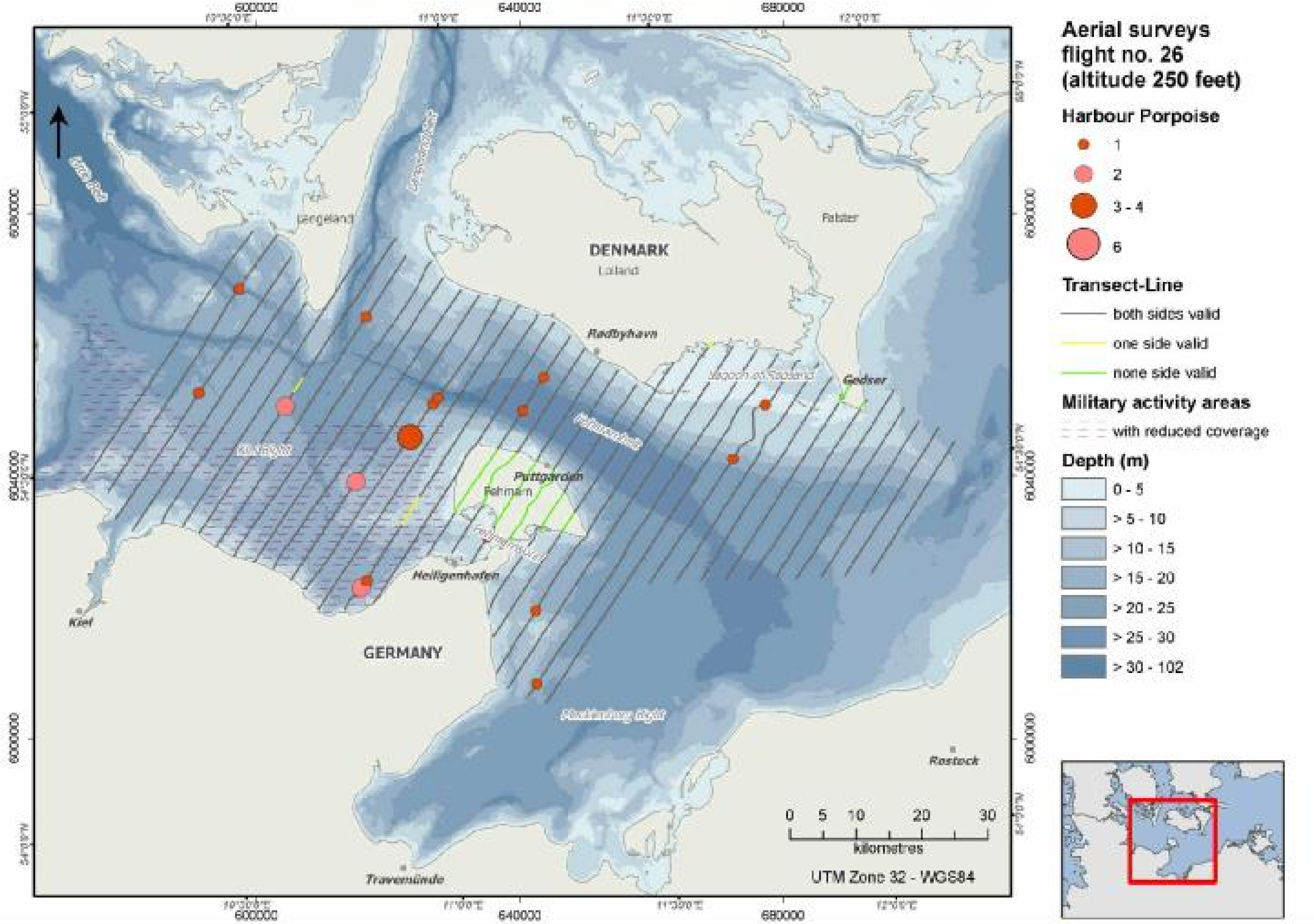

Figure 7.2-26 Locations of harbour porpoise sightings in flight No 26 (April 06 and 08 2010) in a flight altitude of 76 m.

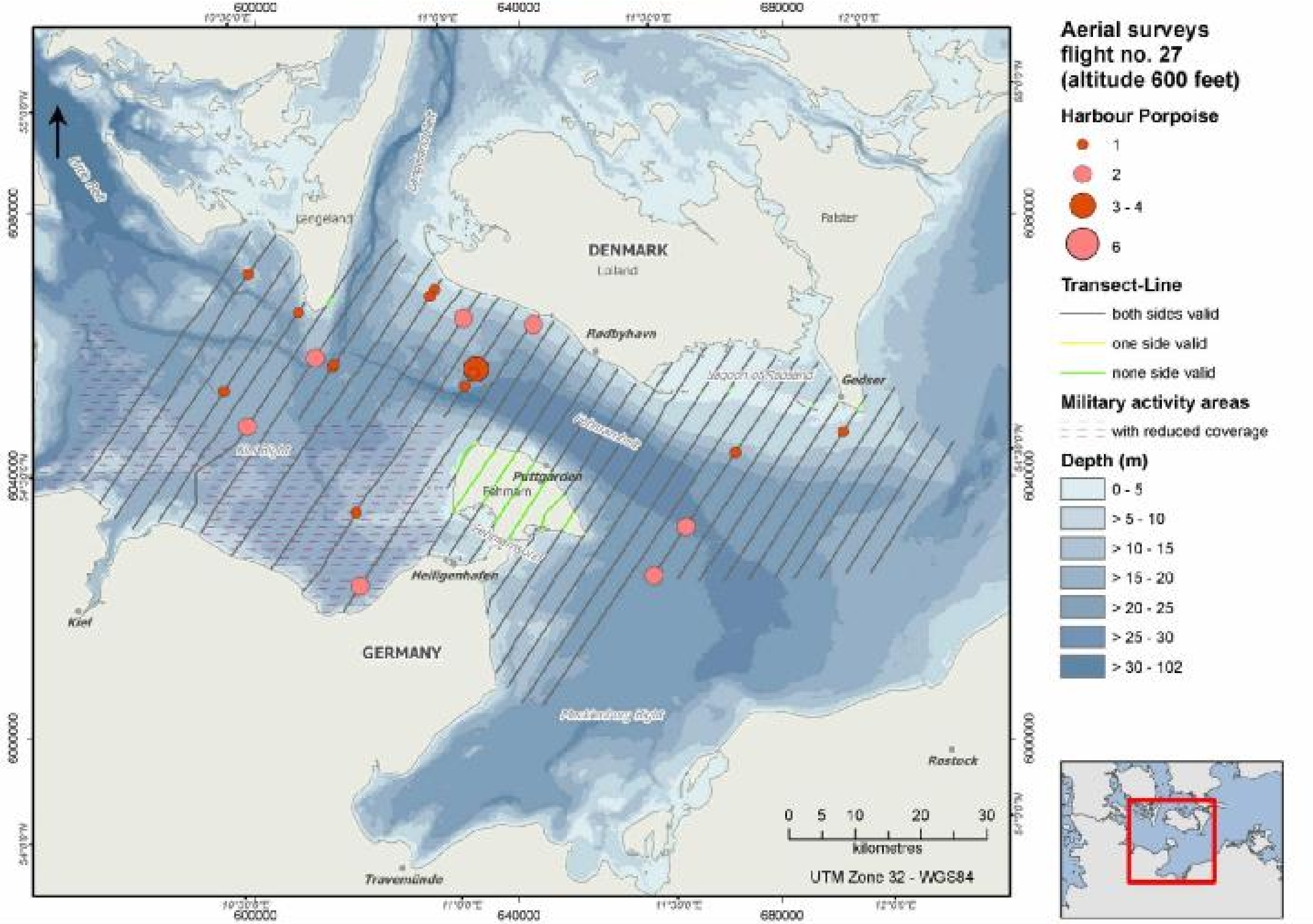

Figure 7.2-27 Locations of harbour porpoise sightings in flight No 27 (April 08, 15 and 28 2010) in a flight altitude of 183 m.

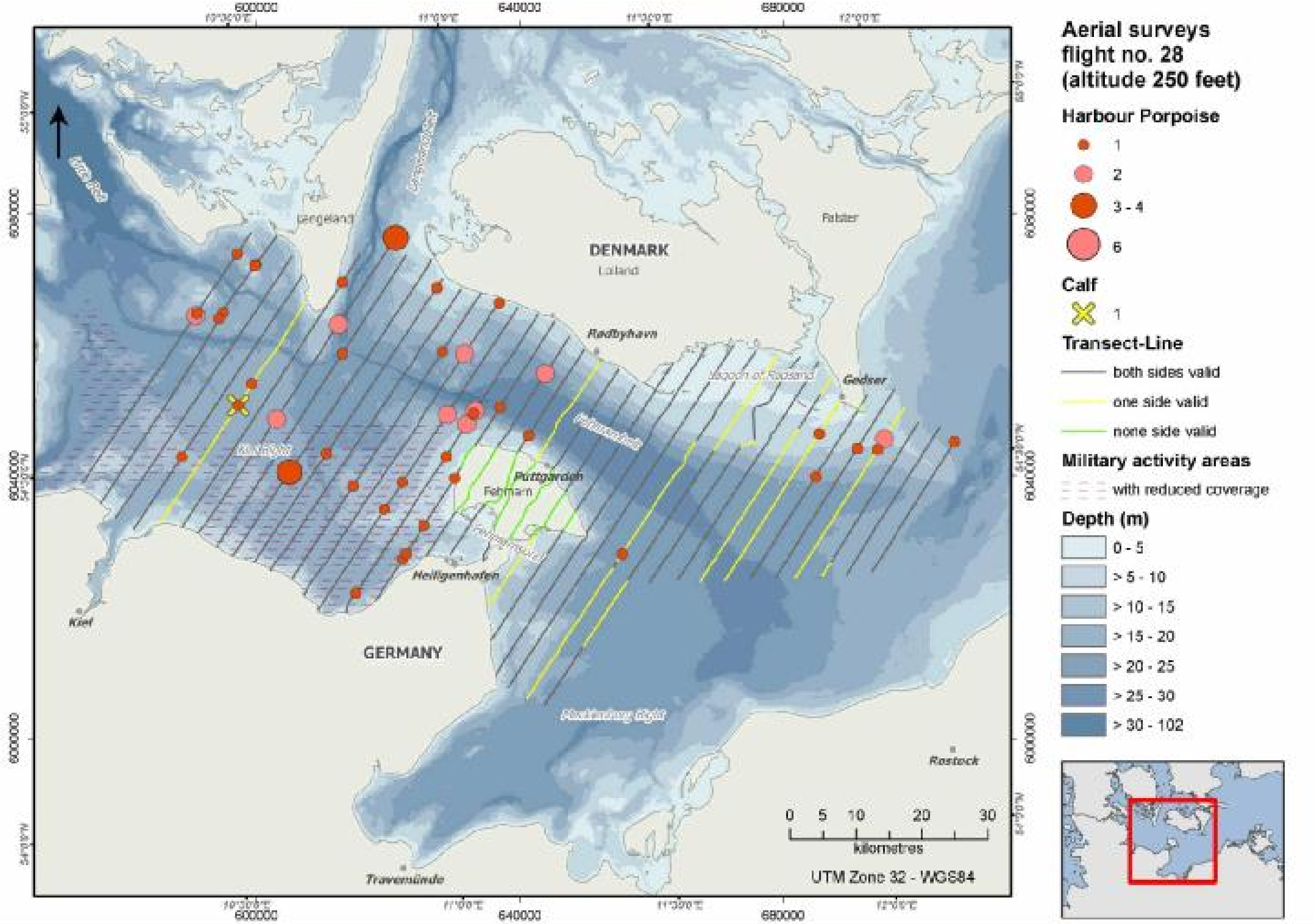

Figure 7.2-28 Locations of harbour porpoise sightings in flight No 28 (May 02 2010) in a flight altitude of 76 m.

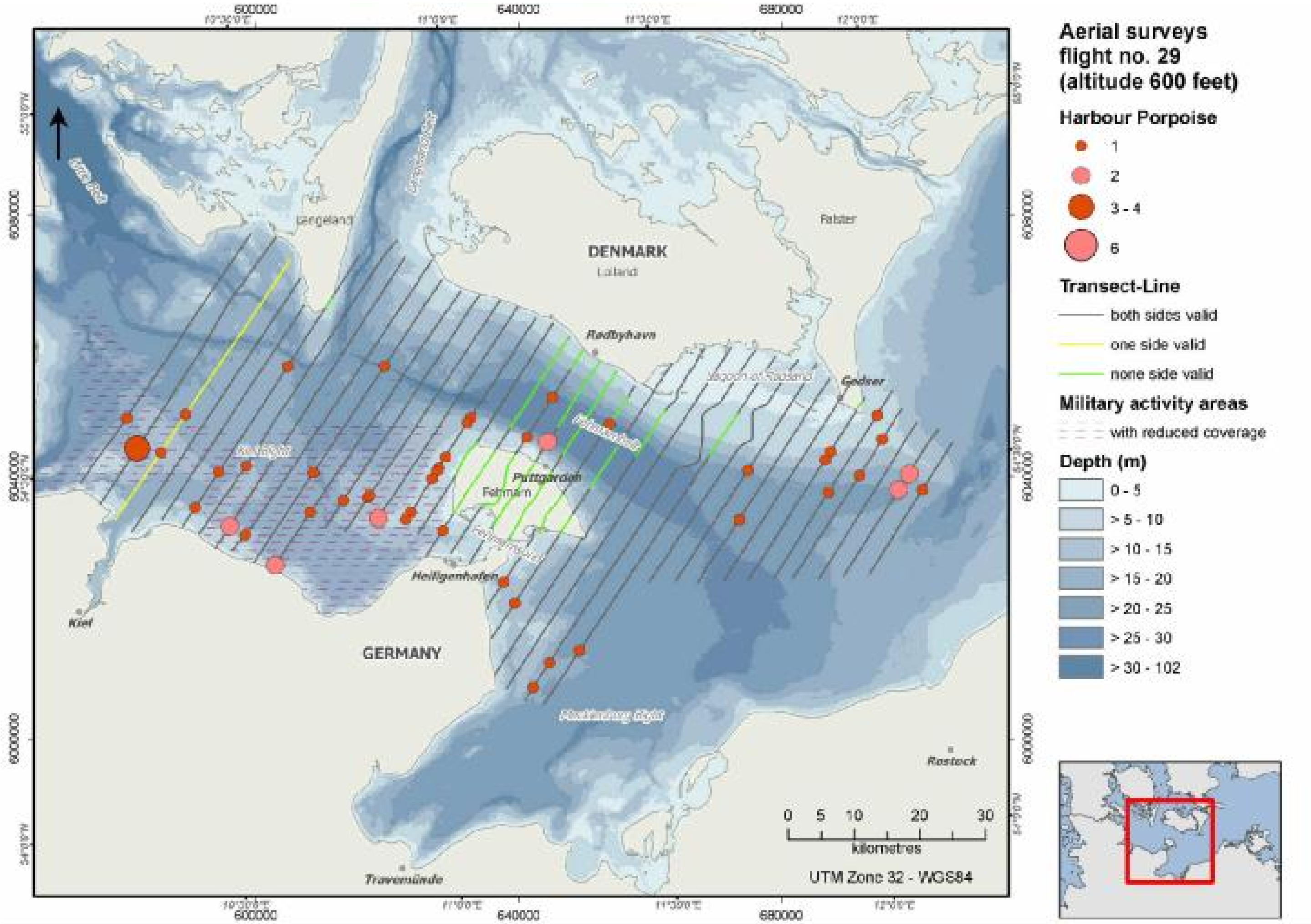

Figure 7.2-29 Locations of harbour porpoise sightings in flight No 29 (May 10 2010) in a flight altitude of 183 m.

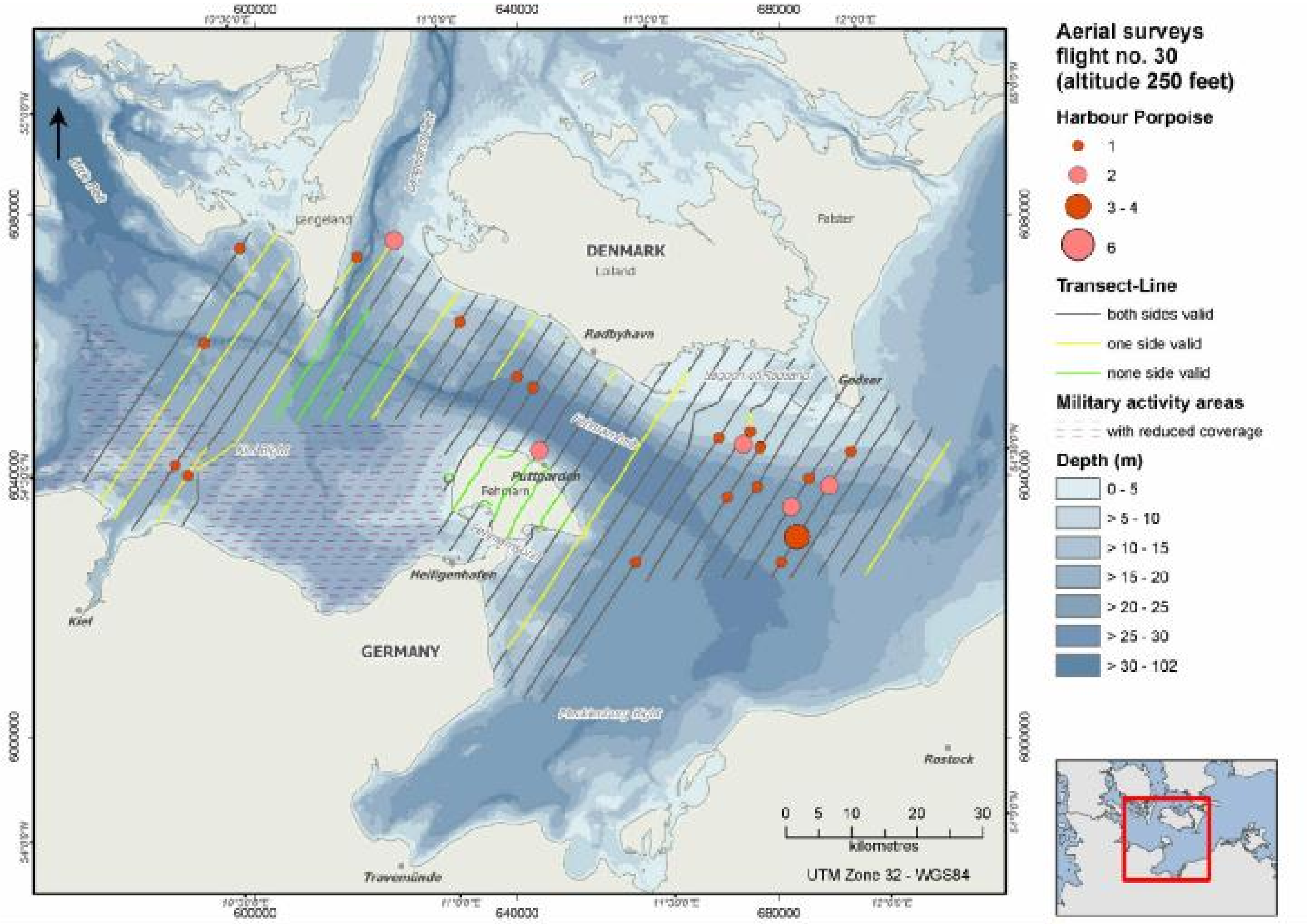

Figure 7.2-30 Locations of harbour porpoise sightings in flight No 30 (June 04 2010) in a flight altitude of 76 m.

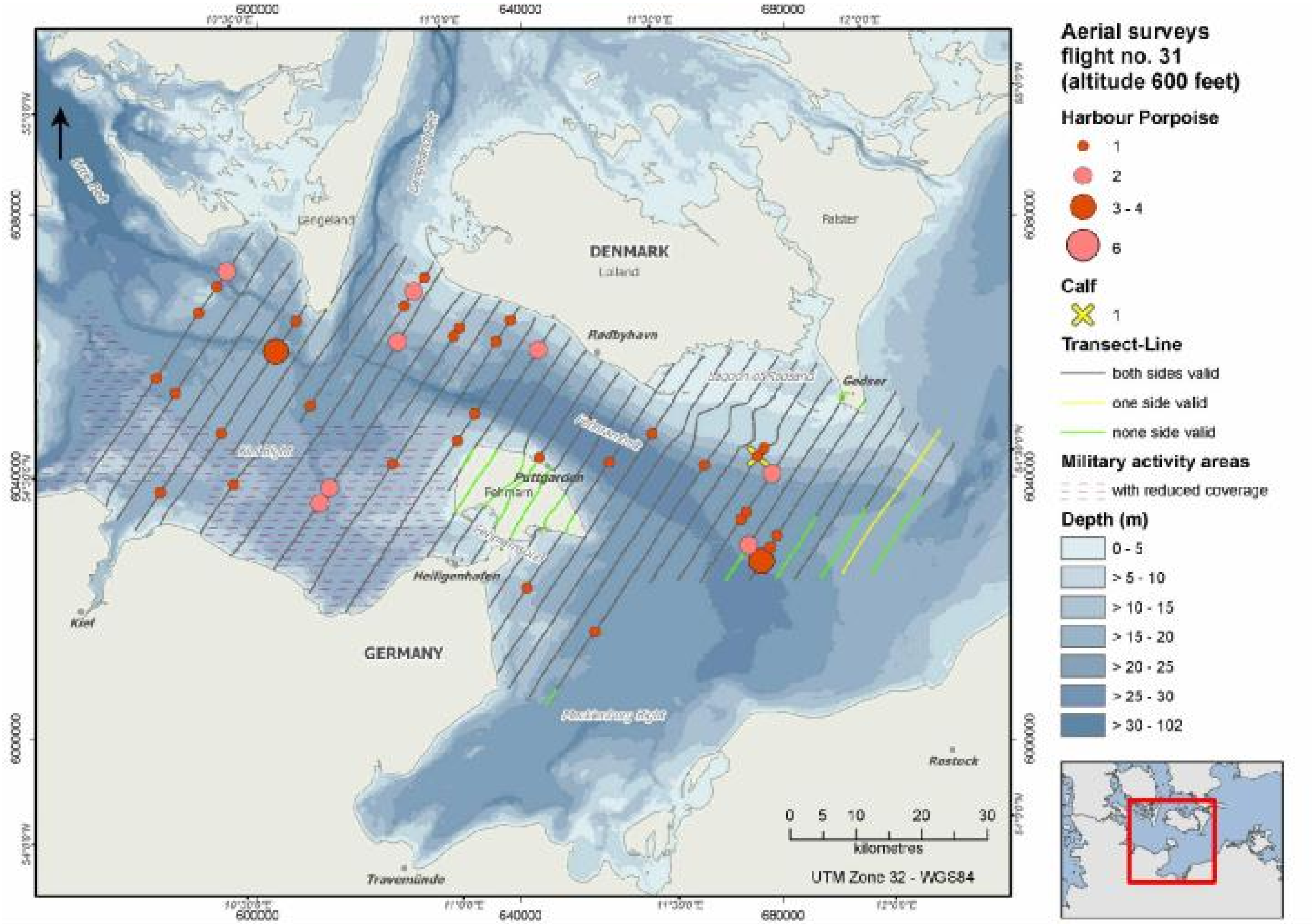

Figure 7.2-31 Locations of harbour porpoise sightings in flight No 31 (June 05 and 08 2010) in a flight altitude of 183 m.

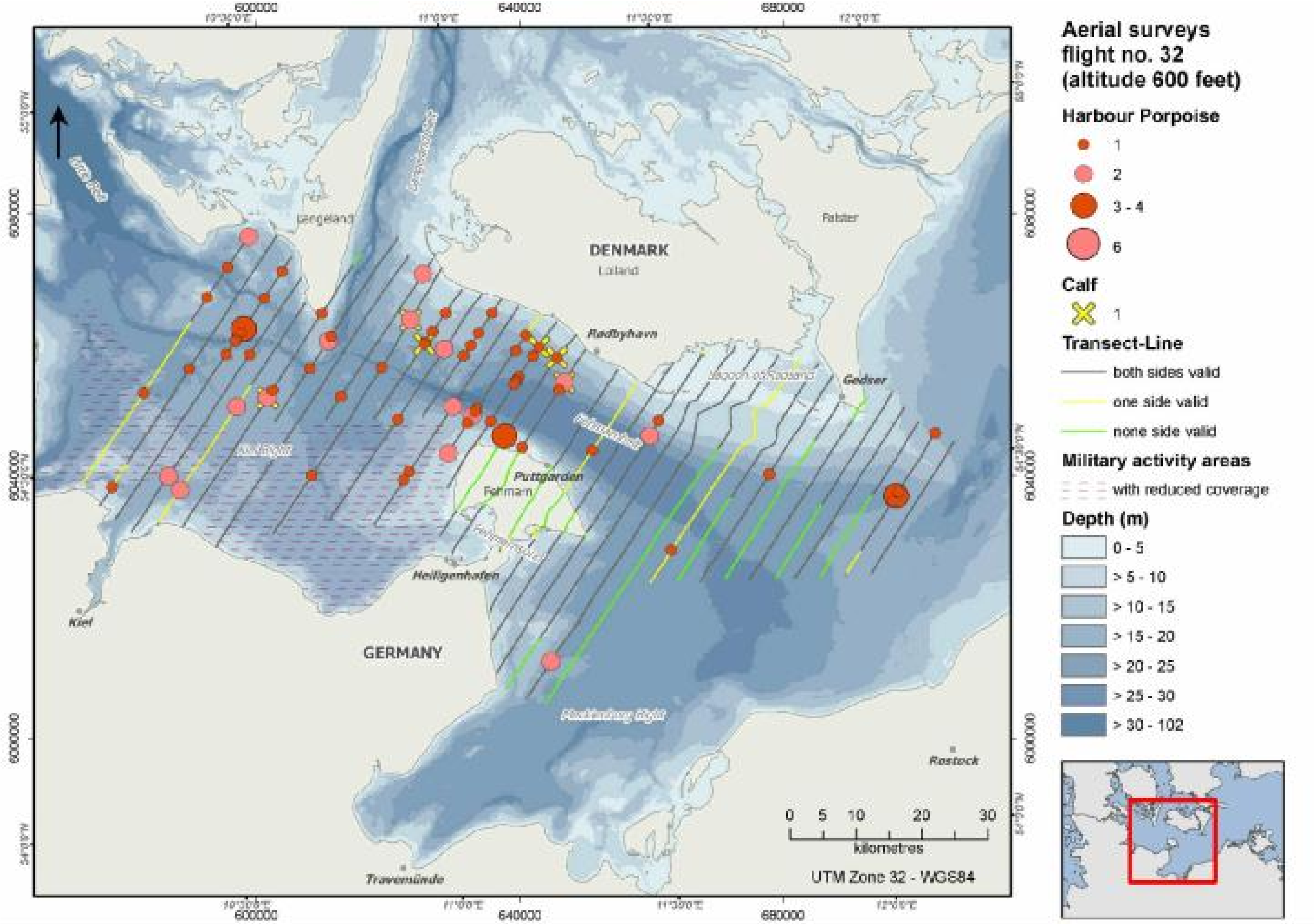

Figure 7.2-32 Locations of harbour porpoise sightings in flight No 32 (July 01 and 09 2010) in a flight altitude of 183 m.

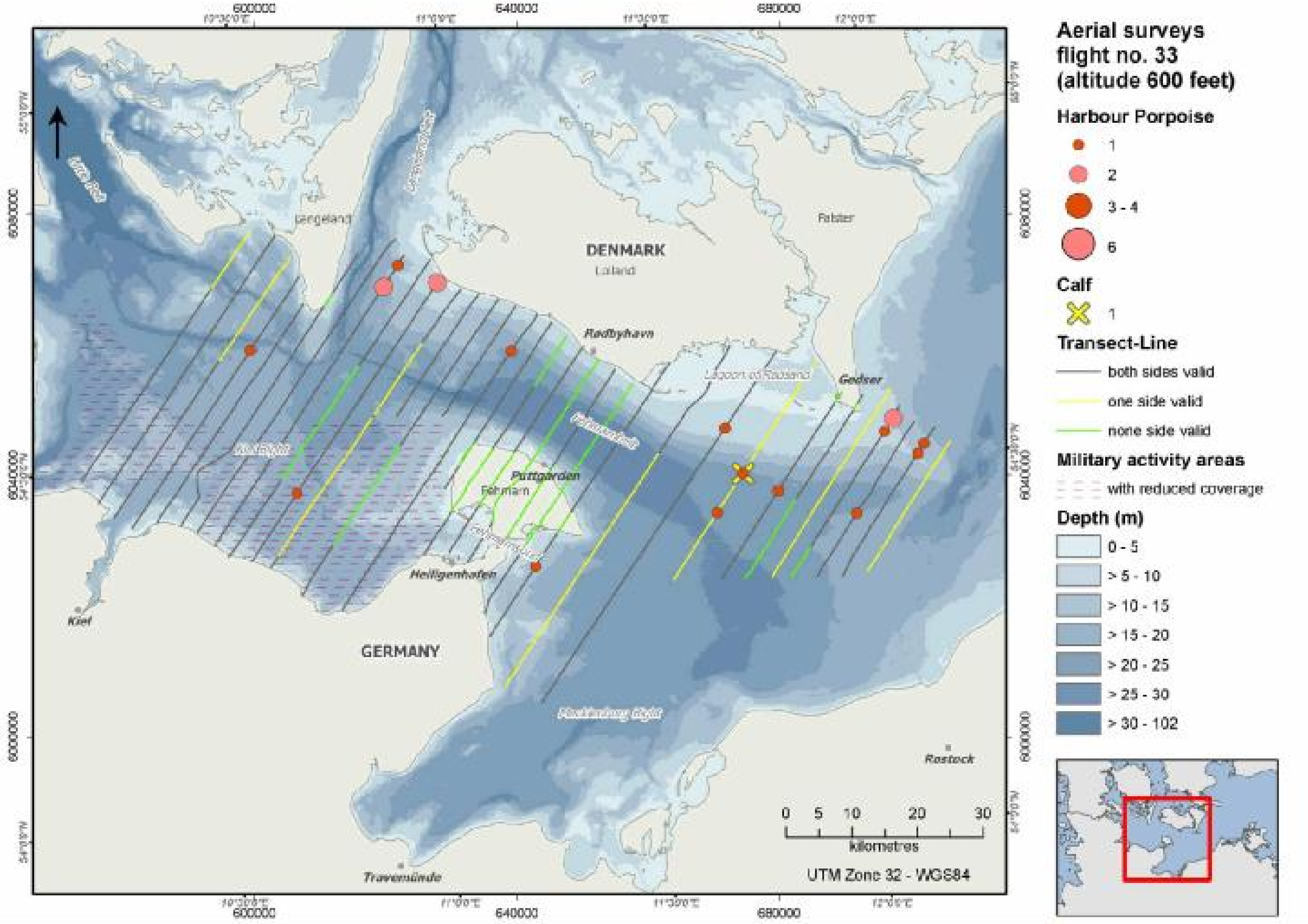

Figure 7.2-33 Locations of harbour porpoise sightings in flight No 33 (August 06 and 26 2010) in a flight altitude of 183 m.

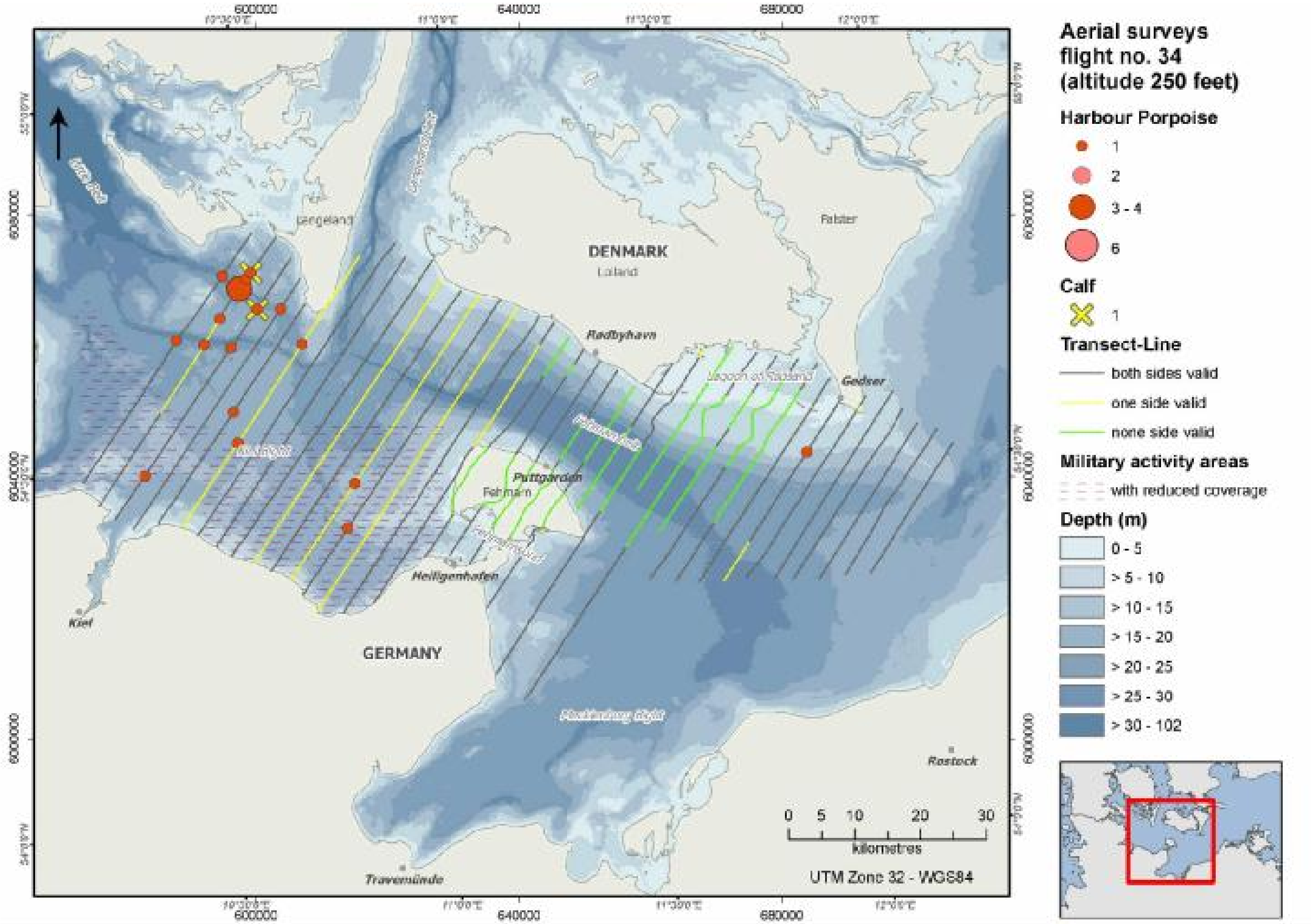

Figure 7.2-34 Locations of harbour porpoise sightings in flight No 34 (August 07 2010) in a flight altitude of 76 m.

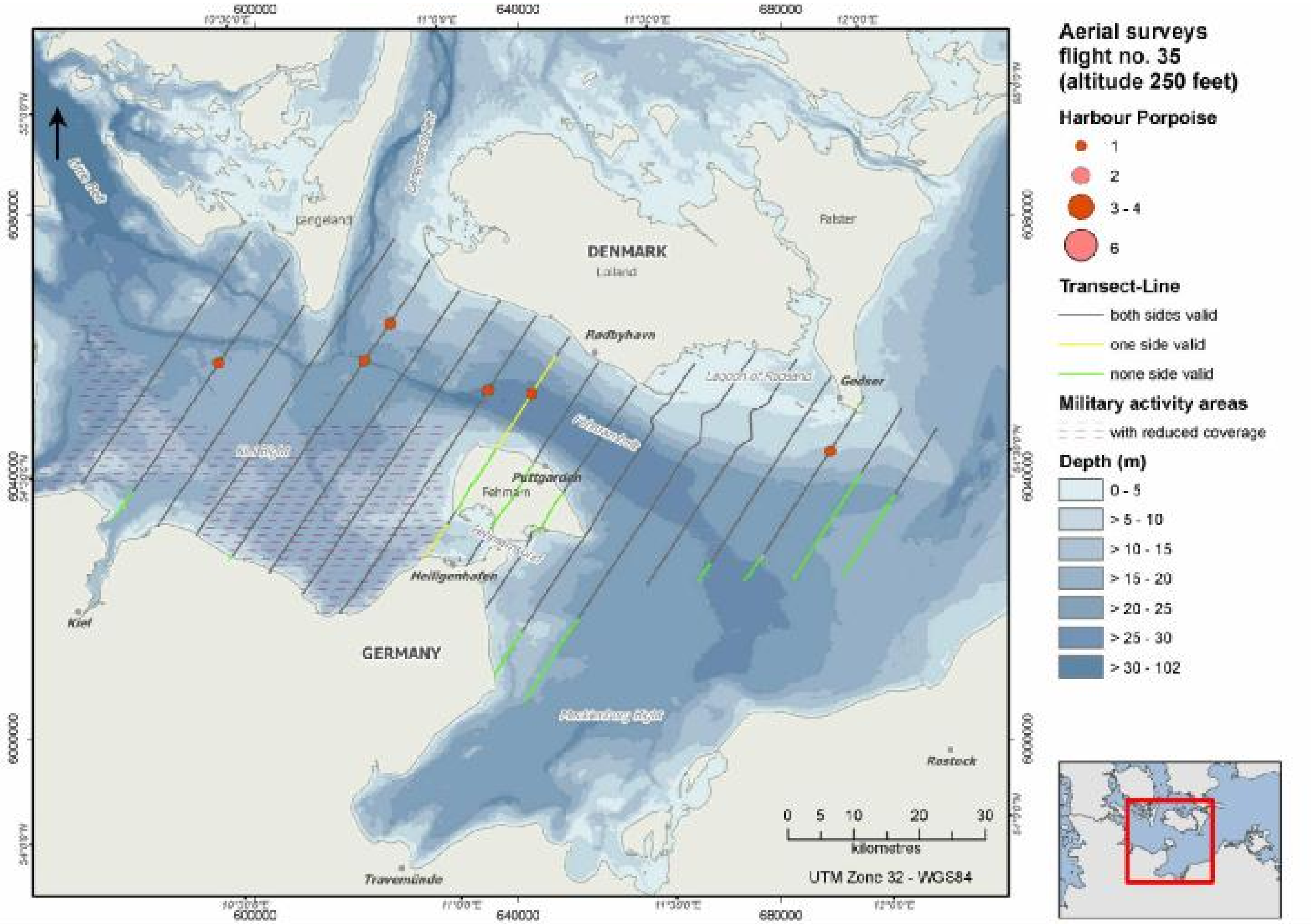

Figure 7.2-35 Locations of harbour porpoise sightings in flight No 35 (September 05 2010) in a flight altitude of 76 m.

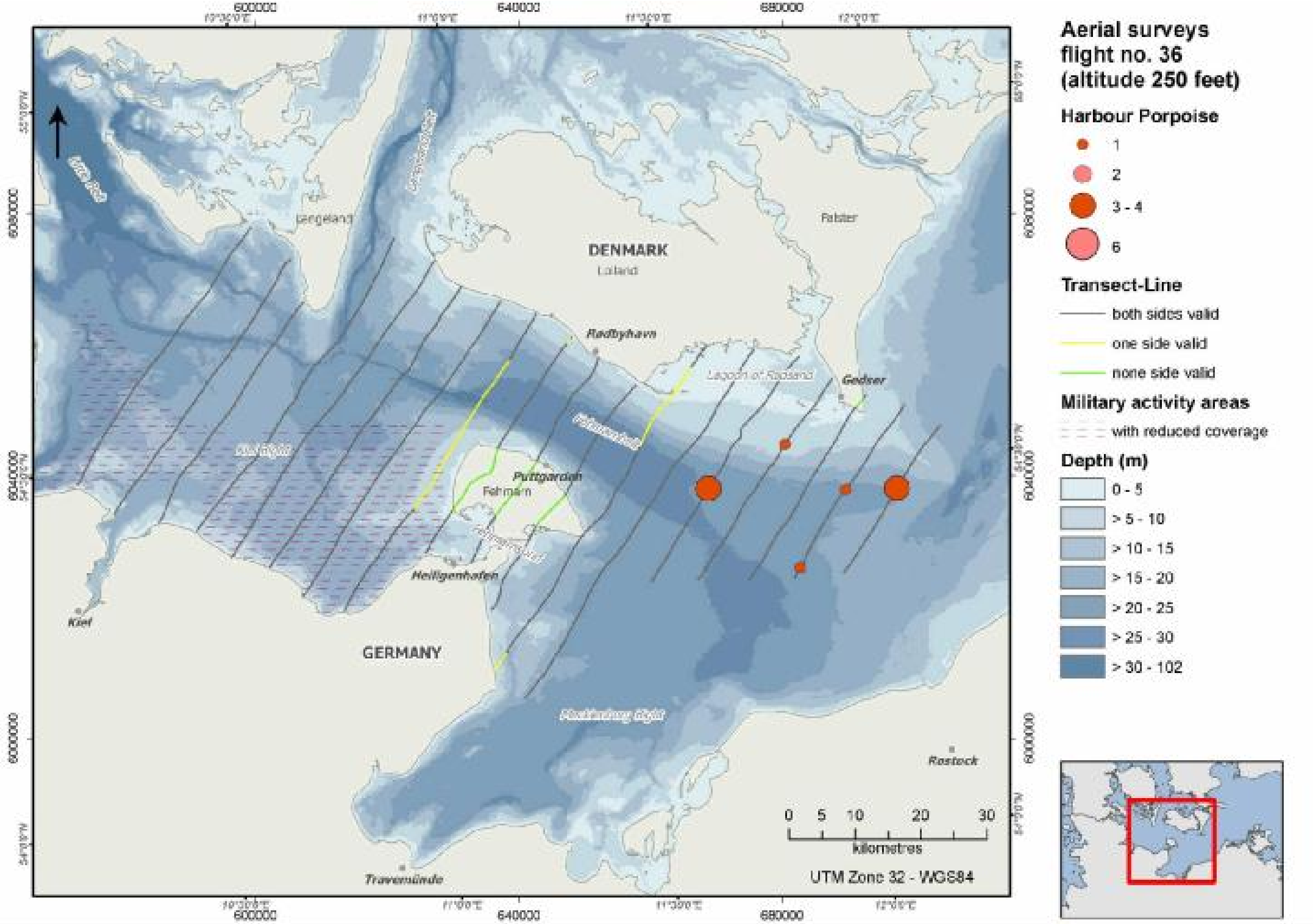

Figure 7.2-36 Locations of harbour porpoise sightings in flight No 36 (September 12 2010) in a flight altitude of 76 m.

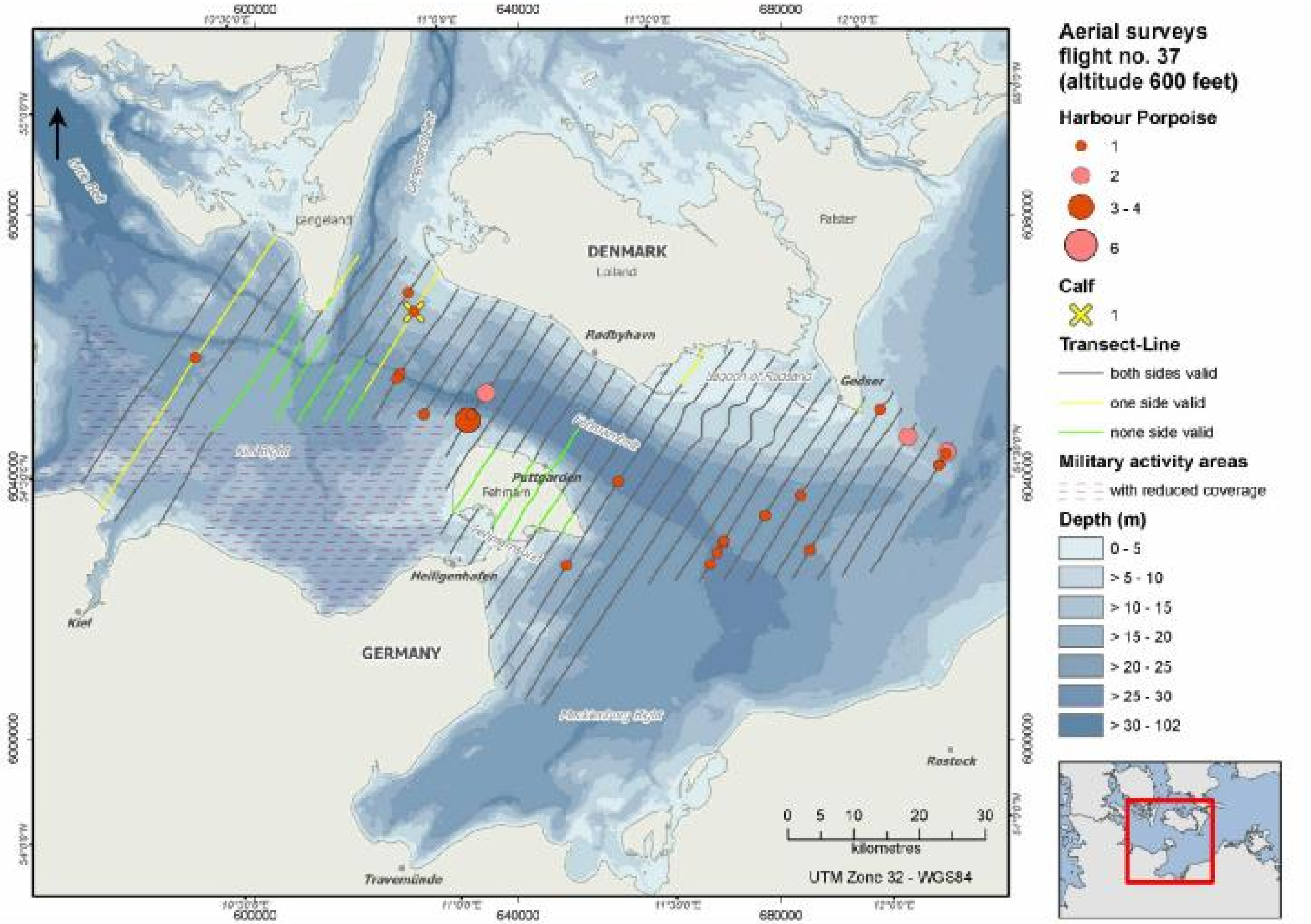

Figure 7.2-37 Locations of harbour porpoise sightings in flight No 37 (September 22 2010) in a flight altitude of 183 m.

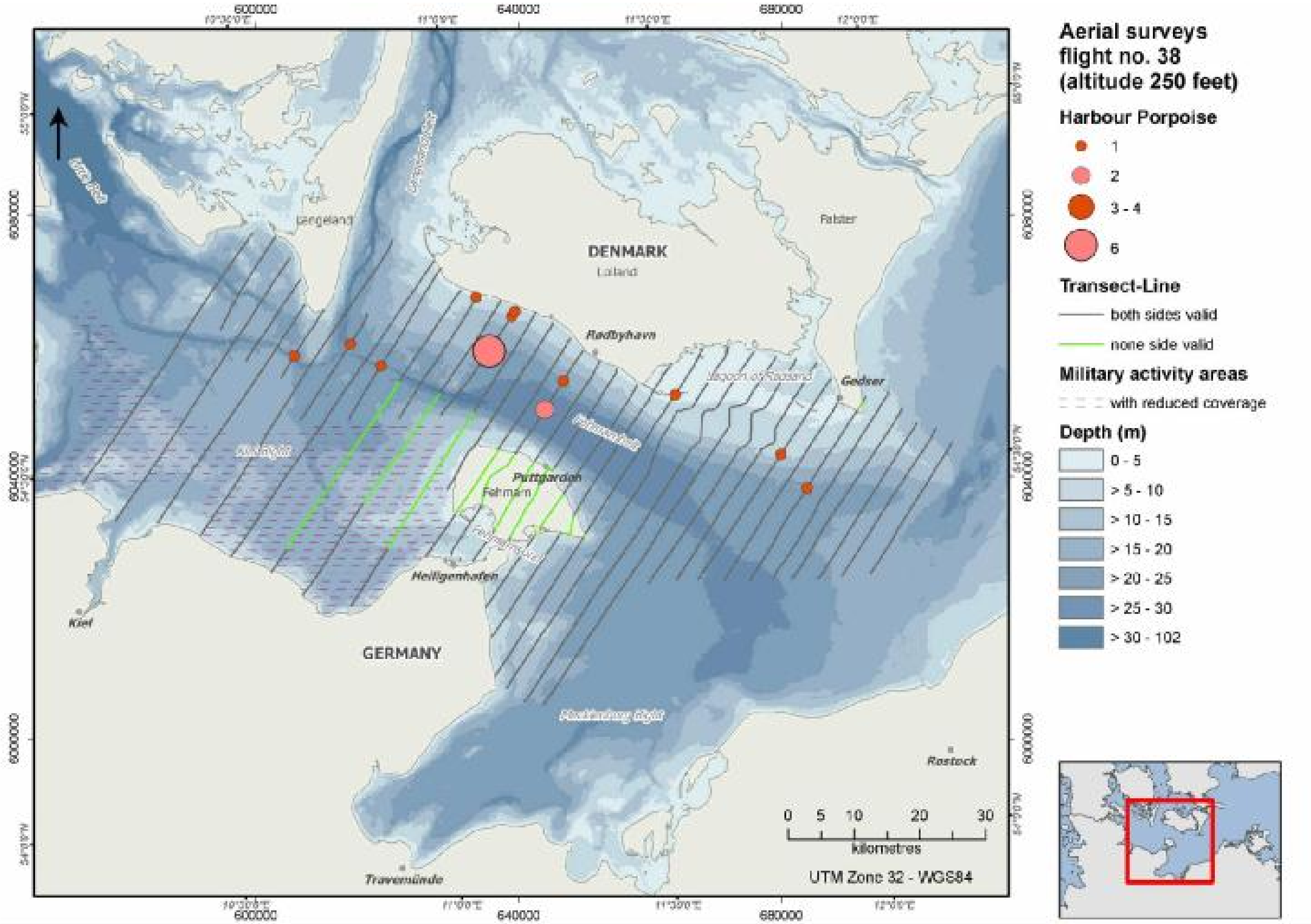

Figure 7.2-38 Locations of harbour porpoise sightings in flight No 38 (October 10 and 13 2010) in a flight altitude of 76 m.

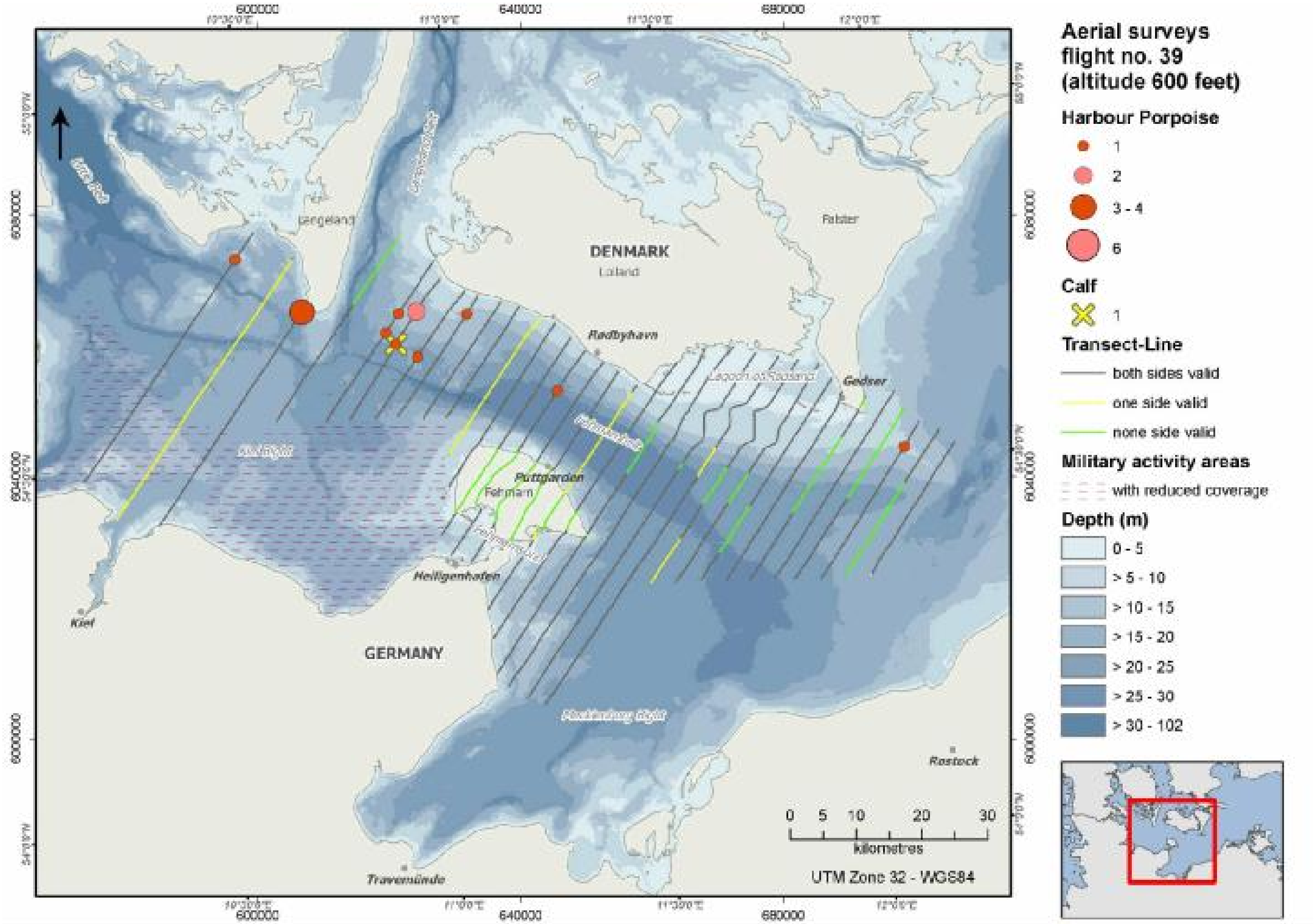

Figure 7.2-39 Locations of harbour porpoise sightings in flight No 39 (October 15 and 26 2010) in a flight altitude of 183 m.

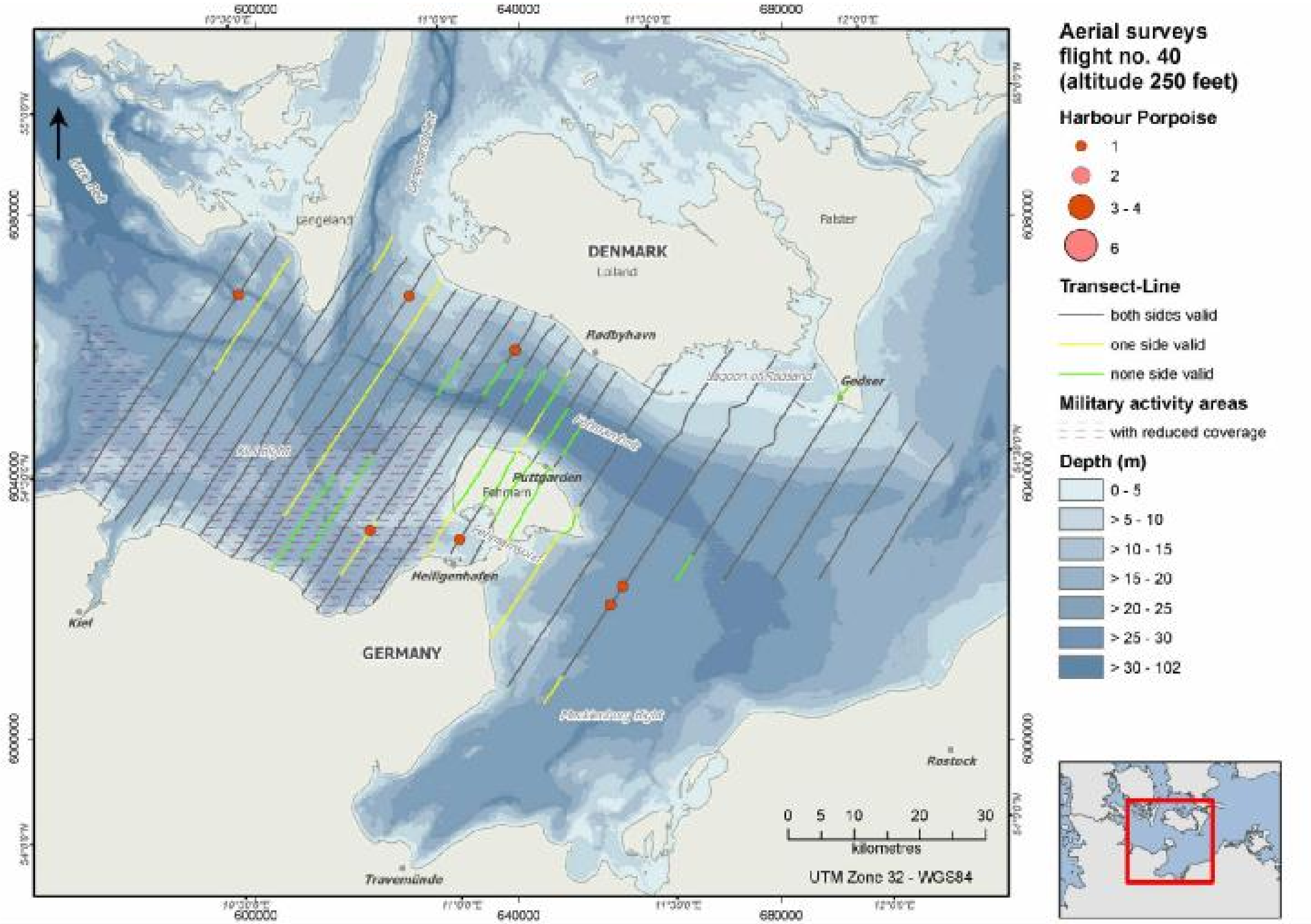

Figure 7.2-40 Locations of harbour porpoise sightings in flight No 40 (November 07 2010) in a flight altitude of 76 m.

7.3. Appendix 3

(Distribution and abundance of harbour porpoises - Part 1: Design-based analysis)

Table 7.3-1 Flight transect waypoints and distances in transect (flight scheme "A")

Waypoint	Transect No	N	E	distance (km)
1	1	54.4927600	10.1355636	
2	1	54.6952500	10.3794580	27,51
3	1	54.7493740	10.4452270	7,37
4	1	54.8320137	10.5460729	11,26
5	2	54.7951363	10.6368423	
6	2	54.7124210	10.5370910	11,23
7	2	54.6448520	10.4537850	9,24
8	2	54.4427518	10.2115331	27,42
9	3	54.4340726	10.3133000	
10	3	54.6218850	10.5358250	25,39
11	3	54.6677890	10.5906340	6,23
12	3	54.7321398	10.6684616	8,75
13	4	54.8182808	10.8847773	
14	4	54.5739260	10.5915520	33,13
15	4	54.4189725	10.4057531	21,03
16	5	54.3862170	10.4806605	
17	5	54.5739000	10.7097520	25,63
18	5	54.7877510	10.9722753	29,21
19	6	54.7463814	11.0373164	
20	6	54.5738750	10.8246690	23,60
21	6	54.3672473	10.5725591	28,22
22	7	54.3341296	10.6474666	
23	7	54.5732110	10.9373950	32,59
24	7	54.7301298	11.1292191	21,41
25	8	54.7084501	11.2161871	
26	8	54.5213850	10.9920200	25,36
27	8	54.3099840	10.7426376	28,56
28	9	54.3835477	10.9392289	
29	9	54.4124280	10.9732100	3,90
30	9	54.6765653	11.2889074	35,80
31	10	54.6427396	11.3610774	
32	10	54.3722847	11.0398962	36,60
33	11	54.3108752	11.0769923	
34	11	54.6076078	11.4398107	40,55
35	12	54.6564034	11.6111832	
36	12	54.2139269	11.0850205	59,93
37	13	54.1826200	11.1588364	
38	13	54.6490425	11.7271806	63,69
39	14	54.6356189	11.8267502	
40	14	54.5755880	11.7516670	8,26
41	14	54.5679200	11.7160300	2,46
42	14	54.5295460	11.7110900	4,28

Waypoint	Transect No	N	E	distance (km)
43	14	54.5199500	11.6826100	2,13
44	14	54.3374865	11.4579097	25,00
45	15	54.3371365	11.5772039	
46	15	54.6078275	11.9016678	36,75
47	16	54.5806546	11.9826056	
48	16	54.3355049	11.6904761	33,22
49	17	54.3354805	11.7982784	
50	17	54.5636909	12.0701290	30,92
51	18	54.5332914	12.1494187	
52	18	54.3370634	11.9153865	26,60

Table 7.3-2 Flight transect waypoints and distances in Transect (flight scheme "B")

Waypoint	Transect No	N	E	distance (km)
1	19	54.4607165	10.1738083	
2	19	54.6652770	10.4133290	27,52
3	19	54.7309020	10.4911590	8,86
4	19	54.8262845	10.6051621	12,91
5	20	54.7681017	10.6592270	
6	20	54.6971200	10.5742730	9,61
7	20	54.6327160	10.4964460	8,75
8	20	54.4279894	10.2536412	27,68
9	21	54.4314929	10.3702072	
10	21	54.6097120	10.5795800	24,03
11	21	54.6192880	10.5905430	1,28
12	21	54.7979602	10.8015610	24,10
13	22	54.7944404	10.9088099	
14	22	54.5739140	10.6484630	29,74
15	22	54.4013130	10.4462143	23,26
16	23	54.3807483	10.5348262	
17	23	54.5738880	10.7666630	26,23
18	23	54.7613472	10.9941147	25,51
19	24	54.7390531	11.0821752	
20	24	54.5738620	10.8815800	22,49
21	24	54.3547066	10.6195969	29,73
22	25	54.3132148	10.6819026	
23	25	54.5731990	10.9921180	35,25
24	25	54.7196113	11.1696946	19,93
25	26	54.6979276	11.2544724	
26	26	54.4739900	10.9919310	30,16
27	26	54.3209053	10.8132502	20,62
28	27	54.3848173	10.9950476	
29	27	54.6590197	11.3228023	37,18
30	28	54.6290108	11.3999039	
31	28	54.3918566	11.1192805	32,05
32	29	54.2687121	11.0862168	
33	29	54.6356839	11.5301560	49,98
34	30	54.6560737	11.6730190	
35	30	54.2003772	11.1189225	62,18
36	31	54.1758329	11.2036962	
37	31	54.5474700	11.6596800	50,89
38	31	54.5724000	11.6630000	2,78
39	31	54.5787900	11.6991400	2,44
40	31	54.6413725	11.7769639	8,59
41	32	54.6295438	11.8738003	
42	32	54.5442500	11.7702200	11,62
43	32	54.5237700	11.7636100	2,32
44	32	54.5161000	11.7360000	1,98
45	32	54.3384346	11.5219366	24,17
46	33	54.3368029	11.6346614	

47	33	54.5972765	11.9459722	35,33
48	34	54.5873482	12.0466426	
49	34	54.3364530	11.7517665	33,85
50	35	54.3351468	11.8584723	
51	35	54.5425809	12.1018286	27,97
52	36	54.5134428	12.1838568	
53	36	54.3376900	11.9750352	23,80

7.4. Appendix 4

7.4.1. Hydrographic covariates

Parameter name	Description
Position	X and Y UTM32N
Depth	Water depth in metres
Substrate	Median grain size (mm)
Distance to the alignment	
Distance to land	Euclidian distance to shore (small islands excluded) in metres
Distance to wind farms	Euclidian distance to Nysted and Rødsand2 wind farms in metres
Distance to shipping lanes	Euclidian distance to areas of high shipping intensity in metres
Discharge salinity	Measure of inflow/outflow
Pycnocline depth	Depth of stratified layer deduced by Brunt–Väisälä frequency values > 0.1
Pycnocline strength	Strength of stratification measured by Brunt–Väisälä frequency
Frontal strength	Horizontal gradient of surface currents
Salinity (-1m ie. surface)	Surface salinity (PSU)
Salinity (+3m off bottom)	
Temperature (-1m ie. surface)	Surface temperature (C^0)
Temperature (+3m off bottom)	
Current speed (-1m ie. surface)	
Current speed (+3m off bottom)	
Sediment grain size	
Current gradient (-1m ie. surface)	
Current gradient (+3m off bottom)	
Density (-1m surface)	Water density measure in kg/m^3
Density (+3m bottom)	
U velocity (-1m ie. surface)	E - W current velocity (metres/second – m/s) at the surface
U velocity (+3m off bottom)	
Vorticity (-1m ie. surface)	Eddy activity measured as relative vorticity dV/dx - dU/dy
Vorticity (+3m off bottom)	
V velocity (-1m ie. surface)	N - S current velocity (m/s) at the surface
V velocity (+3m bottom)	
W velocity (-1m ie. surface)	Upwelling/downwelling velocity (m/s) at the surface
W velocity (+3m off bottom)	
W velocity (at 10m water depth)	

7.4.2. Introduction

The purpose of this document is to describe the hydrographic variables applied for the analyses of the field data collected as part of the FEMM baseline studies. The hydrographic variables have been applied for the analyses of the following sets of field data from the Fehmarnbelt area:

1. Passive acoustic monitoring (PAM) of harbour porpoise;
2. Visual (aerial) surveys of harbour porpoise;
3. Telemetry data from satellite tagged harbour porpoises;
4. Telemetry data from satellite tagged seals.

The hydrographic variables applied include the following variables:

1. Horizontal current components in the surface and bottom layers;
2. Vertical current velocity as a measure of up- and downwelling in the surface and bottom layers and at 10 m depth;
3. Current speed (magnitude) in the surface and bottom layers;
4. Current gradient as a measure of frontal strength in the surface and bottom layers;
5. Vorticity as a measure of eddy potential in the surface and bottom layers;
6. Water temperature, salinity and density in the surface and bottom layers;
7. Strength and depth of the vertical maximum Brunt-Vaisala frequency as measures of the stratification of the water column;
8. The integrated discharge (or flux) of salt across the Puttgarden-Rødbyhavn cross-section as a measure of the flow regime (inflow or outflow from the Baltic).

These variables are all dynamic. Further they are all spatially varying except the discharge of salt across the Puttgarden-Rødbyhavn cross-section, which is an integrated variable. The hydrographic variables are all extracted from the FEHY hydrodynamic models. Some are direct output from the hydrodynamic models and some (denoted derived variables) are the result of a post-processing of the model results.

Other environmental variables applied for the FEMM data analyses include:

1. Bathymetry (water depth);
2. Surface sediment grain size;

3 Distances to land, to the bridge/tunnel alignment and to nearby offshore wind farms;

4 Distance to shipping lanes and/or shipping intensity.

These static variables are not treated in this document.

7.4.3. FEHY Hydrodynamic Models

7.4.3.1. Introduction

The hydrographic variables applied for the FEMM data analyses originate from the FEHY hydrodynamic models. These models are:

1. FEHY regional hydrodynamic model;
2. FEHY local hydrodynamic model;
3. Fehmarnbelt Water Forecast hydrodynamic model.

Hydrographic variables from the regional model have been applied for the analyses of the harbour porpoise telemetry data, which covers the period from 1997 to 2010. The variables from the regional model cover a long period, but at the cost of a rather coarse spatial resolution.

The two latter models are very similar and both have a fine spatial resolution in the Fehmarnbelt area. Hydrographic variables from these models in combination have been applied for the analyses of the PAM, harbour porpoise visual survey and seal telemetry datasets, which all fall within the period 2009-2010.

In the following sections a summary of the FEHY models is presented. Further, a justification for combining the two latter models in order to obtain a full set of hydrographic variables from 1 Jan 2009 to 31 Dec 2010 is given.

7.4.3.2. FEHY Regional Hydrodynamic Model

The FEHY regional hydrodynamic model covers the Baltic Sea, the Belt Sea, Kattegat and part of Skagerrak. It is a 3D hydrodynamic model based on the MIKE 3 FM modelling system. The model has an open boundary in Skagerrak between Hanstholm, Denmark and Mandal, Norway.

In Figure 7.4-1 the bathymetry of the FEHY regional model is presented. The bathymetry is based on the FEHY 50x50 m bathymetry for the area from southern Kattegat to Bornholm and on the FEHY 500x500 m bathymetry for the remaining area.

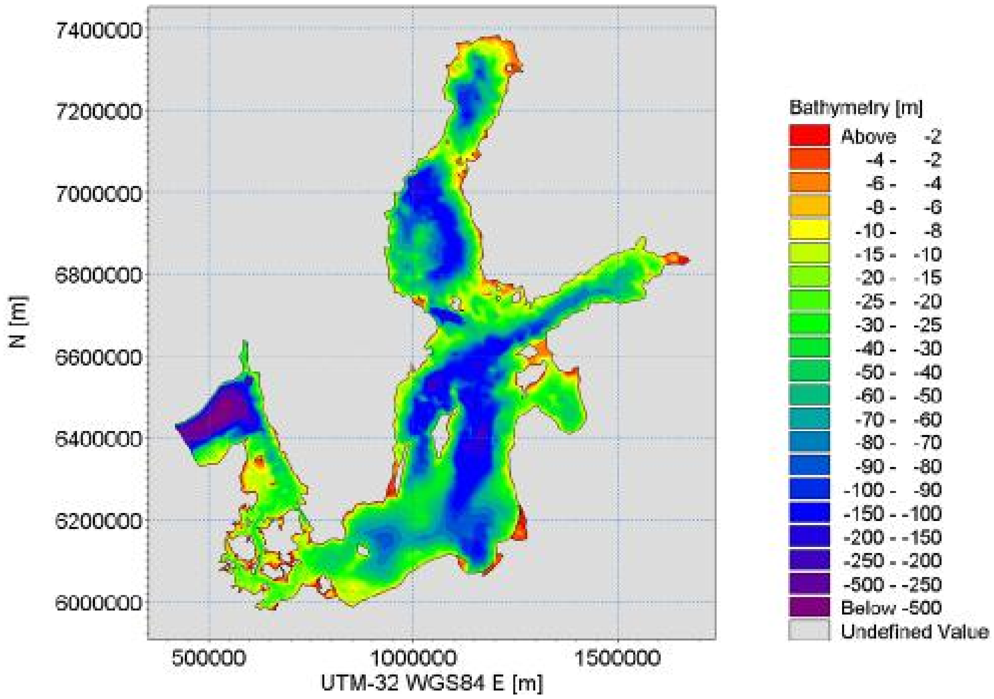

Figure 7.4-1 FEHY regional model bathymetry

The regional model has a horizontal resolution varying from 15 km in the eastern Baltic Sea to about 3 km in the Fehmarnbelt area. A detail of the mesh in the Fehmarnbelt area is shown in Figure 7.4-2. The vertical resolution of the regional model is 1 m in the Fehmarnbelt area.

The regional model is forced by open boundary conditions in the Skagerrak (water level and current, salinity, temperature), by meteorological forcing (wind, air pressure, air temperature, cloudiness, precipitation) from a meteorological model and by freshwater runoff from the catchment of the model area.

The model output consists of temporally and spatially varying fields of water level, currents (3 components), water temperature, salinity and density. The simulation timestep is 300s and the model output applied for the FEMM analyses is saved every 24 hours.

The calibration period of the regional model is 1970-1999 and the validation period is 2000-2007. Furthermore the model has been run for the period 2008- May 2010. For the purpose of the FEMM analyses, model results from 1997 to May 2010 have been applied.

The regional model is validated based on FEHY's quantitative acceptance criteria. For water level (1 station) the acceptance criteria are that the standard deviation of the difference between measurement and model is less than 0.1 m and that the explained variance is larger than 0.8 for a central station in the Baltic Sea . For salinity and temperature (21 stations, each 7-45 levels) the acceptance criteria are that the root mean square error (RMSE) between measurement and model is less than 2°C or 3PSU and that the bias between measurement and model is less than 1°C/1PSU for 80% or more of all the station levels. Finally for the flow and current, the regional model is too coarse in the Fehmarnbelt for a proper current comparison, so instead the distribution of mean water discharges through the Little Belt, the Great Belt and the Sound was compared to literature values.

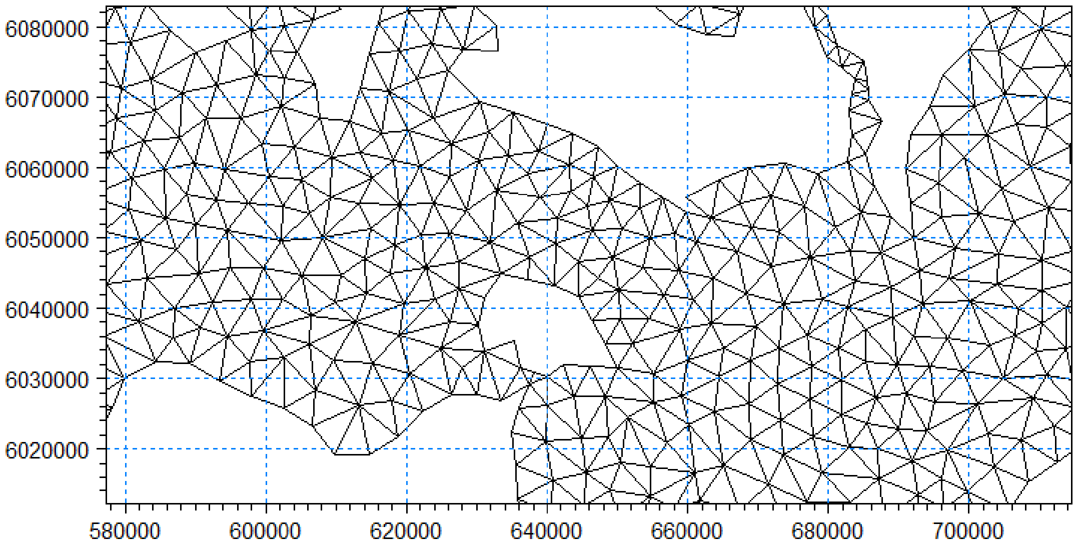

Figure 7.4-2 Detail of the FEHY regional model mesh in the Fehmarnbelt area

For the purpose of the FEMM analyses, FEHY regional model run No. 6.42, 6.45 and 6.45ext have been applied. The FEHY regional model is documented in the MIKE Regional Model Calibration and Validation Report (FEHY, 2013a).

7.4.3.3. FEHY Local Hydrodynamic Model

The FEHY local model covers the area from southern Kattegat to Bornholm. It is a 3D hydrodynamic model based on the MIKE 3 FM modelling system. The model has open boundaries in Kattegat and to the north and south of Bornholm.

In Figure 7.4-3 the FEHY local model bathymetry is shown. The bathymetry is based on the FEHY 50x50 m bathymetry.

The local model has a horizontal resolution varying from 5-6 km in areas like Arkona Basin to 400 m close to Puttgarden and Rødbyhavn. In the Fehmarnbelt area the resolution is down to about 500 m near the link alignment and 300 m at the landfall areas. A detail of the mesh in the Fehmarnbelt area is shown in Figure 7.4-4. The vertical resolution of the local model is 1 m in the Fehmarnbelt area (less at water depths below 10 m).

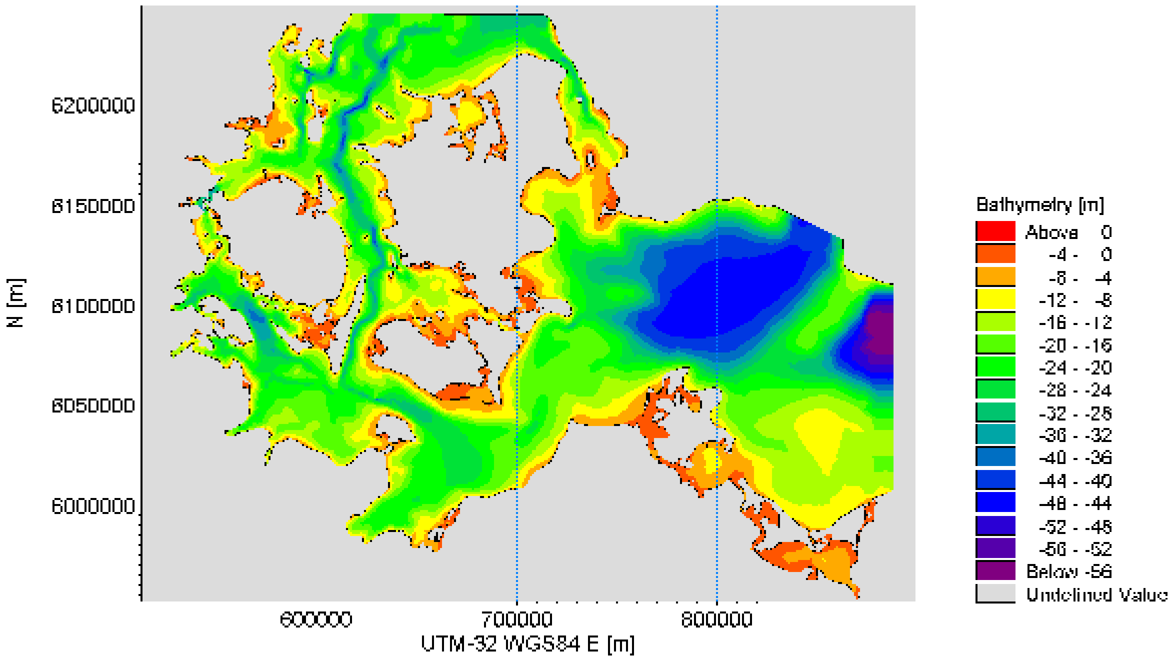

Figure 7.4-3 FEHY local model bathymetry

Similarly to the regional model, the local model is forced by boundary conditions at the open boundaries, by meteorological forcing from a meteorological model and by freshwater runoff from the catchment of the model area. The forcing data (meteorology and runoff) of the local model are from the same dataset as the forcing data of the regional model.

The model output consists of temporally and spatially varying fields of water level, currents, water temperature, salinity and density. The simulation time step is 300s and the model output applied for the FEMM analyses is saved every 180 minutes.

The calibration period of the regional model is the year 2005 and the validation period is 1 Jan – 1 Oct 2009. Furthermore the model has been run for the period 1 Oct 2009 - 1 June 2010. For the purpose of the FEMM analyses model results from Jan 2009 to May 2010 have been applied.

The local model is validated based on FEHY's quantitative acceptance criteria. For water level (7 stations) the acceptance criteria are that the standard deviation of the difference between measurement and model is less than 0.1 m and that the explained variance is larger than 0.8 for minimum 80% of the local gauge stations. For salinity and temperature (15 stations, each 4-34 levels), the acceptance criteria are that the root mean square error (RMSE) between measurement and model is less than 2°C/3PSU and that the bias between measurement and model is less than 1°C/1PSU for 80% or more of all the station levels. For current, the current speed and direction have been compared to continuous measurements at the FEHY main stations. The acceptance criteria for current is that the difference between measured and modelled average current for a certain station in a certain level should be below 0.1 m/s and that the similar difference between average current direction (inflow respectively outflow) should be below 10°. Finally for the general flow, the distribution of mean water discharges through the Little Belt, the Great Belt and the Sound was compared to literature values.

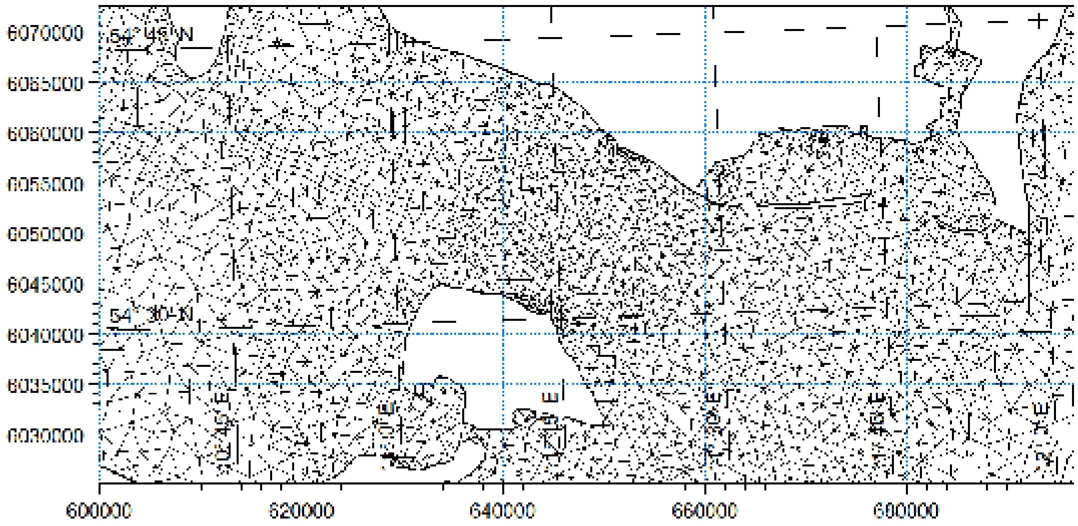

Figure 7.4-4 **Detail of FEHY local model mesh**

For the purpose of the FEMM analyses, FEHY local model run No. 9.15 and 11.20 have been applied. The FEHY local model is documented in the MIKE Local Model Calibration and Validation Report (FEHY, 2013b).

7.4.3.4. The Fehmarnbelt Water Forecast Hydrodynamic Model

This model is established by FEHY for the purpose of providing Femern A/S with forecasts of water level, current, salinity and water temperature in the Fehmarnbelt area. The model is established as a combination of the FEHY regional and local models, i.e. with the model area and regional resolution of the FEHY regional model, but with the local resolution from Kattegat to Bornholm of the FEHY local model. It is a 3D hydrodynamic model based on the MIKE 3 FM modelling system.

The model bathymetry is shown in Figure 7.4-5. The bathymetry is based on the same datasets as the FEHY regional and local models. In the Fehmarnbelt area, the model has a horizontal resolution of down to 1 km and a vertical resolution of 1 m (less at water depths below 10 m).

The model is forced by open boundary conditions in Skagerrak, by meteorological forcing and by freshwater runoff; again the same datasets as used by the FEHY models are used.

Similarly to the two other models, the model output consists of temporally and spatially varying fields of water level, currents, water temperature, salinity and density. The simulation time step is 1800s and the model output applied for the FEMM analyses is saved every 180 minutes.

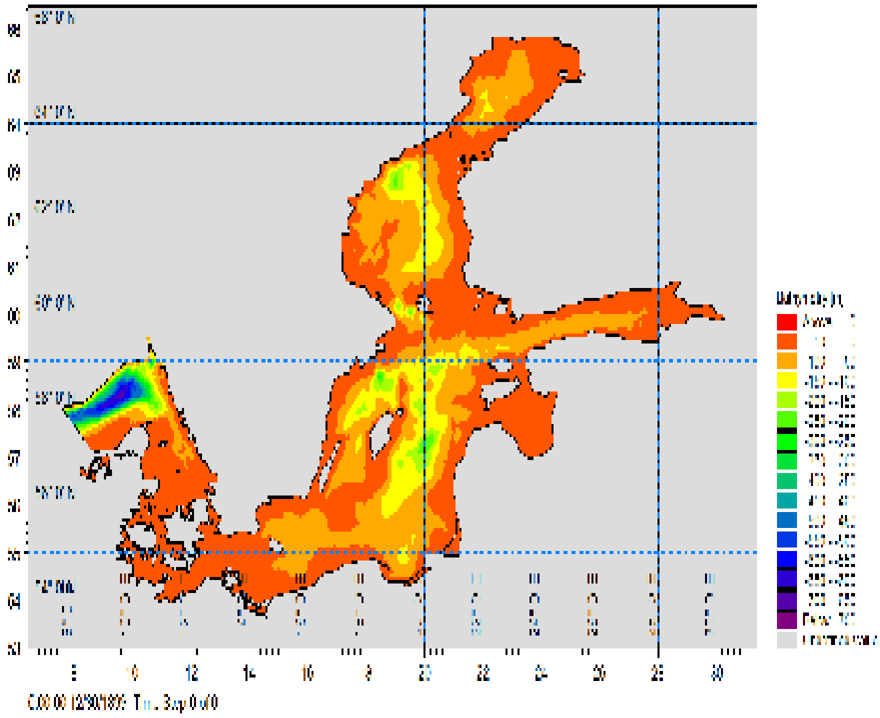

Figure 7.4-5 **Bathymetry of Fehmarnbelt water forecast model**

The calibration period of the Fehmarnbelt water forecast model is the year 2005 and the validation period is the period 1 June 2010 – 1 Jan 2011. Furthermore the model has run operationally (in forecast mode) from 1 Nov 2010. For the purpose of the FEMM analyses model results from July – Dec 2010 have been applied.

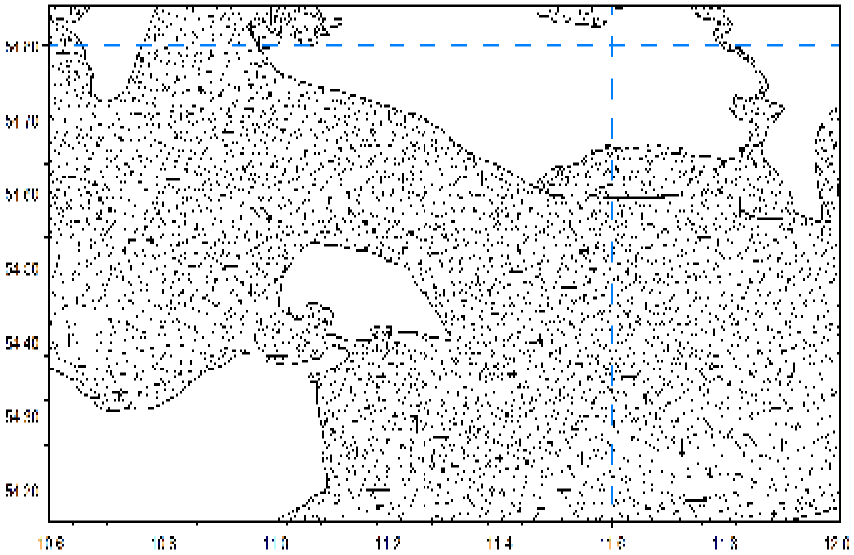

Figure 7.4-6 **Detail of Fehmarnbelt water forecast model mesh**

For the purpose of the FEMM analyses, Fehmarnbelt water forecast model run No. 06 and 07 have been applied. The Fehmarnbelt water forecast model is documented in the Water Forecast Service 2010 Performance Report (FEHY, 2013).

7.4.3.5. Combining Results from the FEHY Local Model and the Fehmarnbelt Water Forecast Model

7.4.3.5.1. Introduction

In order to obtain a set of hydrographic variables covering the period 2009-2010 and having the same spatial resolution, it was decided to combine the results from the FEHY local model and the Fehmarnbelt Water Forecast model. The present section describes the rationale for combining the results of the two models.

7.4.3.5.2. Similarities and Differences

The Fehmarnbelt water forecast model has been established to resemble a combination of the FEHY local and regional models. This goes for:

- Modelling system;
- Model coverage;
- Model bathymetry;
- Model resolution;
- Model forcings;
- Model calibration factors.

With respect to modelling system, both models are based on the MIKE 3 FM modelling system. This means that the hydrodynamic model engine in terms of physics, mathematics, numerics, parameterisations, etc., is the same for the two models.

As can be seen in Figure 7.4-3 and Figure 7.4-5 the two models cover different areas. However since the FEHY local model receives open boundary conditions from an encompassing regional model, it may be said that the FEHY local model and the Fehmarnbelt water forecast model both include the effect of the same model area, which is the area from Skagerrak to the Baltic Sea. This may be taken even further, since the FEHY regional model and the Fehmarnbelt water forecast model both receive open boundary conditions in the Skagerrak from an even larger encompassing North Sea model, which means that both the FEHY local model and the Fehmarnbelt water forecast model take into account the effect of the North Sea.

The model bathymetry of the two models is based on the same dataset, which is prepared by FEHY.

With respect to spatial resolution, the two models are similar but not identical. In Figure 7.4-4 and Figure 7.4-6 the two model meshes are shown in the Fehmarnbelt area. It is observed in the figures that the resolution of the two meshes is quite similar both with mesh sizes down to 0.5-1 km, except for a small area at each landfall where the FEHY local model resolution is increased to about 300 m.

Both models have identical vertical resolutions. In the Fehmarnbelt area both models have a resolution (layer thickness) of 1 m from the water surface to the bottom (less at water depths below 10 m).

With respect to model forcings, both models basically apply the same model forcings:

- Meteorological forcing from StormGEO;
- Open boundary conditions (see discussion above);
- Runoff.

With respect to runoff the FEHY local model applies data from SMHI's HBV runoff model. The operational Fehmarnbelt water forecast model, on the other hand, has for the period 1 June 2010 – 1 Jan 2011 used climatological monthly runoff data from the NOVANA programme.

Finally with respect to model calibration, the MIKE 3 FM model has the following calibration factors: bottom roughness, eddy viscosity, wind friction coefficient and dispersion factors for salinity and heat. These factors are the same for the FEHY local/regional models and for the Fehmarnbelt water forecast model.

7.4.3.5.3. Temporal Variability

Following the above discussion on general similarities of the two models, it may be inferred that the temporal variability of the results of the two models in the area of interest will be similar. This is due in particular to the similar modelling system, similar model forcings and similar model resolution of the two models. In order to illustrate the temporal variability of the model results, and how they compare to measurements, a few examples in terms of time series comparison plots are shown below.

In Figure 7.4-7, Figure 7.4-8, Figure 7.4-9 and Figure 7.4-10 comparisons of measured and modelled surface current at FEHY Main Station 01 (MS01) are shown. Figure 7.4-7 shows how the FEHY local model compares to measurements in July 2009 and Figure 7.4-8 similarly shows how the Fehmarnbelt water forecast model (FB-WF model) compares in July 2010. Figure 7.4-9 and Figure 7.4-10 show similar comparisons for Oct 2009 and Oct 2010, respectively. It is observed in the figures that the current comparison is reasonably good both for current speed and current direction and both for the FEHY local model and for the Fehmarnbelt water forecast model. The temporal variability is also observed in the two figures to be similar for the two models. In Table 7.4-1 the FEHY quantitative measures for the shown surface currents are given. The FEHY compliance criteria state that the difference (Δ) between average measured and average modelled current speed and direction for a certain period should be below 0.1 m/s and 10°, respectively. The criteria are seen, in the table, to be met by both the FEHY local model and the Fehmarnbelt WF model for the periods in question.

In Figure 7.4-11 comparisons of measured and modelled water temperature and salinity at MS01 are shown. Both surface values and bottom values are shown. Notice in the figure that the FEHY local model covers until 1 June 2010 and that the Fehmarnbelt water forecast model (FB-WF model) covers the remaining period. Also this figure shows that the comparison between measured and modelled data is reasonably good, with a correct representation of the annual cycle and also a good representation of the differences between surface and bottom (stratification). It is also noticed that the temporal variability of the two models is similar. In Table 7.4-2 the FEHY quantitative measures for the shown salinity and temperature are given. The FEHY compliance criteria state that the bias and the root mean square error (RMSE) between measured and modelled salinity and temperature for a certain period should be below 1PSU/1°C and 3PSU/2°C, respectively, for 80% of the levels. The criteria for the shown data are seen, in the table, to be met by the FEHY local model and nearly met by the Fehmarnbelt WF model for the periods in question.

Since the plots below may be regarded as representative with respect to the comparability of the two models, it is concluded that the temporal variability (and comparability to measurements) of the two models is similar. Notice that the above mentioned variables have been chosen as examples since they are direct model output and because they represent well the hydrographic variables used by FEMM.

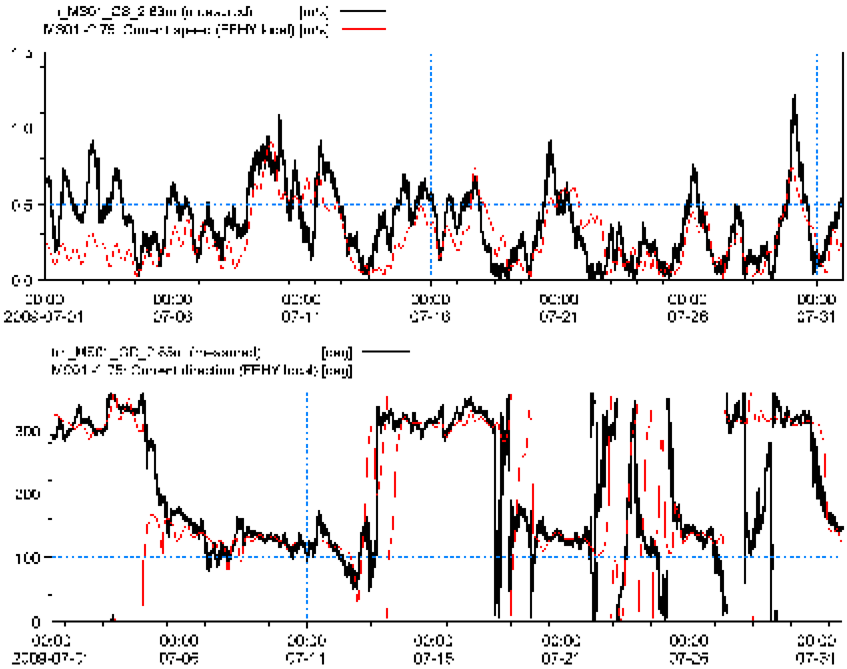

Figure 7.4-7 **Comparison of measured and modelled (FEHY local model) surface current speed (upper) and direction (lower) at MS01 during July 2009**

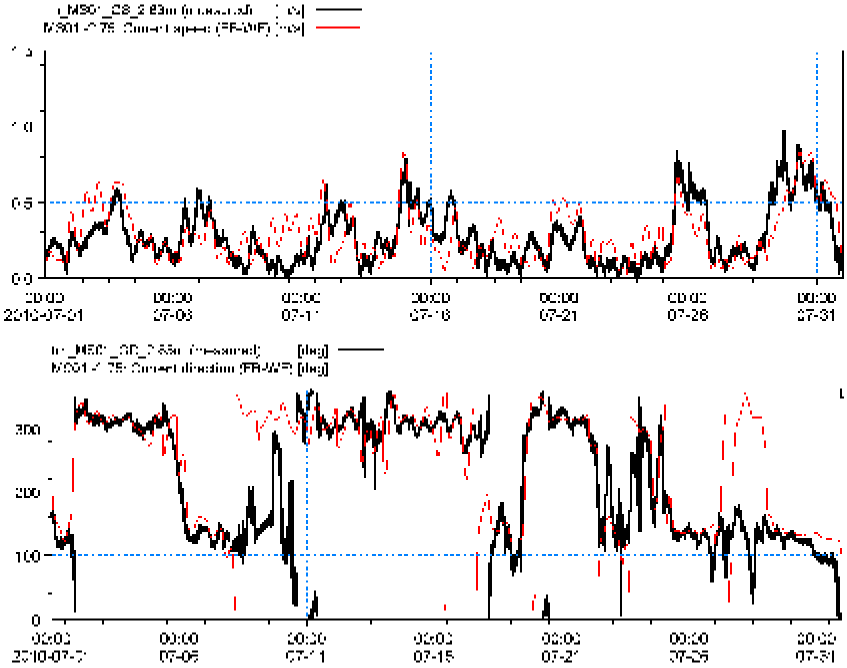

Figure 7.4-8 **Comparison of measured and modelled (Fehmarnbelt WF model) surface current speed (upper) and direction (lower) at MS01 during July 2010.**

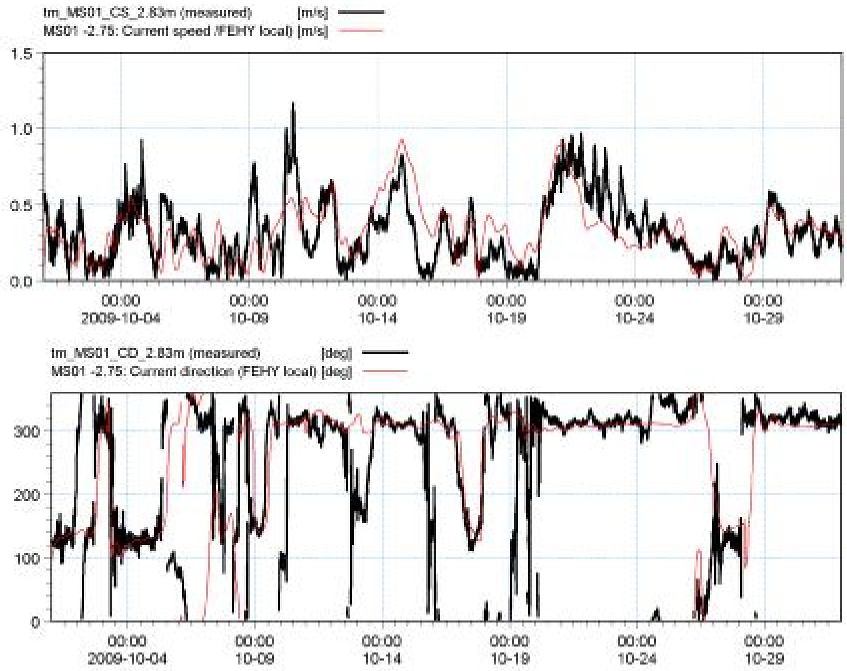

Figure 7.4-9 Comparison of measured and modelled (FEHY local model) surface current speed (upper) and direction (lower) at MS01 during Oct 2009

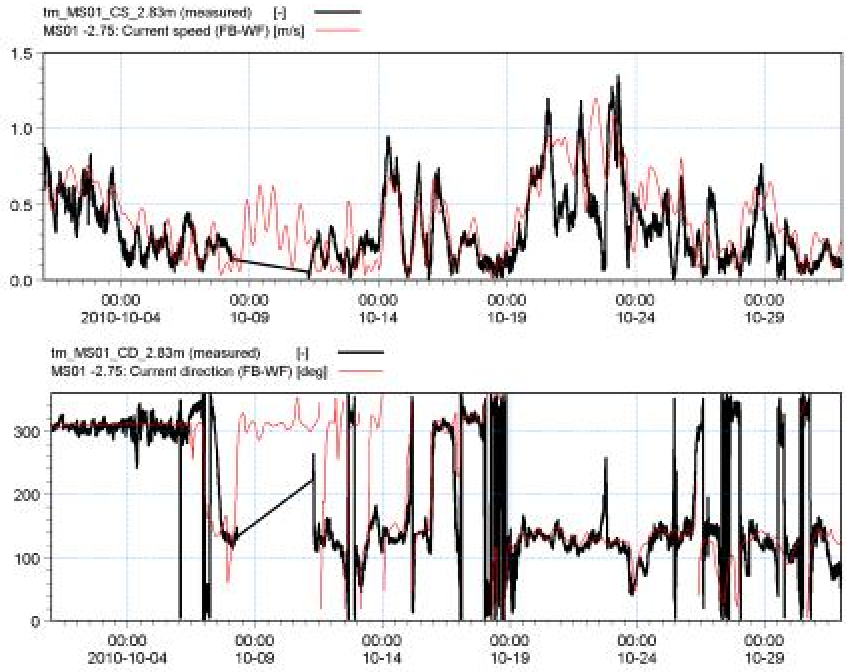

Figure 7.4-10 Comparison of measured and modelled (Fehmarnbelt WF model) surface current speed (upper) and direction (lower) at MS01 during Oct 2010

Table 7.4-1 **FEHY quantitative measures for the shown surface current speed (CS) and direction (CD) at MS01**

Model	Period	Diff Avg CS (Δ < 0.1m/s)	Diff Avg CD (Δ < 10°)
FEHY local model	July 2009	-0.02	3.2
	Oct 2009	-0.06	7.6
Fehmarnbelt WF model	July 2010	0.09	8.3
	Oct 2010	-0.01	3.5

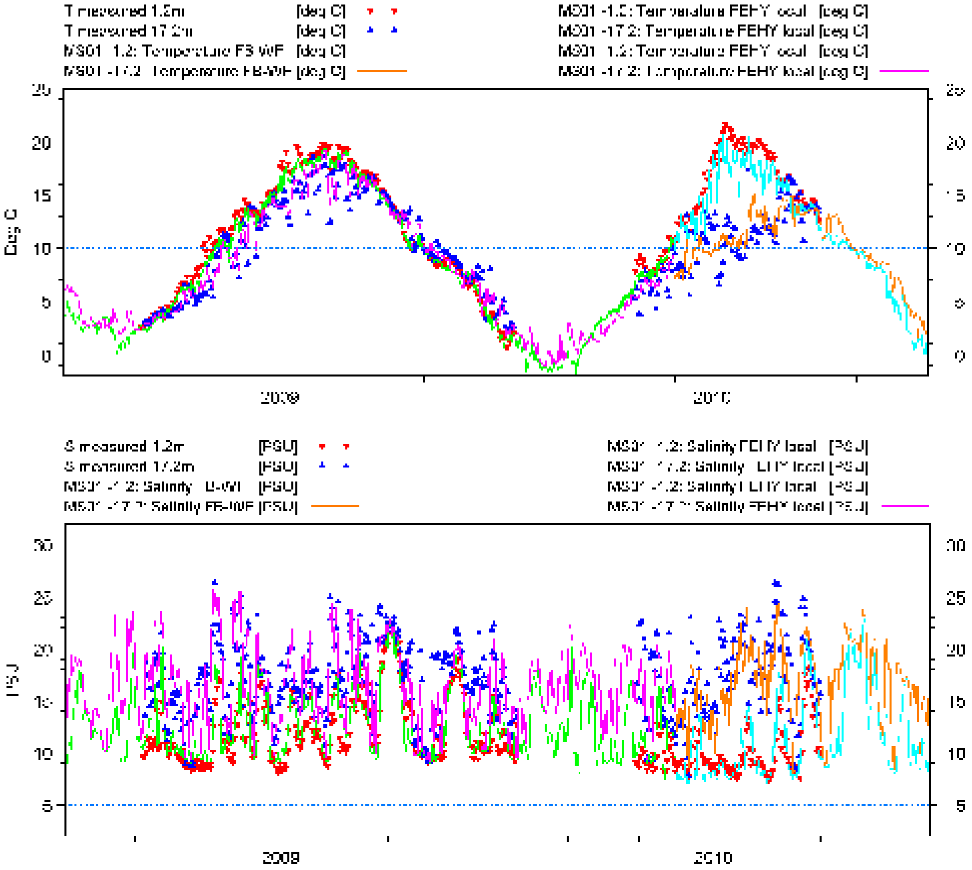

Figure 7.4-11 **Comparison of measured and modelled water temperature (upper) and salinity (lower) at MS01 during the period 2009-2010. Notice that both surface (1.2m) and bottom (17.2m) values are included. Notice that some measurements are missing due to gaps (ice problems) in the database of the Fehmarnbelt Data Handling Centre.**

Table 7.4-2 **FEHY quantitative measures for the shown surface and bottom salinity and temperature at MS01**

Model/period	Depth of sensor	Salinity		Temperature	
	(m)	Bias (<1PSU)	RMSE (<3PSU)	Bias (<1°C)	RMSE (<2°C)
FEHY local model (June-Sep 2009)	1.2	0.39	1.35	-0.48	0.71
	17.2	-0.96	2.22	0.38	1.03
Fehmarnbelt WF model (June-Sep 2010)	1.2	0.33	1.55	-1.44	1.83
	17.	-0.56	2.60	-0.29	1.79

7.4.3.5.4. Spatial Variability

Following the above discussion on general similarities of the two models (Section 7.4.3.5.2), it may also be inferred that the spatial variability of the results of the two models in the area of interest will be similar. This is due in particular to the similar model resolution of the two models within the Fehmarnbelt area.

In Figure 7.4-12 and Figure 7.4-13 examples of instantaneous surface salinity and current from the two models during arbitrary outflow and inflow events, respectively, are shown. Please notice that the instantaneous fields are very variable and that the examples shown are just snapshots and not in any way representative for the total spatial variability. However the figures illustrate well that both models have high spatial variability and that no one model appears to have more variability than the other.

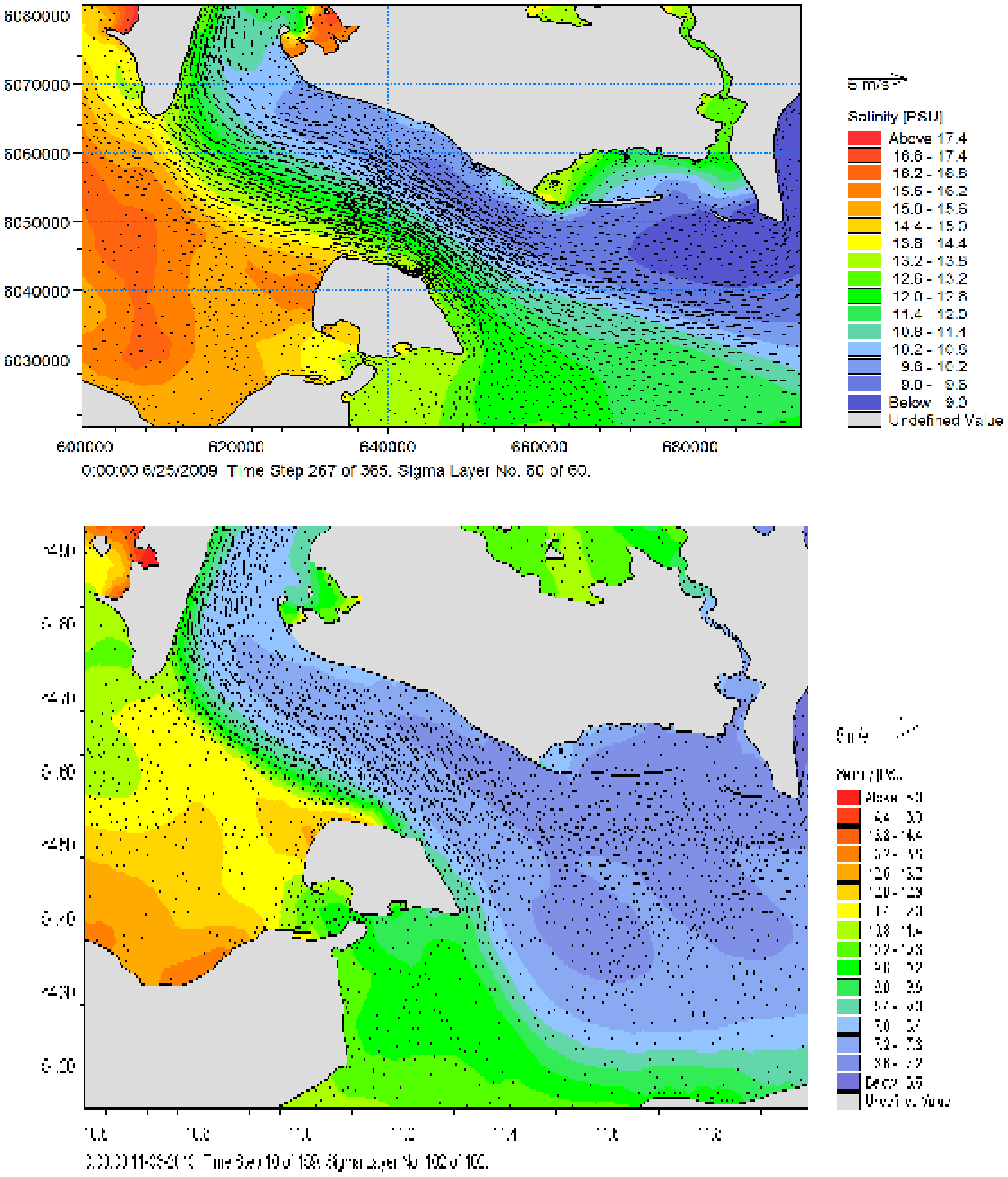

Figure 7.4-12 **Examples of instantaneous outflow surface salinity (colours) and current (vectors) in the Fehmarnbelt area from the FEHY local model (upper) and the Fehmarnbelt water forecast model (lower)**

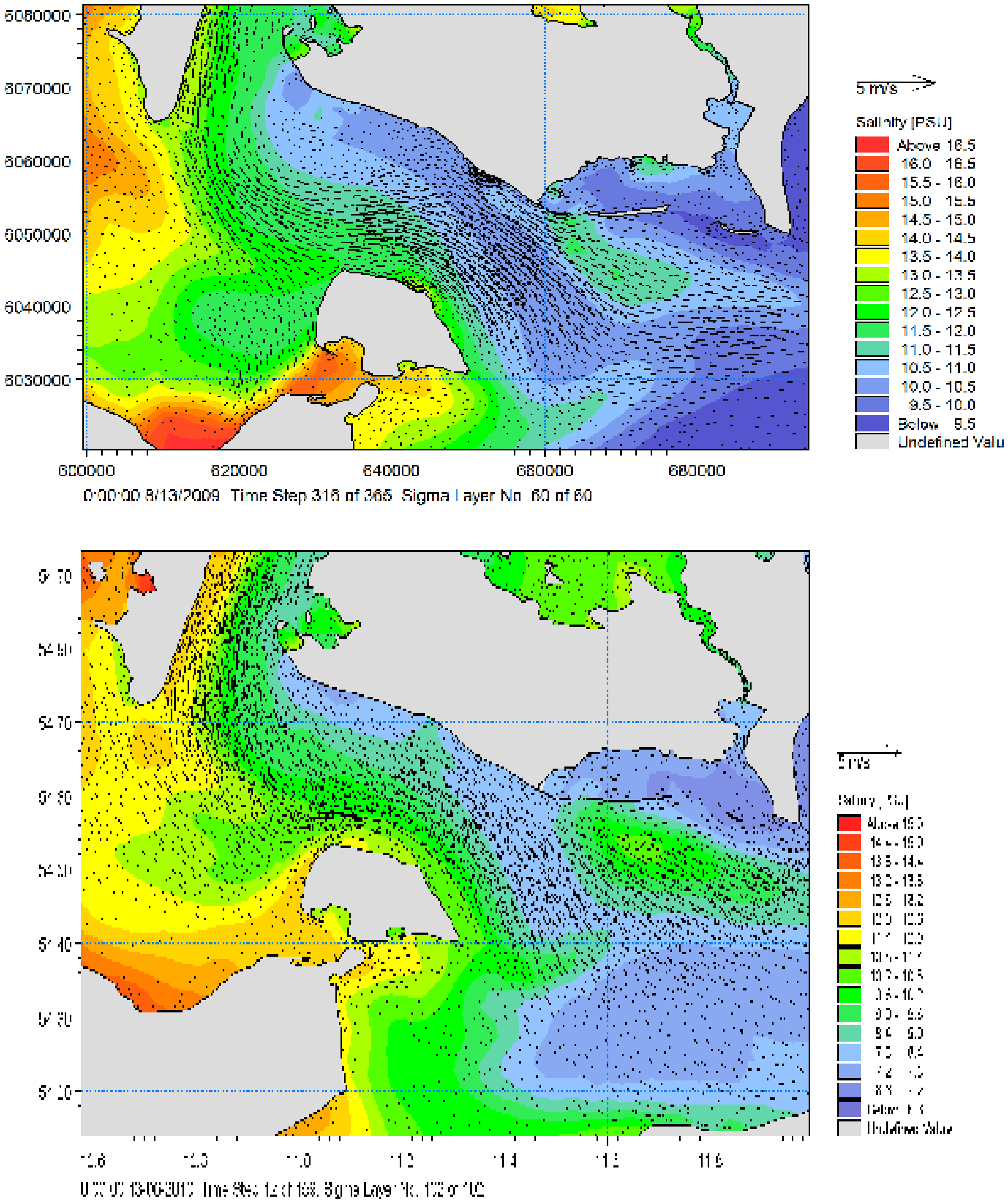

Figure 7.4-13 **Examples of instantaneous inflow surface salinity (colours) and current (vectors) in the area of interest from the FEHY local model (upper) and the Fehmarnbelt water forecast model (lower)**

7.4.3.5.5. Discussion

Because of the many similarities of the two models, including the same hydrodynamic engine, the same bathymetry and resolution and the same (or similar) model forcings, it is concluded that the FEHY local model and the Fehmarnbelt water forecast model are very similar in the Fehmarnbelt area. As a result of these many similarities, the two models will be able to describe the same hydrodynamic processes and hence demonstrate the same variability in the results.

Based on the above discussion it is therefore concluded that hydrographic data extracted from the Fehmarnbelt water forecast model will be equally suitable for the FEMM analyses as are the data from the FEHY local model. Furthermore the data from the Fehmarnbelt water forecast model are very similar in terms of quality and variability to the data from the FEHY local model, so much so that it will be justified to combine the two datasets for the purpose of covering the whole two-year period 1 Jan 2009 to 1 Jan 2011. This is valid for both the direct model output variables such as current and salinity, but also for the derived (calculated) variables such as current gradient and vorticity.

7.4.4. Processing of Hydrographic Variables

7.4.4.1. Introduction

For the FEMM data analyses both hydrographic variables, which are direct model output, and hydrographic variables, which are calculated on the basis of model output, have been applied. The variables calculated on the basis of the direct model output are in the following called ‘derived’ variables.

The hydrographic variables have been extracted for both the surface layer and for the bottom layer. In order to process the variables and calculate the derived variables, the unstructured result files (based on flexible mesh) from the model simulations have been interpolated to a structured 3D Cartesian grid. This grid has a resolution of 500 m horizontally/1 m vertically for the FEHY local model results/Fehmarnbelt WF model results, and 2 km horizontally/1 m vertically for the FEHY regional model results. Based on these grids, the variables have been extracted and the derived variables have been calculated and extracted.

Having calculated and extracted the surface and bottom hydrographic variables, they have been integrated with the FEMM field datasets, such that every observation (or aggregate observation) has been assigned a value of each of the hydrographic variables corresponding to the position and time of the observation. Having integrated the FEMM field data and the hydrographic variables (and the additional static variables), the datasets have been applied for the subsequent FEMM data analyses.

For some of the FEMM field datasets, so called prediction grids have been prepared in addition to the integrated datasets. The prediction grids consist of an interpolation to a certain grid (typically a 750m grid has been applied) of selected temporally averaged hydrographic variables. The averaging periods depend on the specific analysis.

In the following sections the different hydrographic variables applied and their processing are described.

7.4.4.2. Current Velocities

7.4.4.2.1. Description

The vector components (U, V and W) in the East, North and vertical direction (positive upwards) have been applied. These are direct output from the hydrodynamic models. Also the current speed or magnitude (CS) is a direct output from the model. The unit for these current-related variables is m/s.

These variables have in common that they are highly variable both in time and space. During an inflow event, the U component may have high positive values in the Fehmarnbelt area, while during outflow it may have equally high negative values. On the other hand, averaging over an inflow and an outflow event may yield a very low average U value.

The current velocities vary with inflow/outflow events, but they also vary on a smaller scale as a result of bathymetry, wind effects, stratification, etc. Generally the current velocities are higher in the surface layer than in the bottom layer.

The vertical velocity W is in this context used as a measure of the local upwelling (positive W) or downwelling (negative W). Similarly to most other hydrographic variables, this variable has been extracted in the surface layer and in the bottom layer, but additionally it has been extracted in 10 m depth. This is due to the fact that the magnitude or trend of the variable sometimes seems to be stronger away from the surface and bottom.

Typical examples of temporal variation of surface current in the FEHY Main Station 01 as calculated by the FEHY local model and by the Fehmarnbelt WF model are shown in Figure 7.4-7, Figure 7.4-8, Figure 7.4-9, Figure 7.4-10.

Typical examples of surface currents during outflow and inflow as calculated by the FEHY local model and by the Fehmarnbelt WF model are shown in Figure 7.4-12 and Figure 7.4-13.

7.4.4.2.2. Data Integration and Prediction Grid

The current variables U, V, W and CS have been integrated with the various FEMM field datasets and prediction grids have been prepared. The specific prediction grids (variables and averaging periods) prepared and applied for each FEMM analysis is described under the reporting of that particular analysis.

In the following, examples of the averaged variables applied for the seal telemetry prediction grid are presented. The seal telemetry dataset covers the period from Oct 2009 to May 2010, and for the prediction grid the hydrographic variables were averaged over the same period. In Figure 7.4-14 and Figure 7.4-15 the averaged horizontal surface and bottom current components (U and V) are shown. In Figure 7.4-16 the averaged surface and bottom current speed (CS) is shown and in Figure 7.4-17 the averaged vertical current component (W) is shown. It is seen in the presented figures that there exist clear patterns in the averaged data.

Notably, it is observed in Figure 7.4-17 that the vertical current component seems to have the strongest signal in 10 m depth and the weakest signal in the surface.

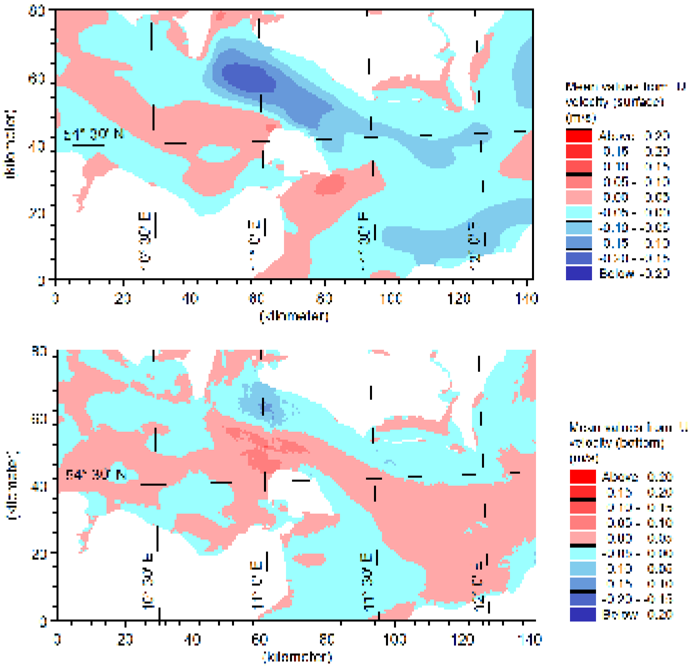

Figure 7.4-14 Mean U velocity component averaged from Oct 2009 to May 2010 in the surface layer (upper) and in the bottom layer (lower)

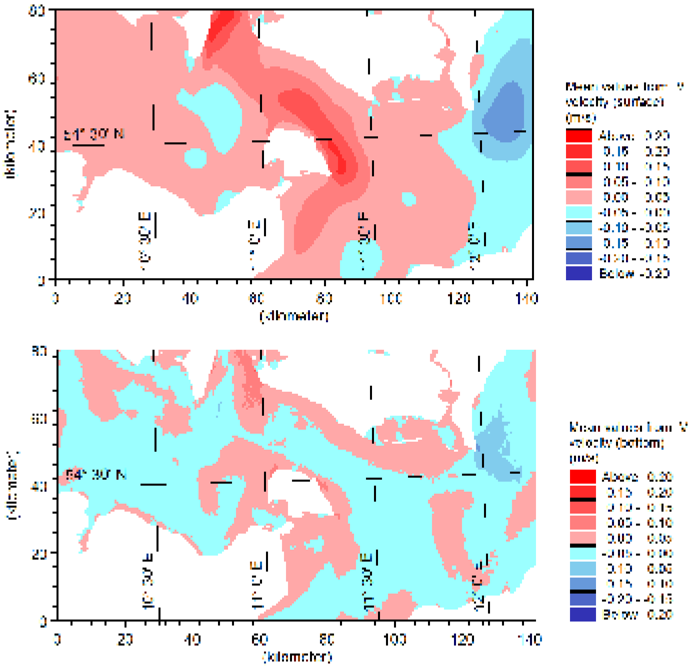

Figure 7.4-15 **Mean V velocity component averaged from Oct 2009 to May 2010 in the surface layer (upper) and in the bottom layer (lower)**

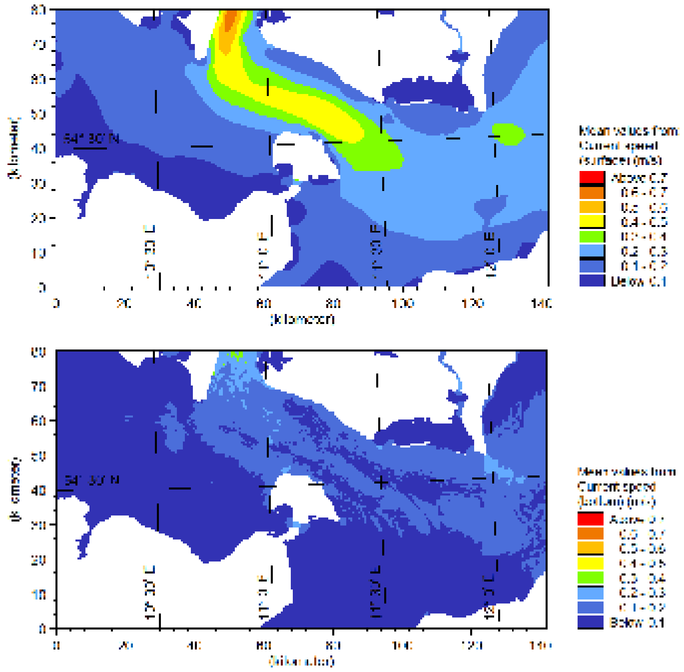

Figure 7.4-16 **Mean current speed CS averaged from Oct 2009 to May 2010 in the surface layer (upper) and in the bottom layer (lower)**

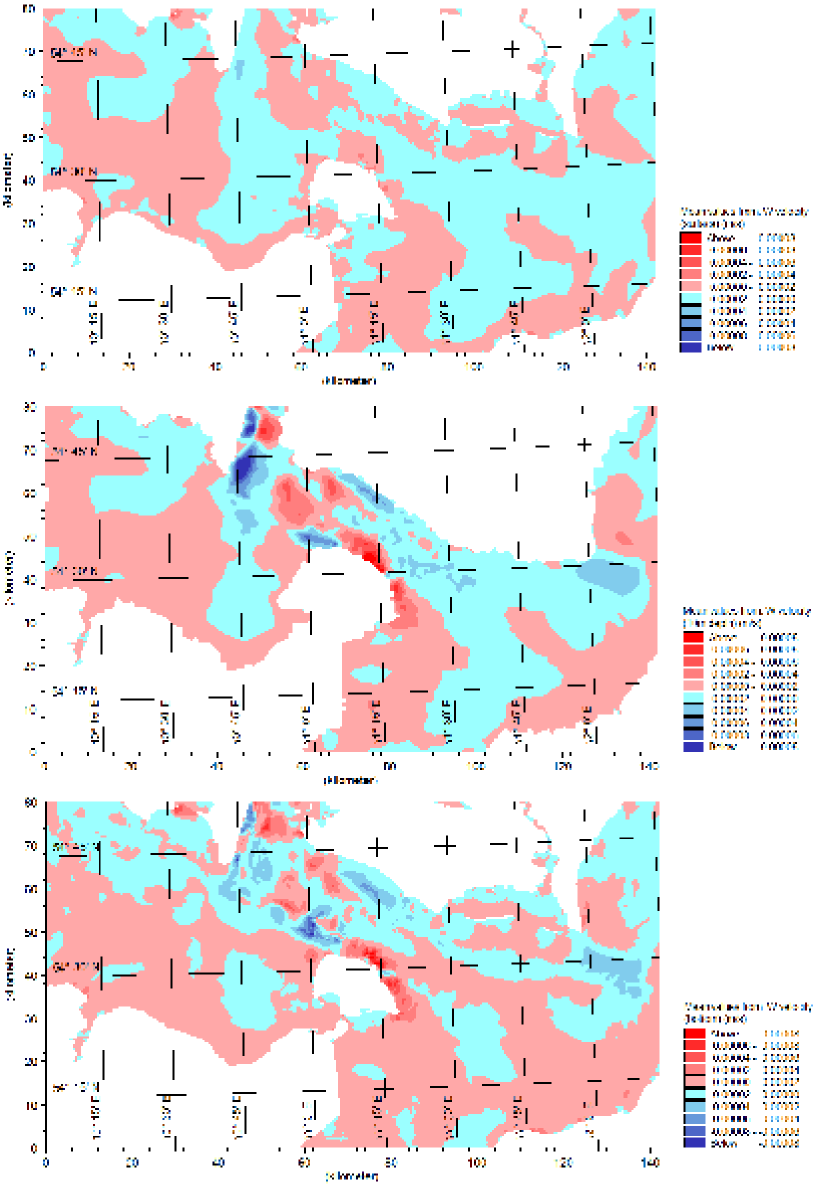

Figure 7.4-17 **Mean vertical velocity W averaged from Oct 2009 to May 2010 in the surface layer (upper), at 10m depth (middle) and in the bottom layer (lower). Notice that red colours represent upwelling and blue colours represent downwelling.**

7.4.4.3. Vorticity and Current Gradient

7.4.4.3.1. Description

The vorticity is a measure of the local rotation of the flow. It is calculated from the horizontal vector components U and V and is thus not a direct output from the model, but is calculated subsequently:

$$Vorticity = \frac{dV}{dx} - \frac{dU}{dy},$$

Where dx and dy are the horizontal grid spacings. The unit of the vorticity is m/s/m and the sign of the vorticity indicates whether the rotation of the flow is clockwise (negative vorticity) or anti-clockwise (positive vorticity). The magnitude of the vorticity indicates the strength of the rotation.

In the present context the vorticity is included as a measure of the eddy (or turbulence) potential in the flow. It is of course important to evaluate the calculated vorticity in relation to the spatial scale applied. For the local model the horizontal grid spacing dx is 500 m, which means that the horizontal scale of the calculated vorticity is in the order of 500-1000 m. For the regional model, the horizontal grid spacing applied is 2 km. It is thus not possible to directly compare the vorticities corresponding to the two quite different model resolutions. Similarly to the current velocities, the vorticity is highly variable in both time and space.

The current gradient is a measure of local gradients in the flow field. It is calculated from the horizontal vector components U and V and is thus not a direct output from the model, but is calculated subsequently:

$$Current\ Gradient = \left|\frac{dU}{dx}\right| + \left|\frac{dV}{dy}\right|,$$

Where dx and dy are the horizontal grid spacings. The unit of the current gradient is m/s/m. The current gradient as applied here may only be positive and the magnitude of the current gradient indicates the strength of the gradient.

In the present context the current gradient is included as a measure of the frontal strength in the flow. Similarly to the vorticity it is important to consider the horizontal scale of the current gradient. Similarly to the current velocities, the current gradient is highly variable in both time and space.

7.4.4.3.2. Data Integration and Prediction Grids

The vorticity and current gradient have been integrated with the various FEMM field datasets and prediction grids have been prepared. In the following, examples of the averaged variables applied for the seal telemetry prediction grid are presented. In Figure 7.4-18 and Figure 7.4-19 the averaged surface and bottom vorticity and current gradient are shown.

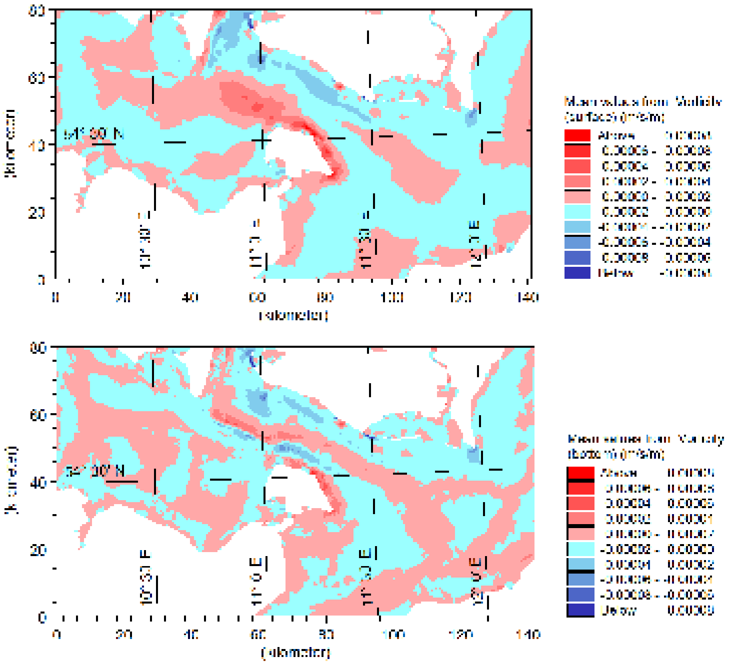

Figure 7.4-18 Mean vorticity averaged from Oct 2009 to May 2010 in the surface layer (upper) and in the bottom layer (lower)

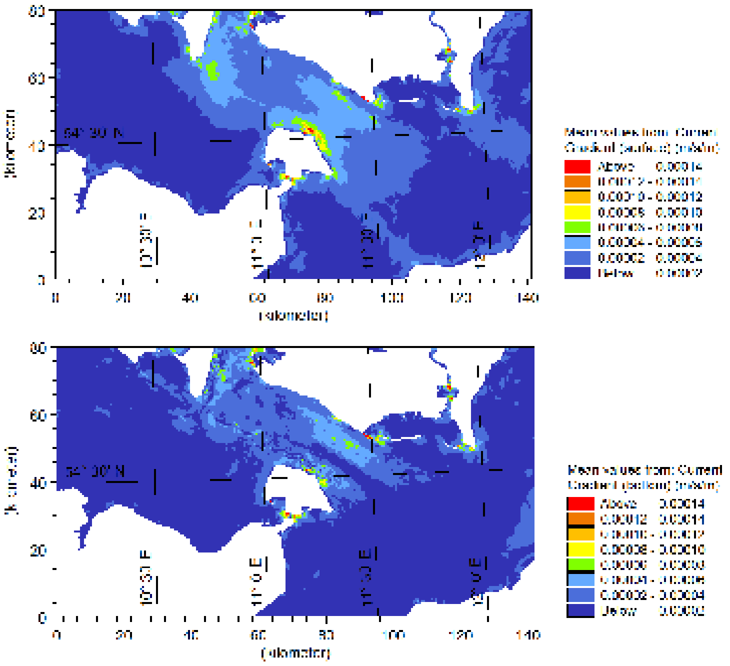

Figure 7.4-19 Mean current gradient averaged from Oct 2009 to May 2010 in the surface layer (upper) and in the bottom layer (lower)

7.4.4.4. Water Temperature, Salinity and Density

7.4.4.4.1. Description

The variation in time and space of the water temperature, salinity and density is a direct output of the model. Temperature (in °C) and salinity (in PSU), and the derived parameter density (in kg/m^3), represent important properties of the water, which affect both the water flow and the biological activity in the water.

There exists a pronounced salinity gradient from East to West in the Fehmarnbelt area due to the mixing of brackish Baltic Sea water and the saline North Sea water. Furthermore the density differences between brackish and saline water create a stratification of the water column, which is particularly pronounced in summer. Contrary to salinity, temperature follows a distinct seasonal pattern with warmer temperatures and thermal stratification of the water column in summer, and colder, well-mixed waters in winter.

In Figure 7.4-20 an example of the summer stratification of the water column in the Puttgarden-Rødbyhavn cross-section as modelled by the FEHY local model is shown.

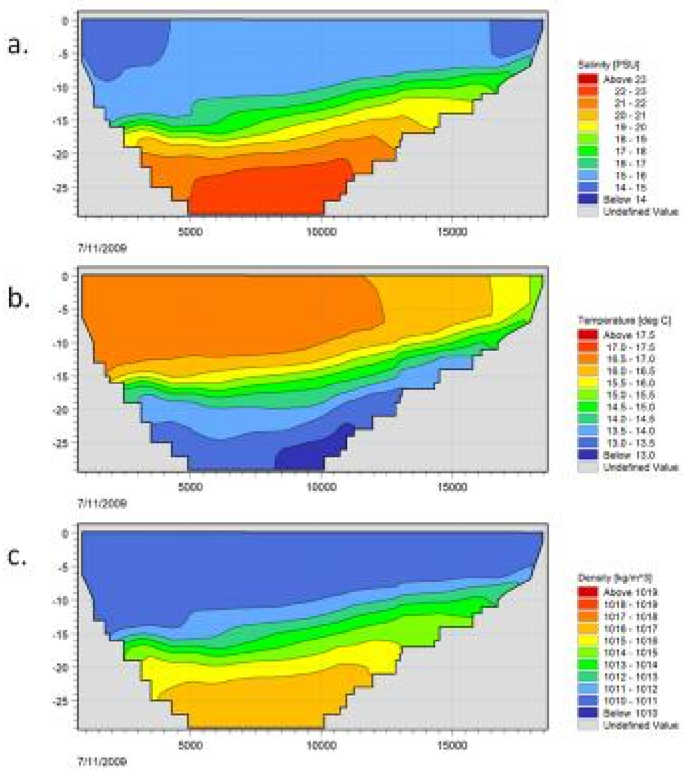

Figure 7.4-20 Snapshots of modelled (a) salinity, (b) temperature and (c) density in the Puttgarden-Rødbyhavn vertical cross-section

An illustrative example of the temporal variation of water temperature and salinity in the FEHY main Station 01 as calculated by the FEHY local model and by the Fehmarnbelt WF model are shown in Figure 7.4-11. This figure shows the temporal variation in the surface and bottom layer during 2009 and 2010. The figure illustrates the annual variation of the water temperature and the stratification of the water column (observed as differences between surface and bottom values), which is more pronounced in summer.

The spatial and temporal variability of the water temperature, salinity and density is lower than for the current velocity and the current velocity derived variables. Figure 7.4-12 and Figure 7.4-13 show examples of the instantaneous spatial variability of the surface salinity.

7.4.4.4.2. Data Integration and Prediction Grids

Water temperature, salinity and density have been integrated with the various FEMM field datasets and prediction grids have been prepared.

In the following, examples of the averaged variables applied for the seal telemetry prediction grid are presented. In Figure 7.4-21, Figure 7.4-22 and Figure 7.4-23 the averaged surface and bottom water temperature, salinity and density are shown. For water temperature it is observed in the figure that the average temperatures are relatively low. This is due to the fact that the averaging period is mainly a winter period. Notice also the gradient in surface salinity and density from East to West.

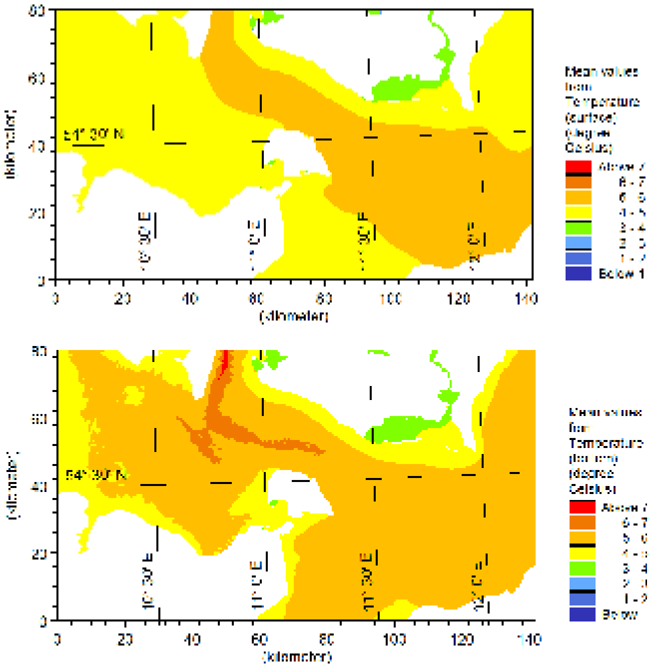

Figure 7.4-21 **Mean water temperature averaged from Oct 2009 to May 2010 in the surface layer (upper) and in the bottom layer (lower)**

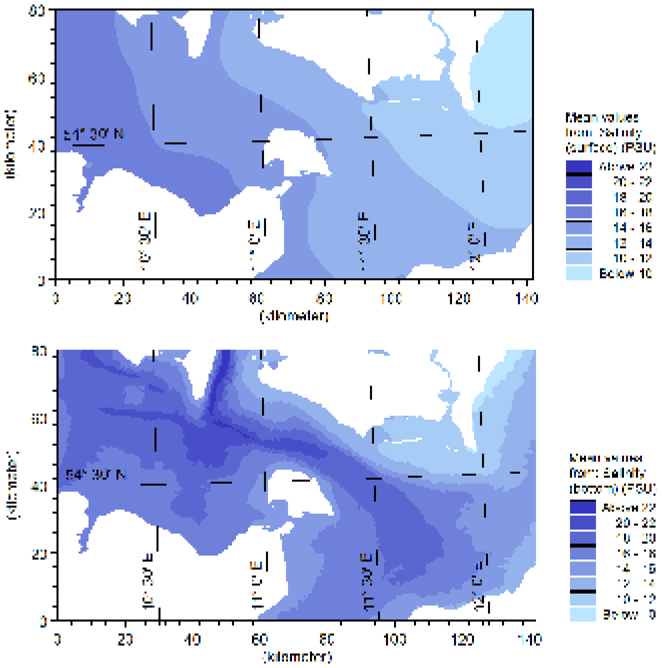

Figure 7.4-22 Mean salinity averaged from Oct 2009 to May 2010 in the surface layer (upper) and in the bottom layer (lower)

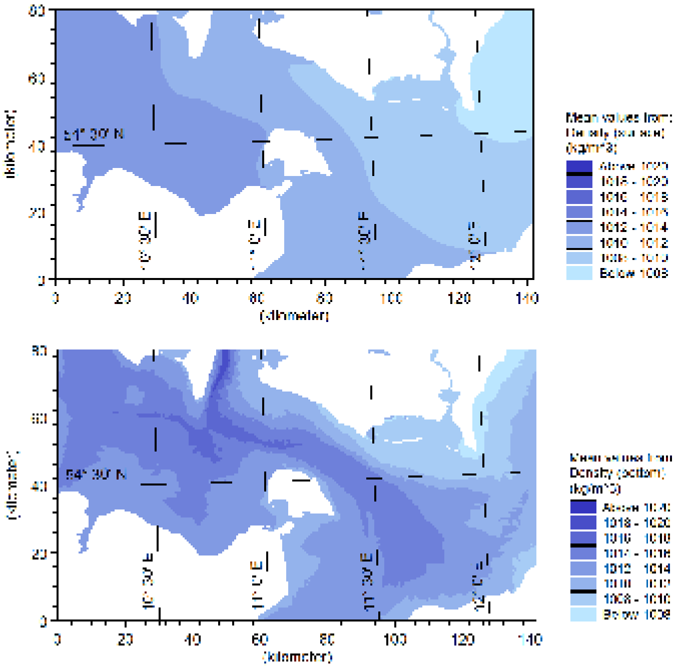

Figure 7.4-23 Mean water density averaged from Oct 2009 to May 2010 in the surface layer (upper) and in the bottom layer (lower)

7.4.4.5. Stratification of the Water Column

7.4.4.5.1. Description

As a measure of the stratification of the water column, the strength and depth of the pycnocline were calculated using Brunt-Vaisala frequencies. At a certain location at a certain time, the magnitude of the maximum Brunt-Vaisala frequency squared, N^2, is calculated as:

$$N^2 = -\frac{g}{\delta_0}\frac{d\delta}{dz},$$

Where g is gravity, δ_0 is a reference water density, δ is local water density and dz (=1 m) is the vertical grid spacing. The unit of the maximum Brunt-Vaisala frequency squared is s^{-2}. The Brunt-Vaisala frequency is a measure of the local stability of the water column; the higher the Brunt-Vaisala frequency the stronger the local stratification.

In this context the Brunt-Vaisala frequency is included as a measure of the strength of the stratification. Furthermore, if the maximum strength is above a certain threshold (set at 0.005 s^{-2}), the depth (in m) of the pycnocline is determined as the depth, where the Brunt-Vaisala frequency is highest (maximum Brunt-Vaisala). In this way horizontally as well as temporally varying strengths and depths of the pycnocline has been determined. Figure 7.4-24 shows an example of the variation of the Brunt-Vaisala frequency over the water column in the Puttgarden-Rødbyhavn cross-section.

In Figure 7.4-25 the temporal variation of the calculated pycnocline depth and strength at the location of the FEHY Main Station 02 (MS02) are shown. The MS02 station is located in the deeper part of the Fehmarnbelt on the alignment between Puttgarden and Rødbyhavn. It is observed in the figure that the pycnocline generally is stronger in summer and that the depth is missing when the strength is below 0.005s^{-2}.

It is important to note that the pycnocline variables are more relevant in deeper water larger than say 15 m. This is due to the fact that the pycnocline is typically located in 15-20 m depth. In more shallow water the pycnocline will still reflect the stratification of the water column, but it will typically be a weaker and less frequent stratification.

Similar to the water temperature, salinity and density, the spatial and temporal variability of the stratification variables is lower than for the current velocity, but contrary to the current velocities they have a marked seasonal variation.

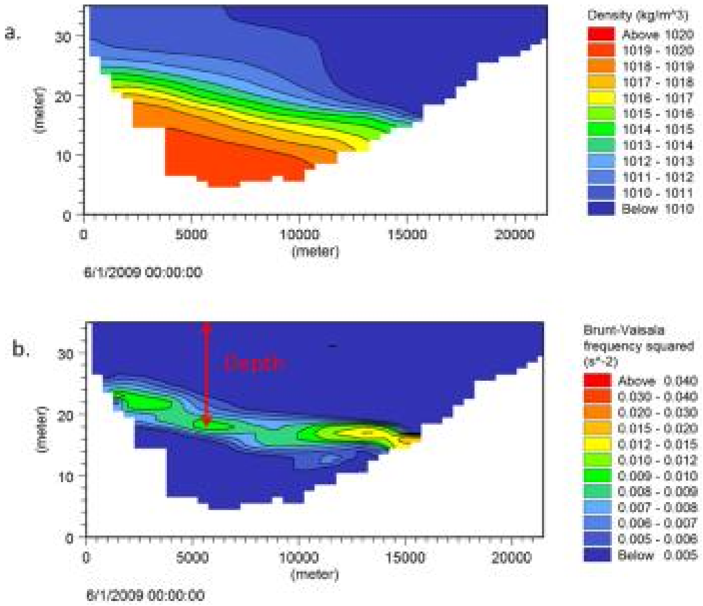

Figure 7.4-24 Snapshot of (a) modelled density and (b) calculated Brunt-Vaisala frequency in the Puttgarden - Rødbyhavn cross-section. The depth of the pycnocline is indicated in panel b

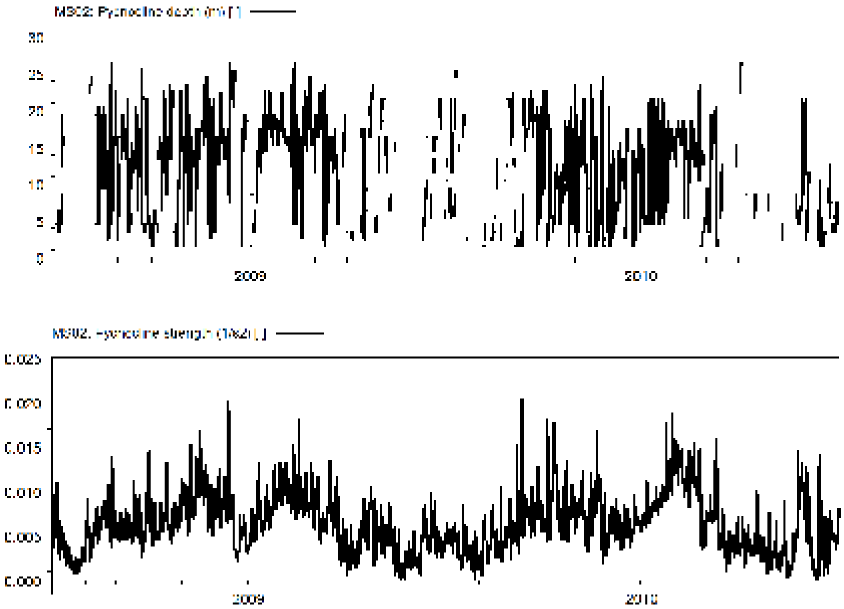

Figure 7.4-25 Temporal variation of calculated pycnocline depth (upper) and strength (lower) at MS02

7.4.4.5.2. Data Integration and Prediction Grids

The pycnocline depth and strength have been integrated with the various FEMM field datasets and prediction grids have been prepared. In the following, an example of the averaged variables applied for the seal telemetry prediction grid is presented. In Figure 7.4-26 the applied averaged depth and strength of the pycnocline are shown. Notice that the pycnocline depth has only been calculated when the strength was above 0.005 s^{-2}, which means that the average depth applied is an average over periods of pronounced stratification.

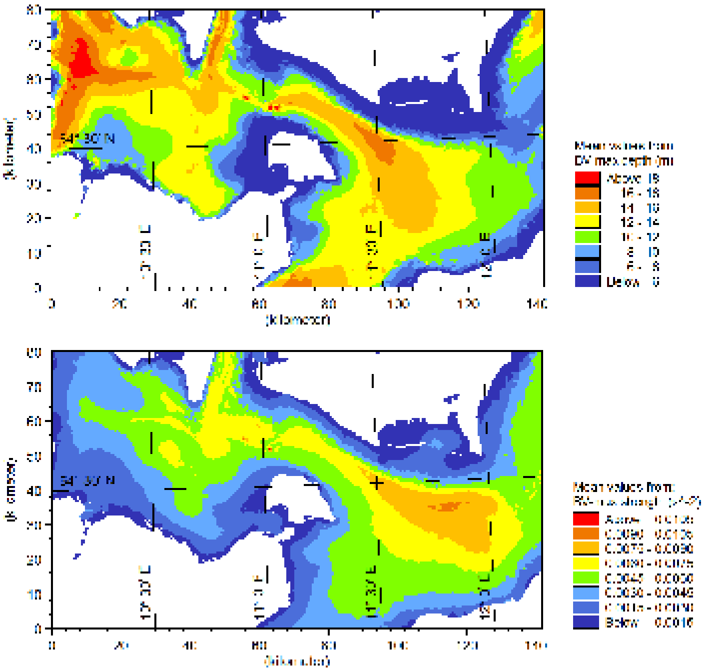

Figure 7.4-26 **Mean depth (upper) and strength (lower) of the pycnocline averaged from Oct 2009 to May 2010**

7.4.4.6. Salinity Discharge

7.4.4.6.1. Description

The final hydrographic variable, which originates from the hydrodynamic model, is the instantaneous salt discharge (or flux) across the Puttgarden-Rødbyhavn cross-section. This variable is a direct output from the model, but it consists of the integrated discharge (in kg/s) of salt over all the grid points along the cross-section. In this way the salt discharge represents the total net amount of salt that is transported across the line between Puttgarden and Rødbyhavn at any time.

In the present context the salt discharge is included as a measure of events of inflow and outflow from the Baltic Sea. A positive salt discharge represents outflow from the Baltic Sea through the cross-section and a negative salt discharge represents inflow to the Baltic Sea.

The magnitude of the salt discharge is a measure of the strength of these inflow/outflow events.

In Figure 7.4-27 the variation of the total salt discharge is shown as calculated by the FEHY local model and the Fehmarnbelt WF model. The figure illustrates the high variability of the duration and strength of inflow and outflow events. It is observed in the figure that inflow or outflow events may last from 1-2 days to 7-10 days and that the strength of the events also varies considerably.

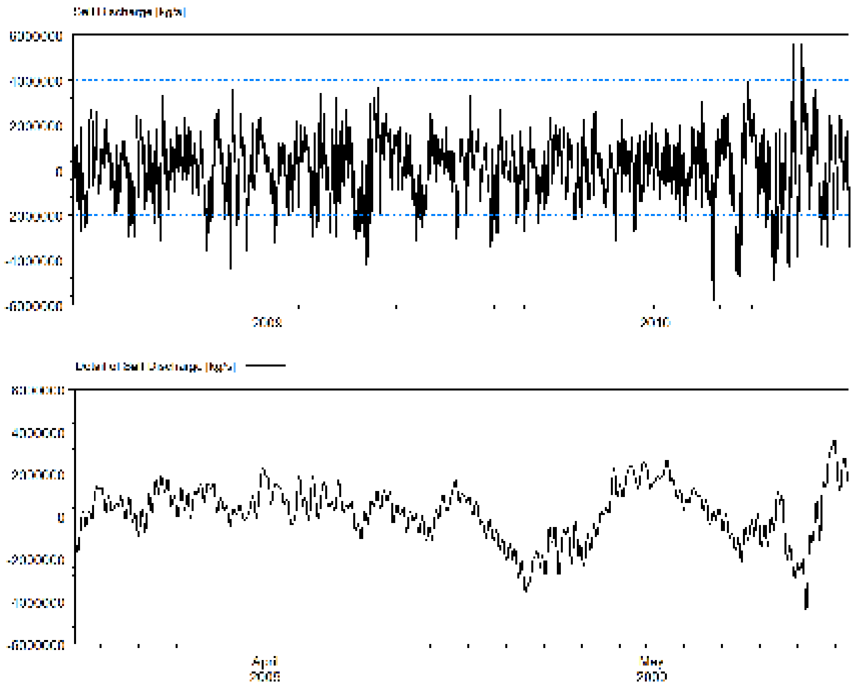

Figure 7.4-27 **Time series plots of the modelled (FEHY local model and Fehmarnbelt WF model) total salt discharge (outflow is positive; inflow is negative) across the Puttgarden-Rødbyhavn cross-section during 2009-2010 (upper) and during a 2-months period in 2009 (lower)**

7.4.4.6.2. Data Integration and Prediction Grids

The salt discharge has been integrated with the FEMM field datasets. Because the salt discharge is not spatially varying (but is integrated over the cross-section), no prediction grids have been established for this variable.

7.4.5. References

FEHY (2013). FEHMARNBELT FIXED LINK HYDROGRAPHIC SERVICES, Water Forecast Service 2010 Performance Report, December 2010 (ATR ENV010025)

FEHY (2013a). FEHMARNBELT FIXED LINK HYDROGRAPHIC SERVICES, Hydrodynamic and water quality modelling, MIKE Regional Model Calibration and Validation (ATR ENV010012)

FEHY (2013b). FEHMARNBELT FIXED LINK HYDROGRAPHIC SERVICES, Hydrodynamic and water quality modelling, MIKE Local Model Calibration and Validation (ATR ENV010012)

7.5. Appendix 5

PAMS

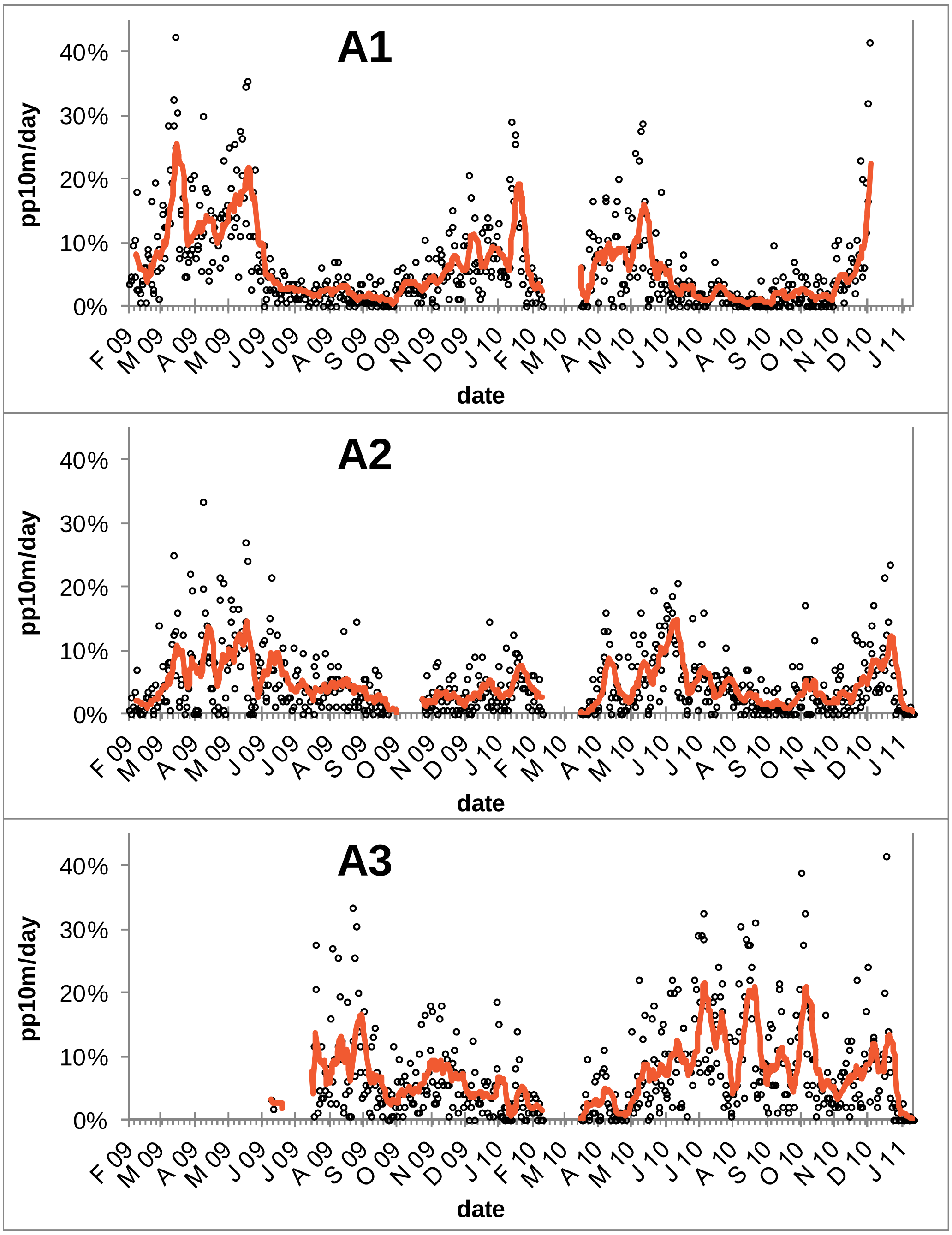

Figure 7.5-1 Plot of pp10m/day against time for two single POD stations from area W. The red line shows the moving average for 10 days.

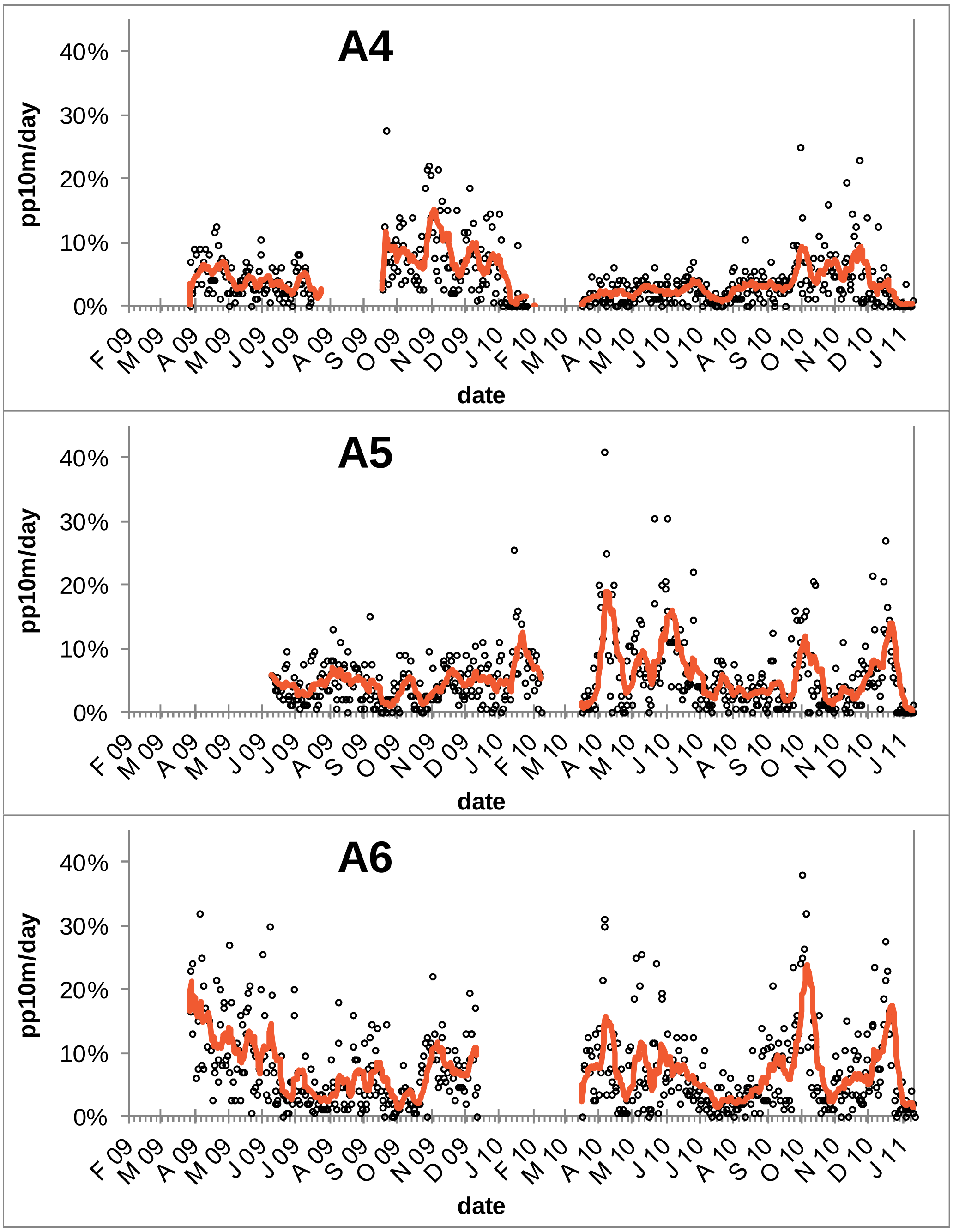

Figure 7.5-2 **Plot of pp10m/day against time for two single POD stations from area W. The red line shows the moving average for 10 days.**

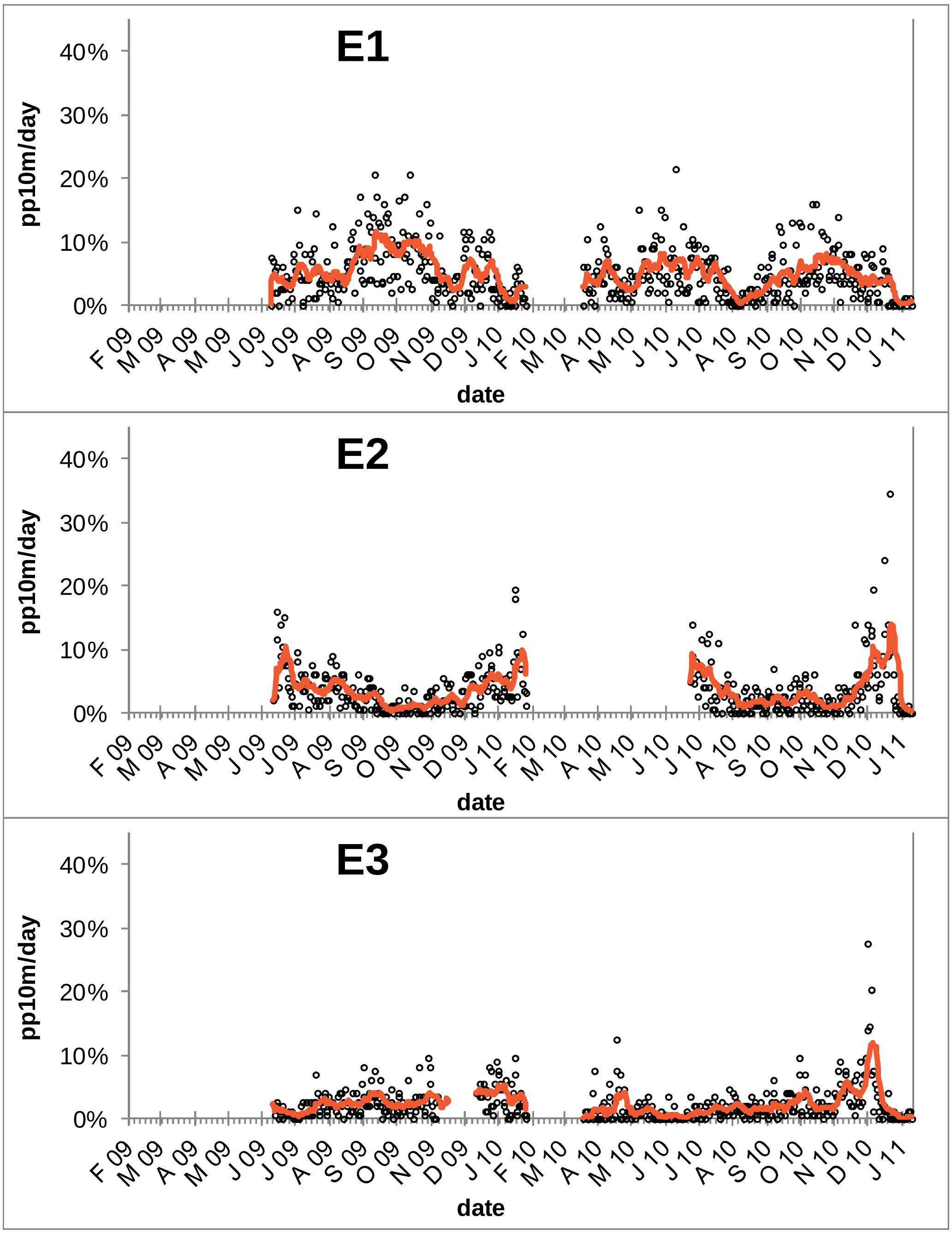

Figure 7.5-3 Plot of pp10m/day against time for two single POD stations from area W. The red line shows the moving average for 10 days.

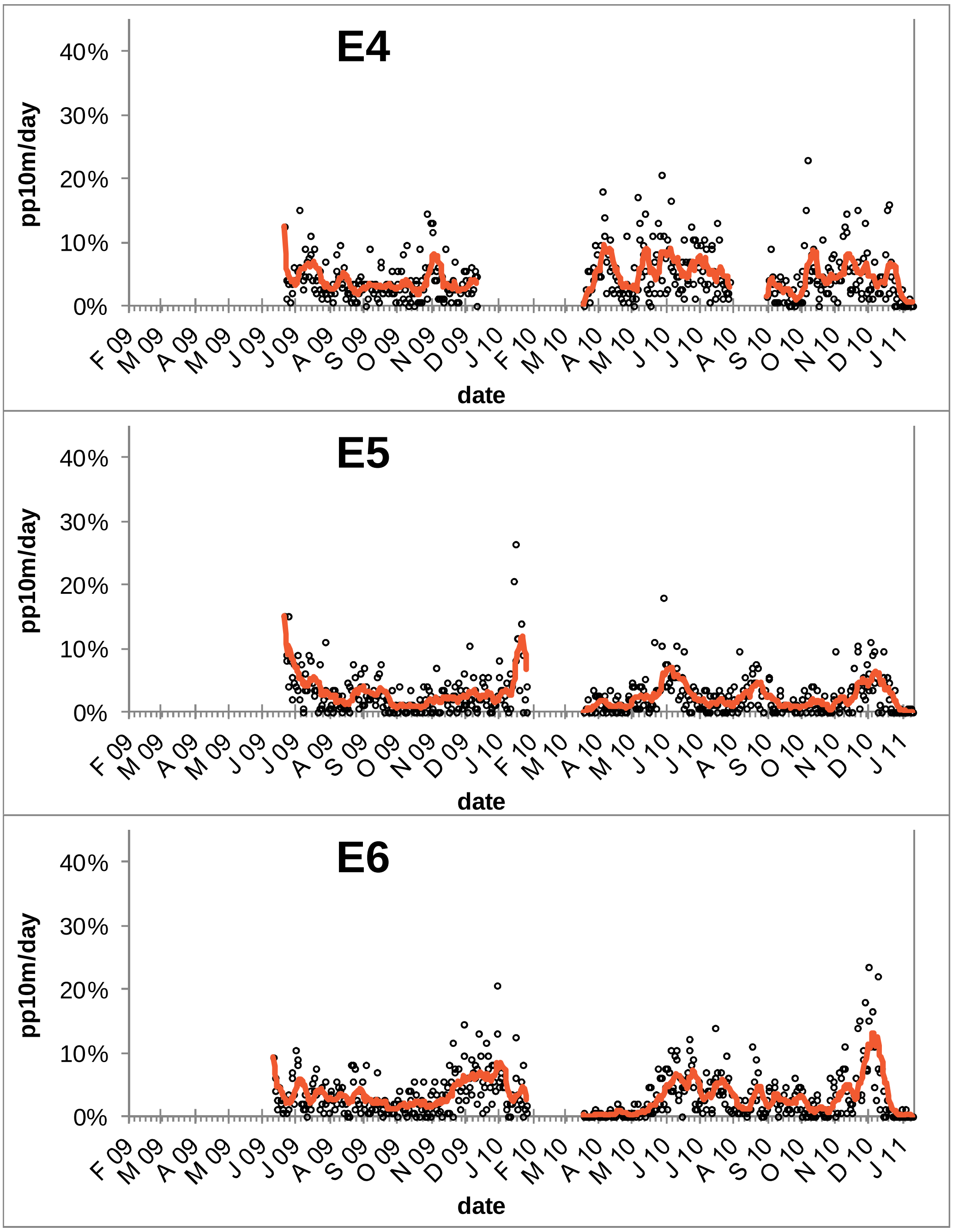

Figure 7.5-4 Plot of pp10m/day against time for two single POD stations from area W. The red line shows the moving average for 10 days.

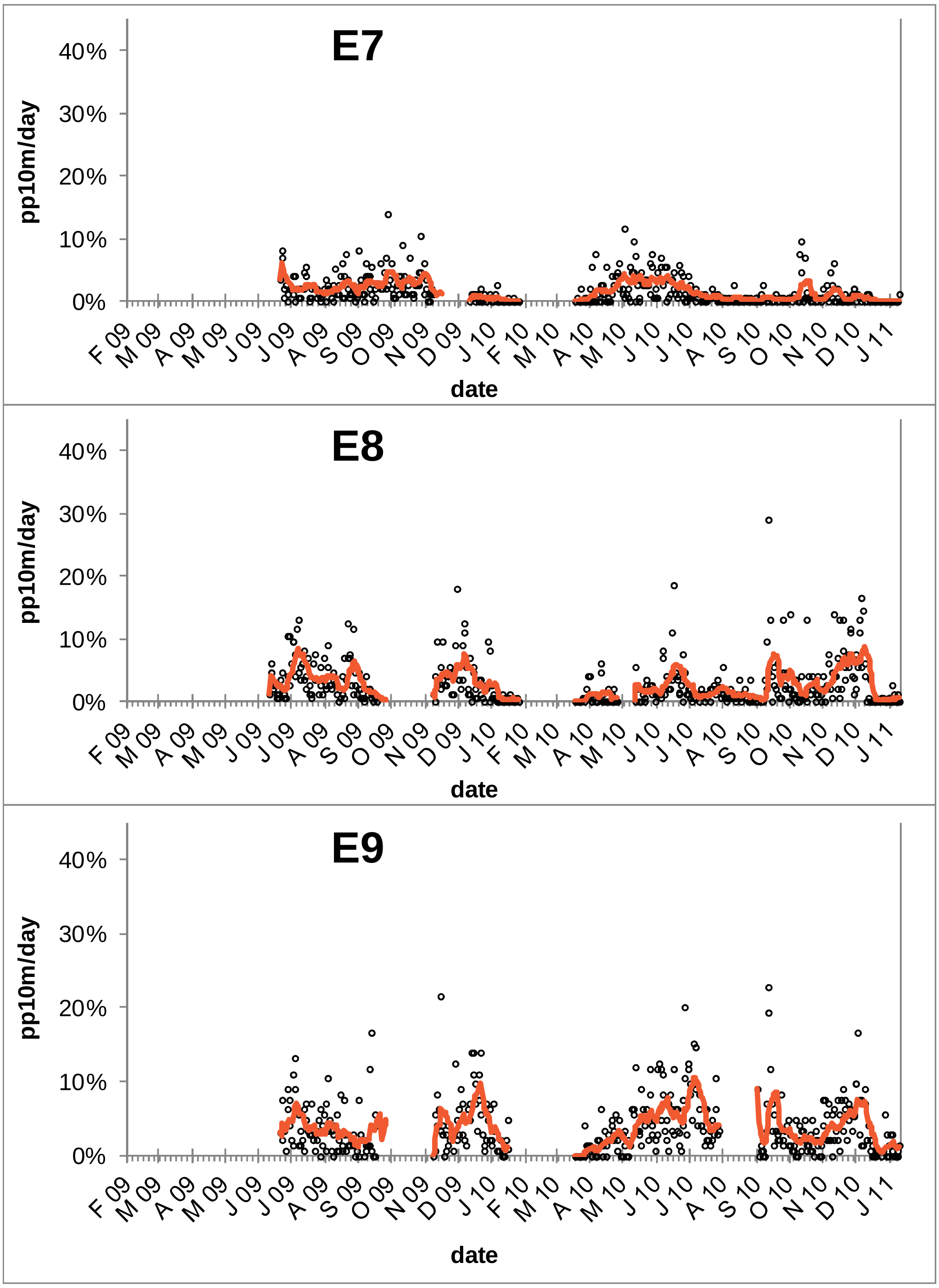

Figure 7.5-5 **Plot of pp10m/day against time for two single POD stations from area W. The red line shows the moving average for 10 days.**

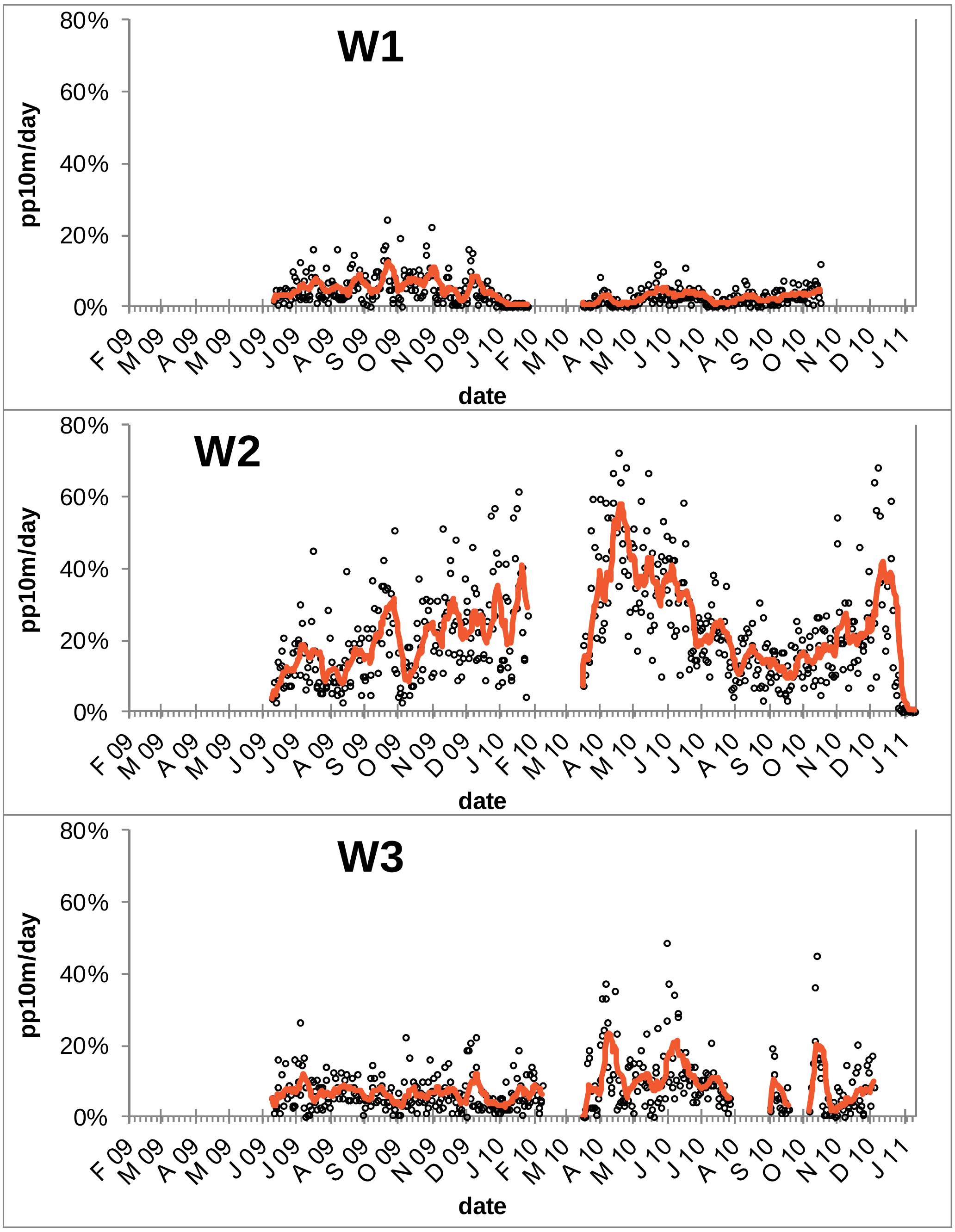

Figure 7.5-6 Plot of pp10m/day against time for two single POD stations from area W. The red line shows the moving average for 10 days.

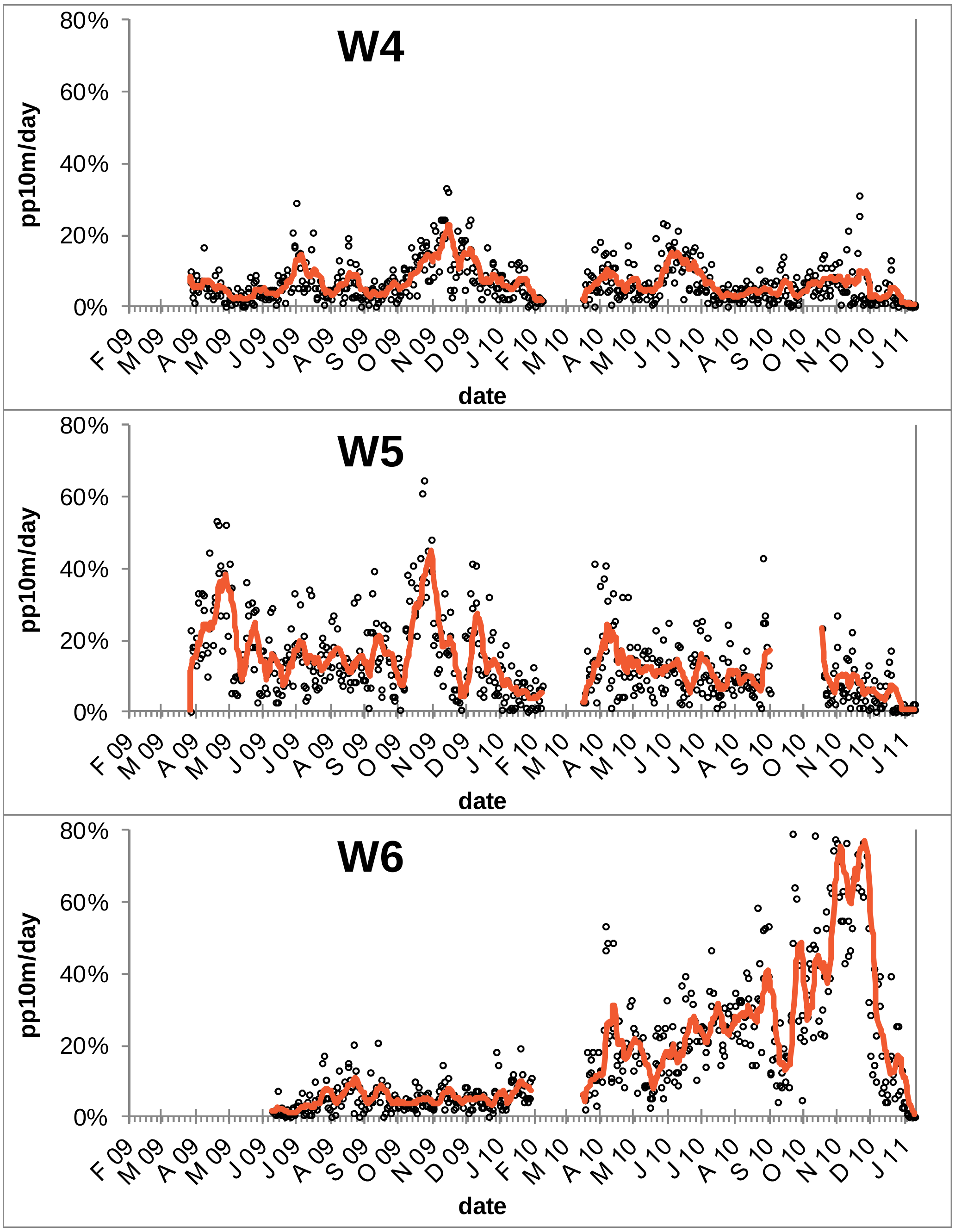

Figure 7.5-7 **Plot of pp10m/day against time for two single POD stations from area W. The red line shows the moving average for 10 days.**

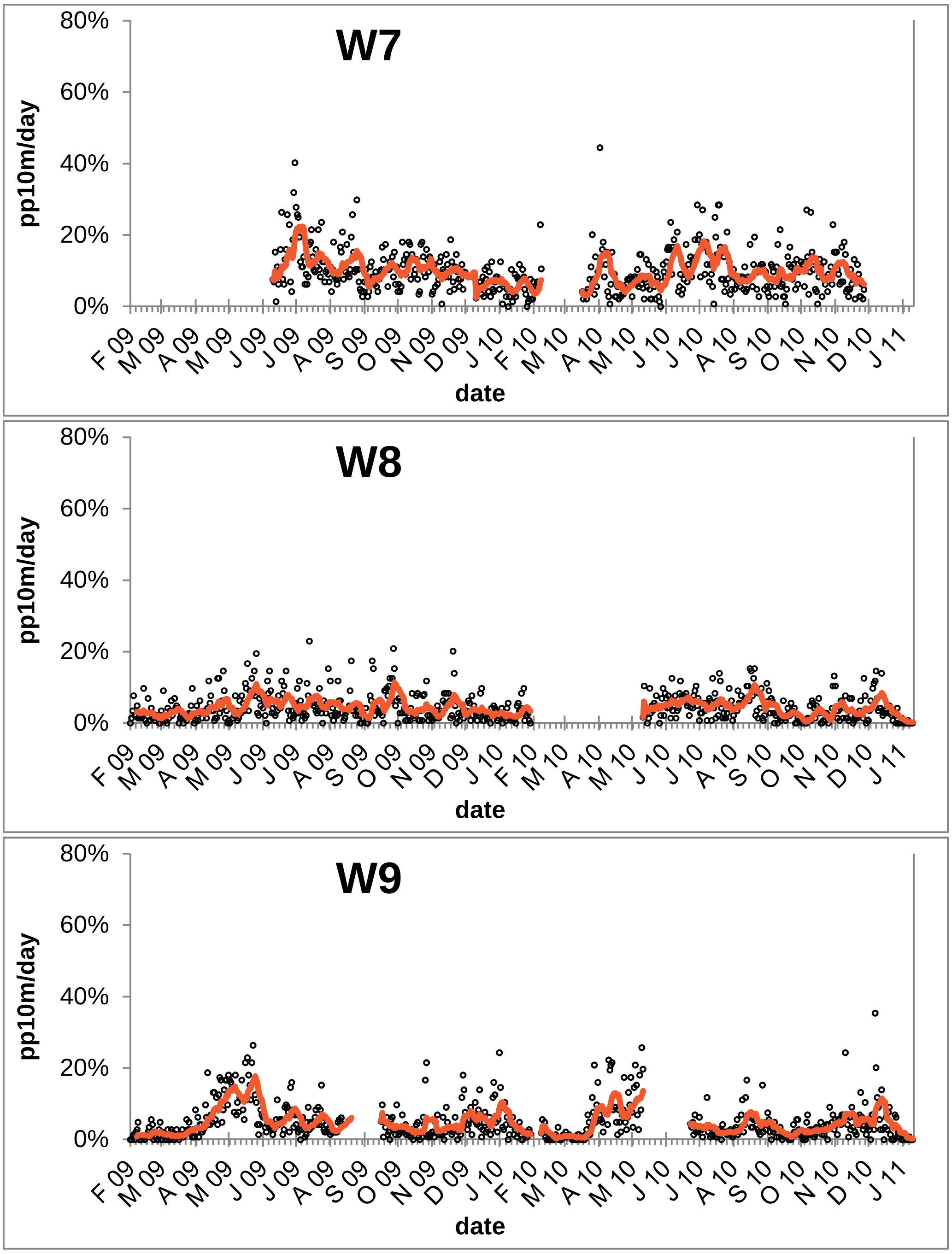

Figure 7.5-8 Plot of pp10m/day against time for two single POD stations from area W. The red line shows the moving average for 10 days.

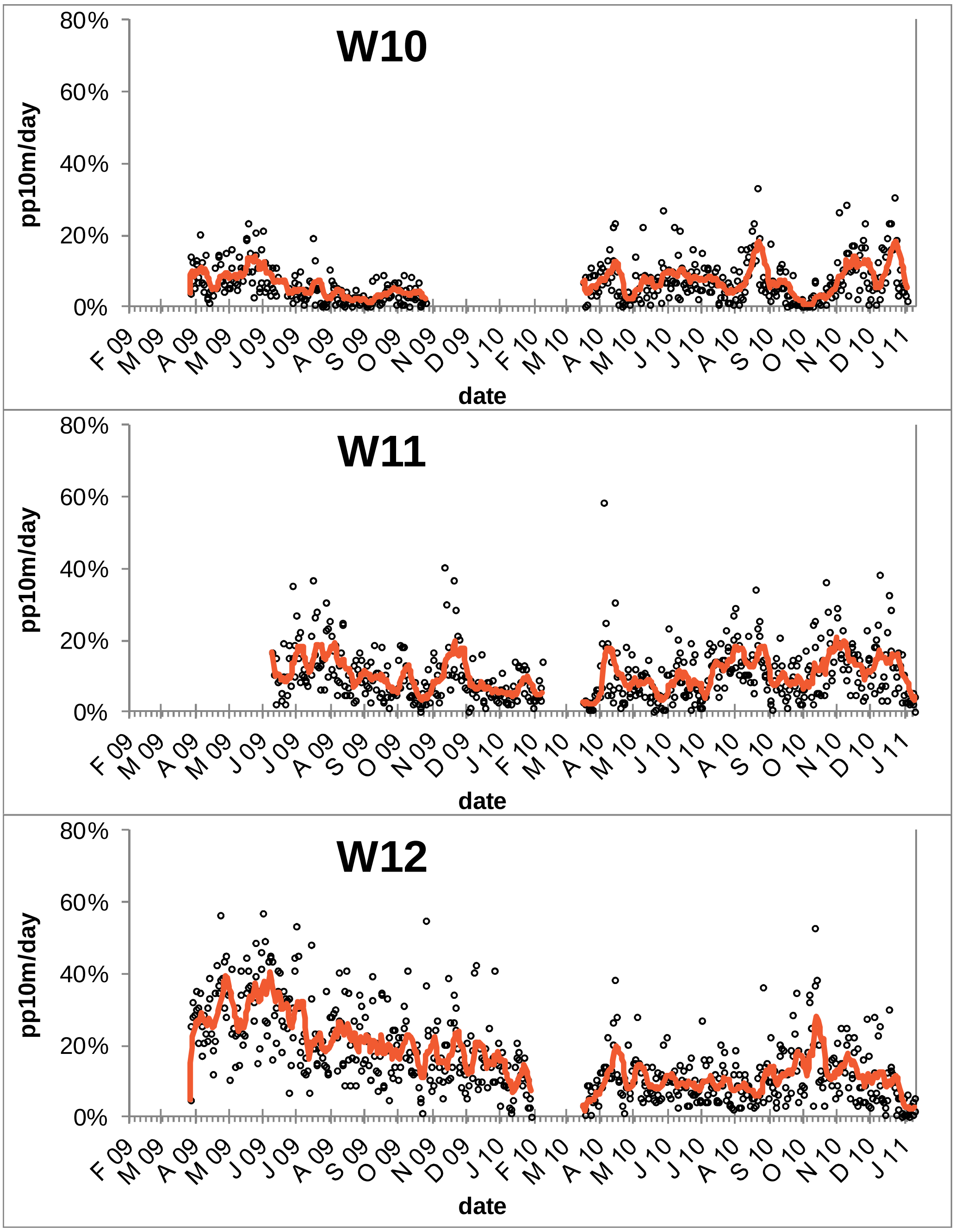

Figure 7.5-9 Plot of pp10m/day against time for two single POD stations from area W. The red line shows the moving average for 10 days.

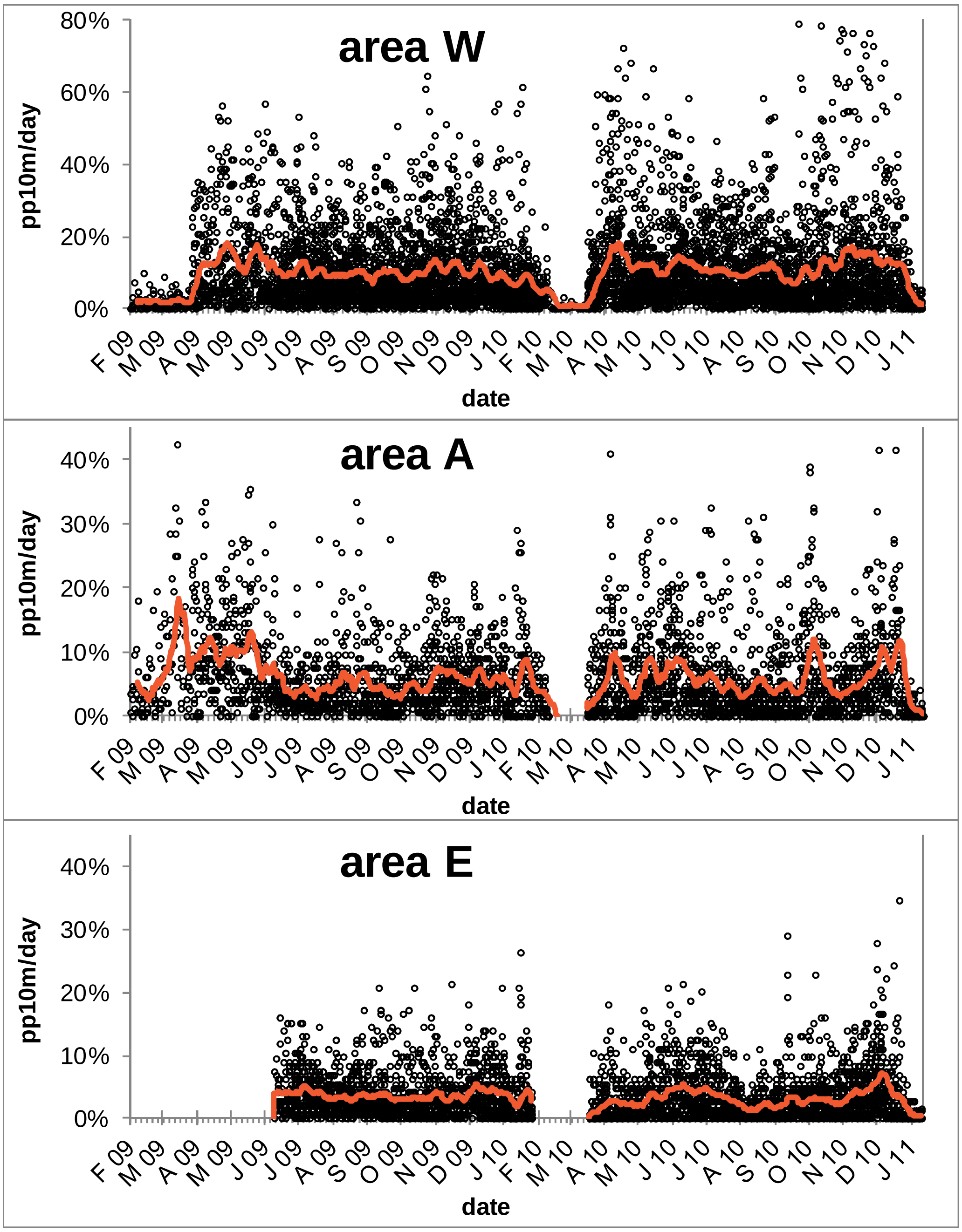

Figure 7.5-10 **Plot of pp10m/day against time for two single POD stations from area W. The red line shows the moving average for 10 days.**

7.6. Appendix 6

Locations of seal groups counted during aerial survey

The following figures show the locations of seal groups counted during aerial surveys (data separated by month).

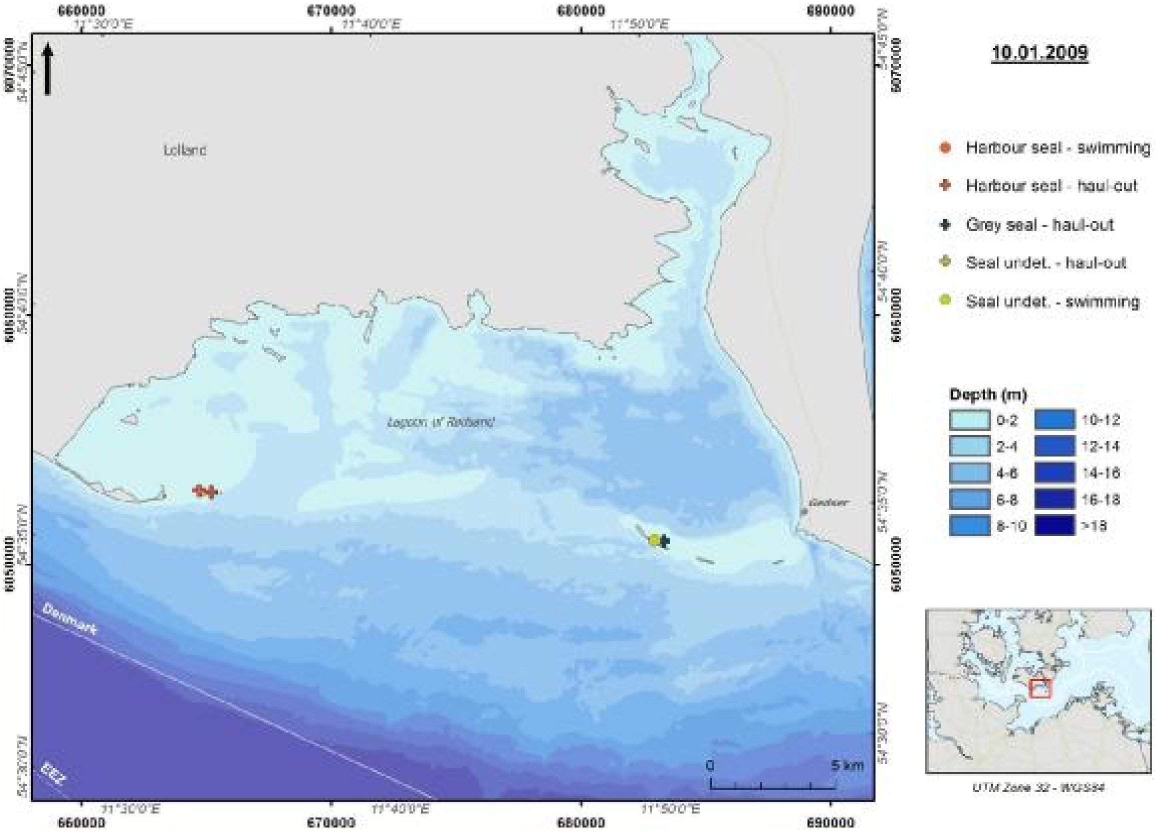

Figure 7.6-1 Locations of seal groups counted during aerial survey, January 2009.

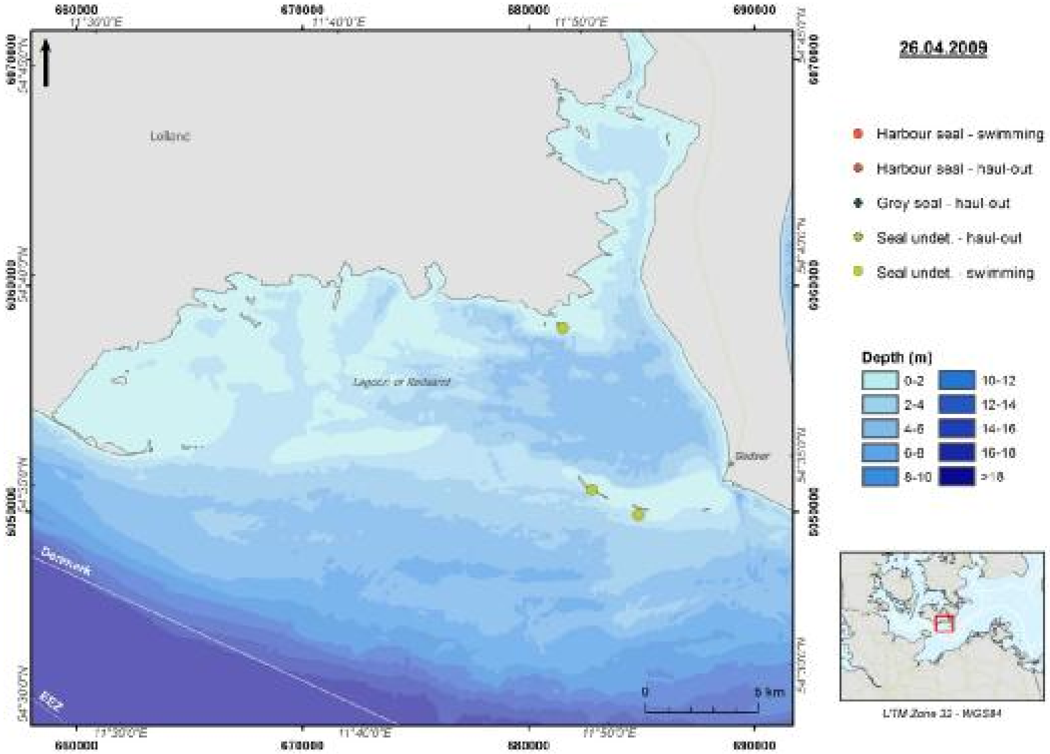

Figure 7.6-2 Locations of seal groups counted during aerial survey, April 2009.

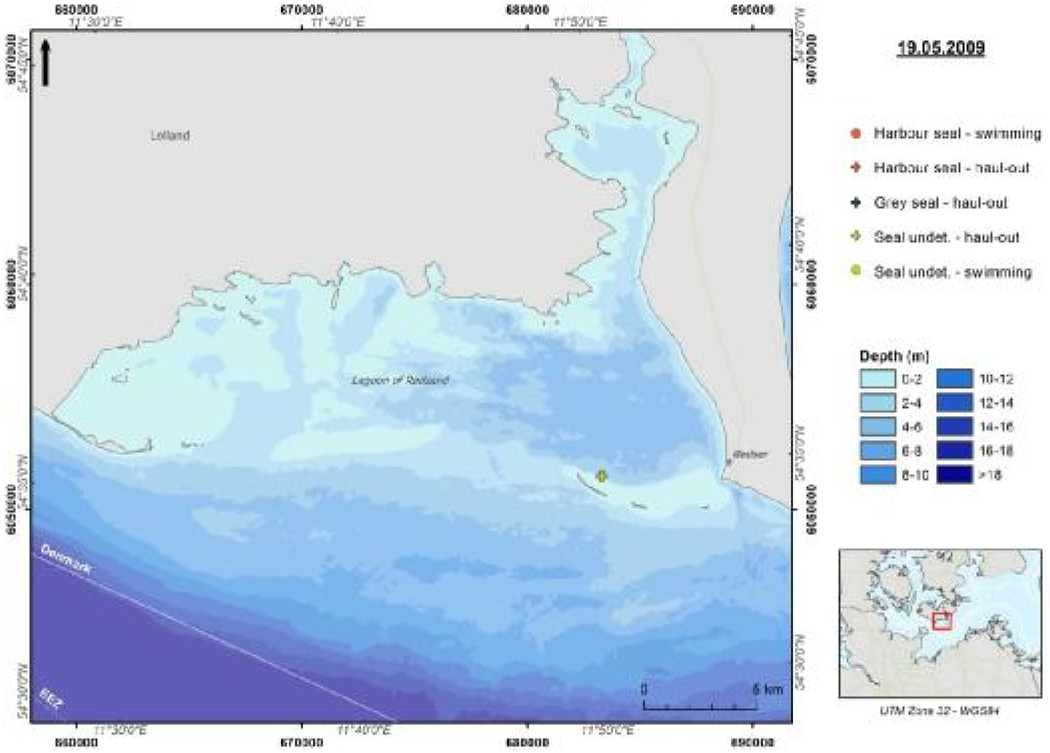

Figure 7.6-3 Locations of seal groups counted during aerial survey, May 2009.

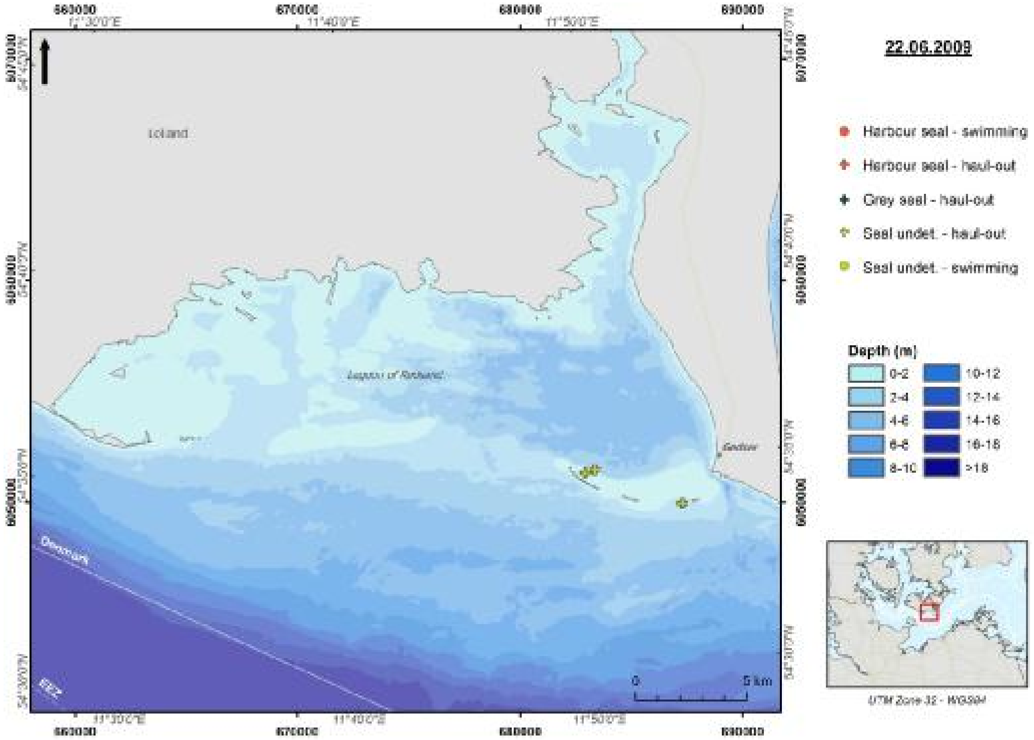

Figure 7.6-4 Locations of seal groups counted during aerial survey, June 2009.

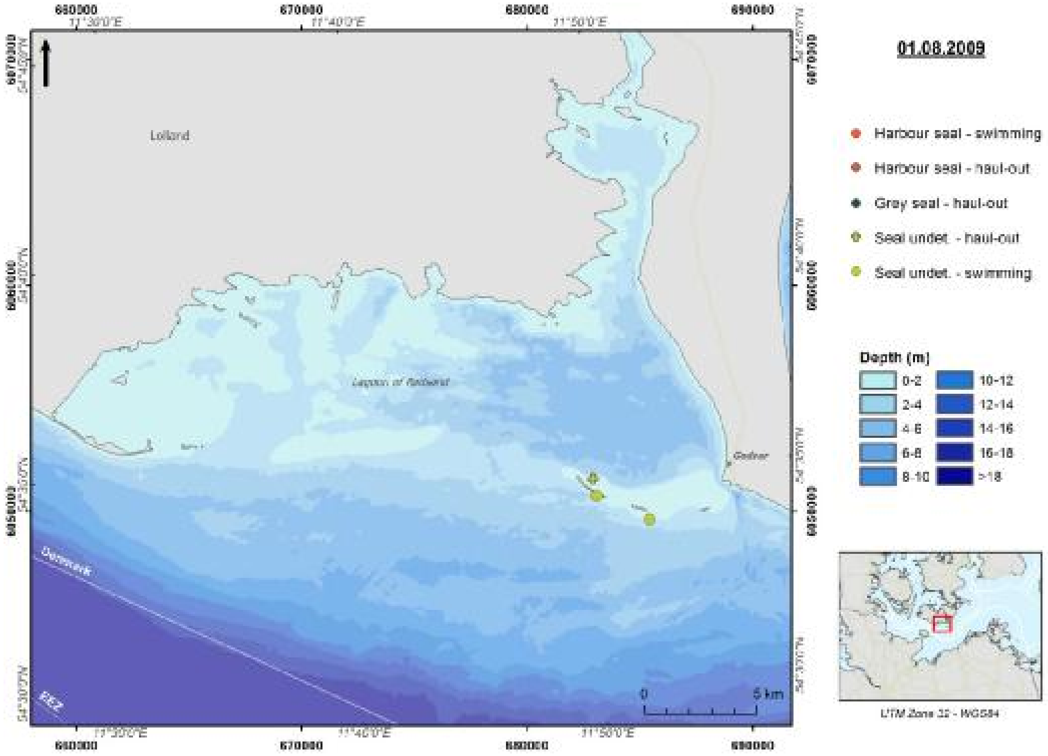

Figure 7.6-5 Locations of seal groups counted during aerial survey, August 2009.

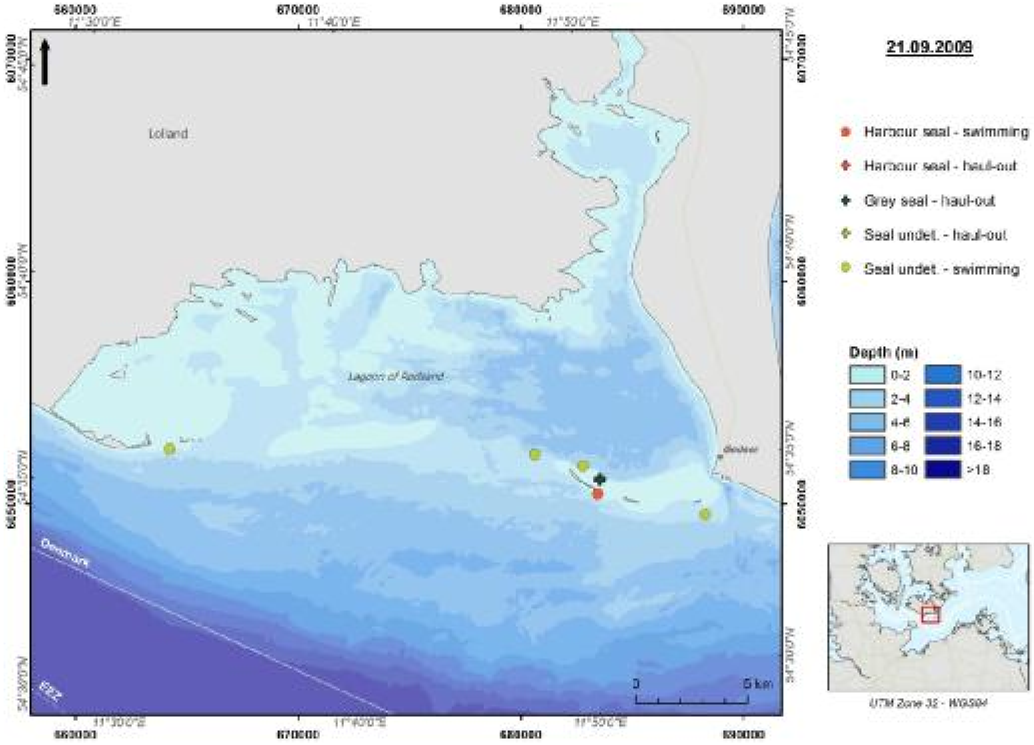

Figure 7.6-6 Locations of seal groups counted during aerial survey, September 2009.

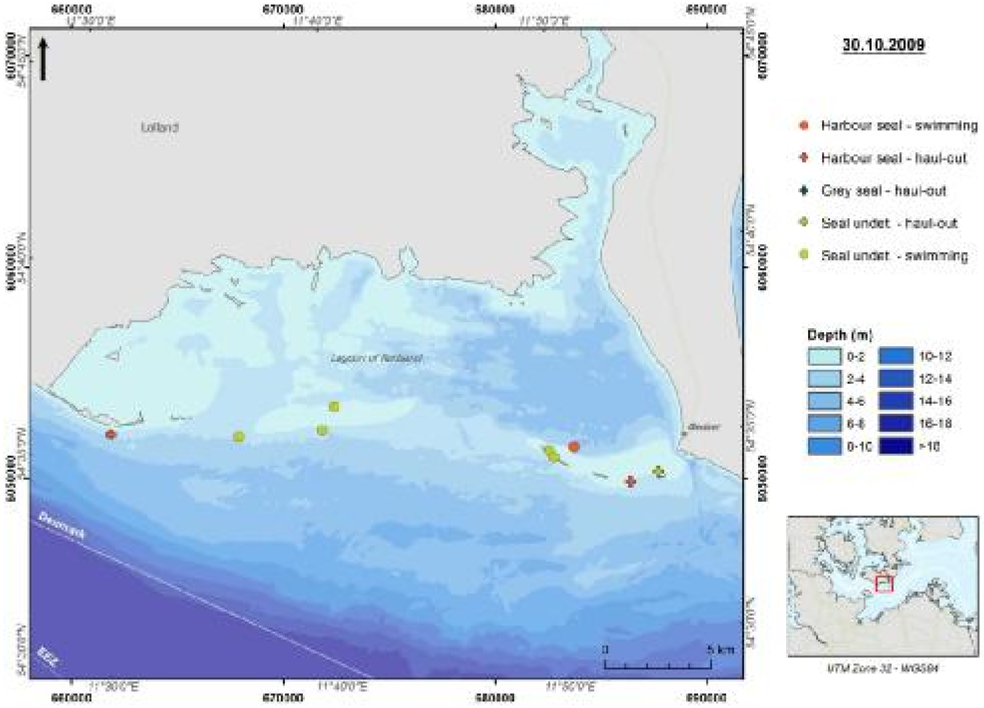

Figure 7.6-7 Locations of seal groups counted during aerial survey, October 2009.

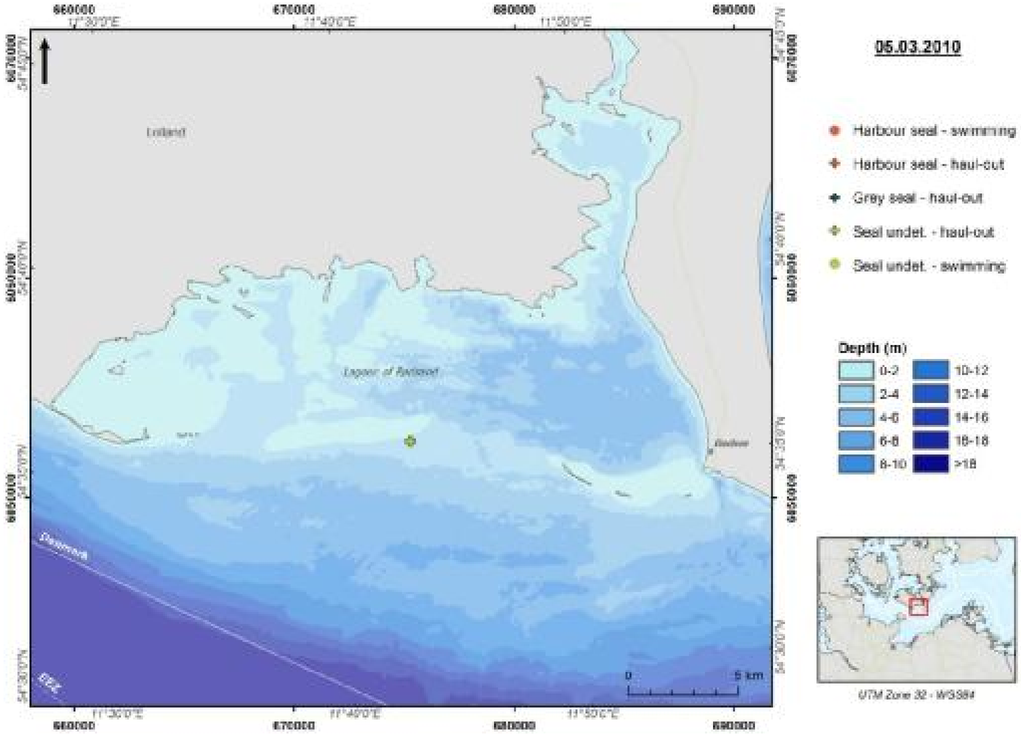

Figure 7.6-8 **Locations of seal groups counted during aerial survey, March 2010.**

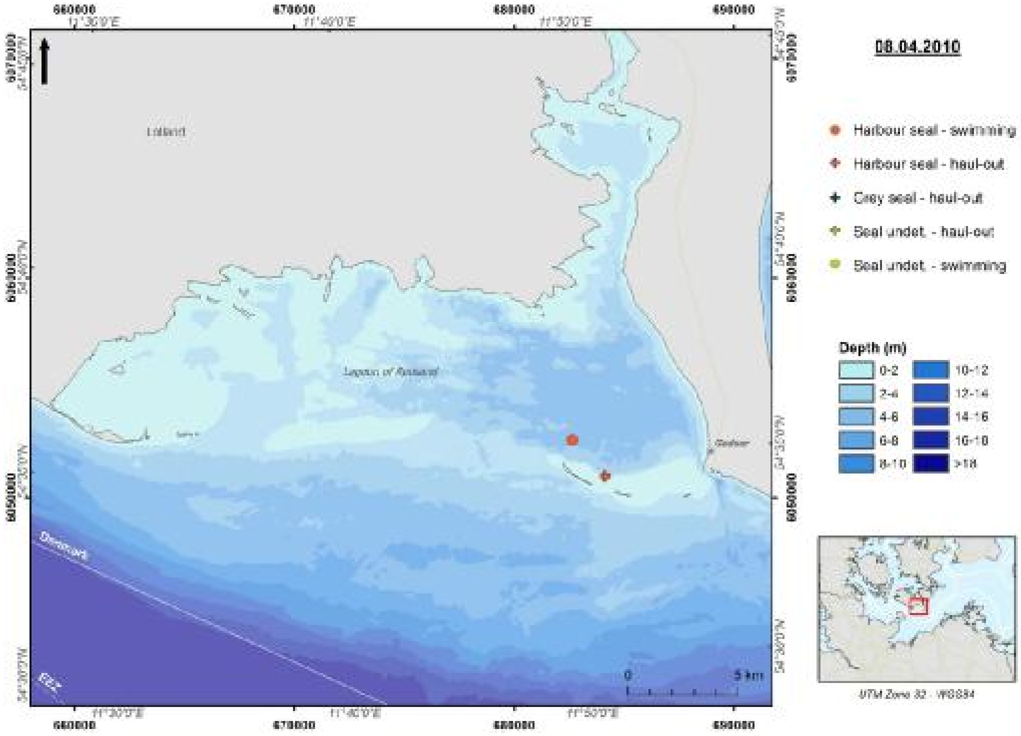

Figure 7.6-9 **Locations of seal groups counted during aerial survey, April 2010.**

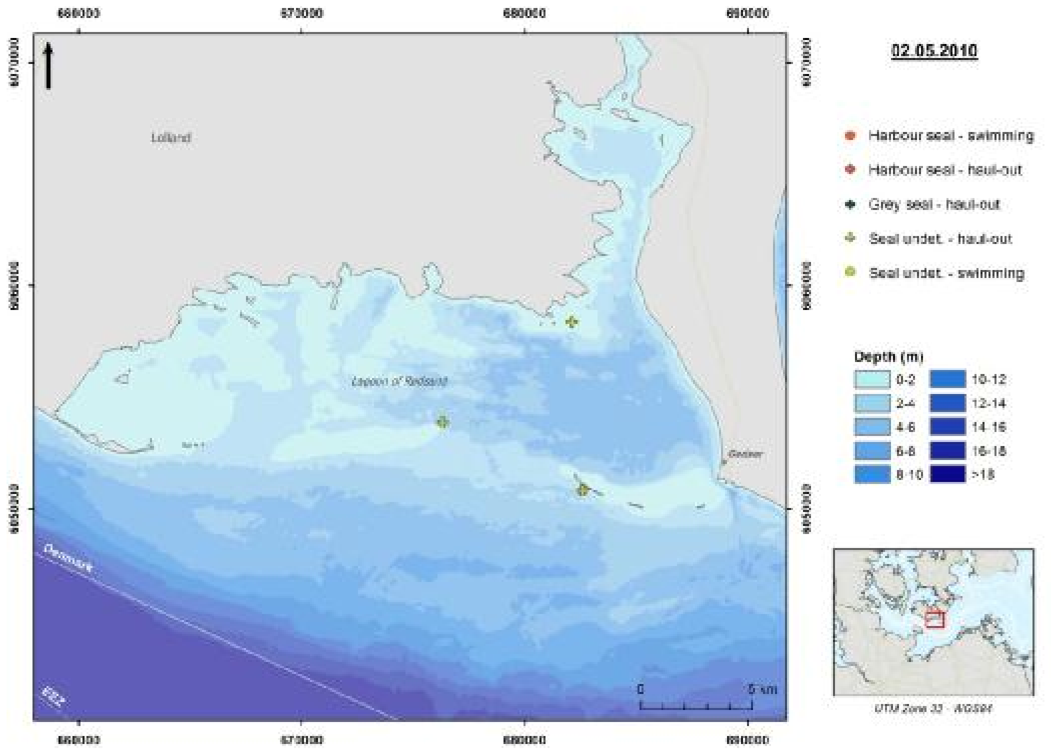

Figure 7.6-10 Locations of seal groups counted during aerial survey, May 2010.

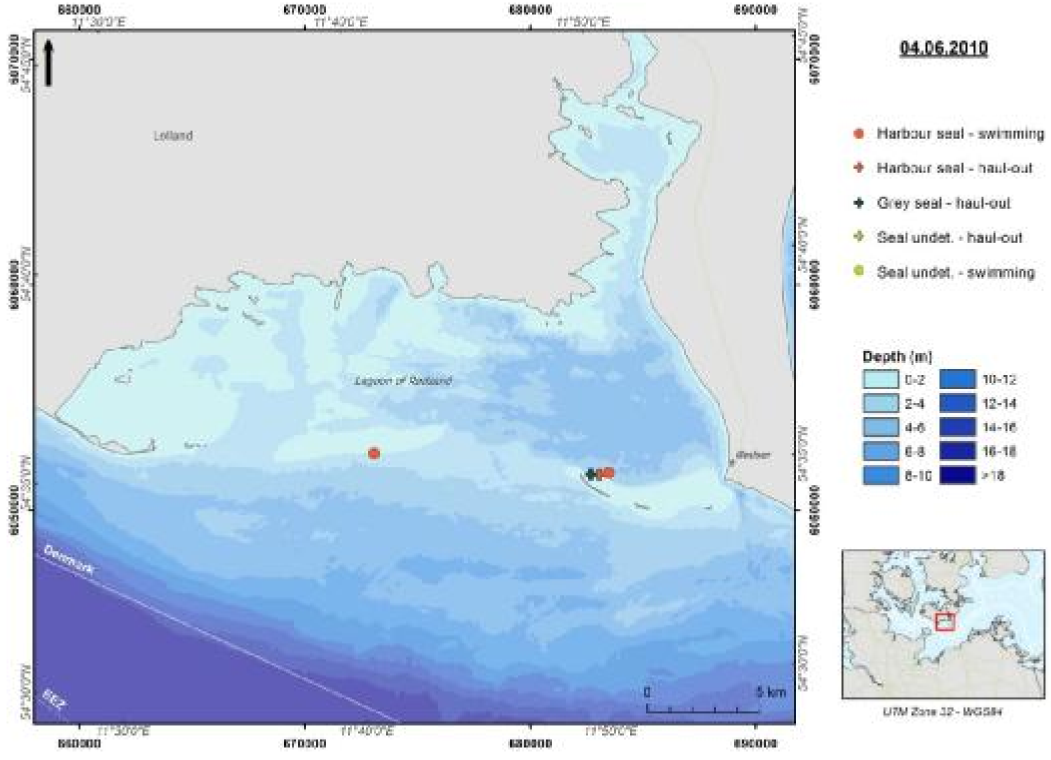

Figure 7.6-11 Locations of seal groups counted during aerial survey, June 2010.

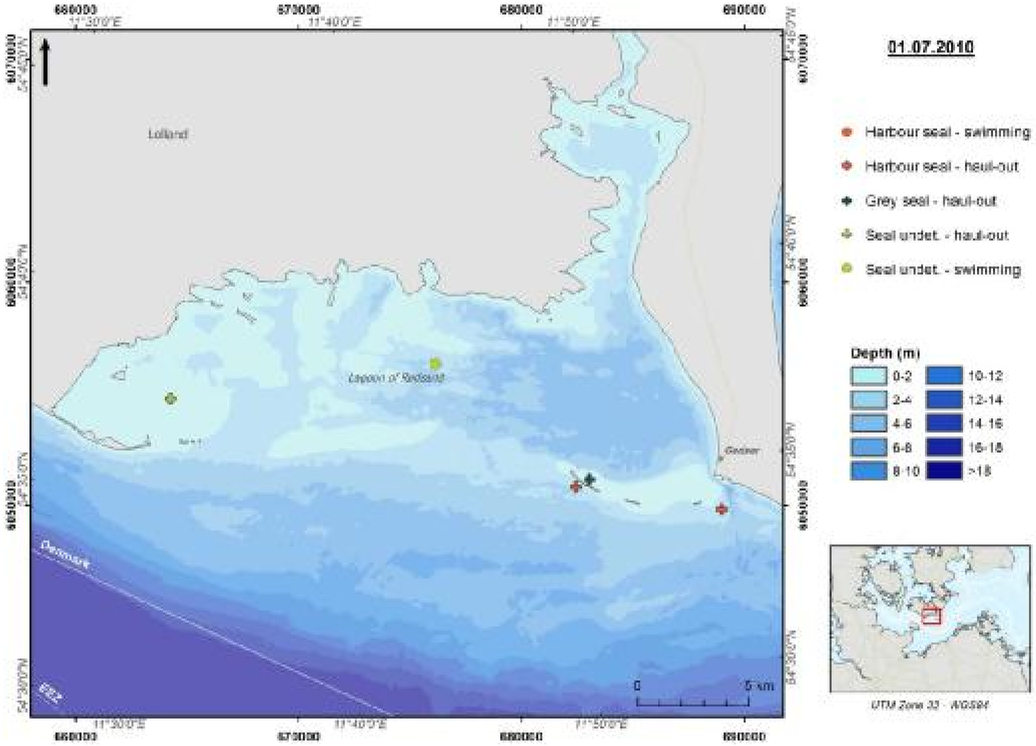

Figure 7.6-12 Locations of seal groups counted during aerial survey, July 2010

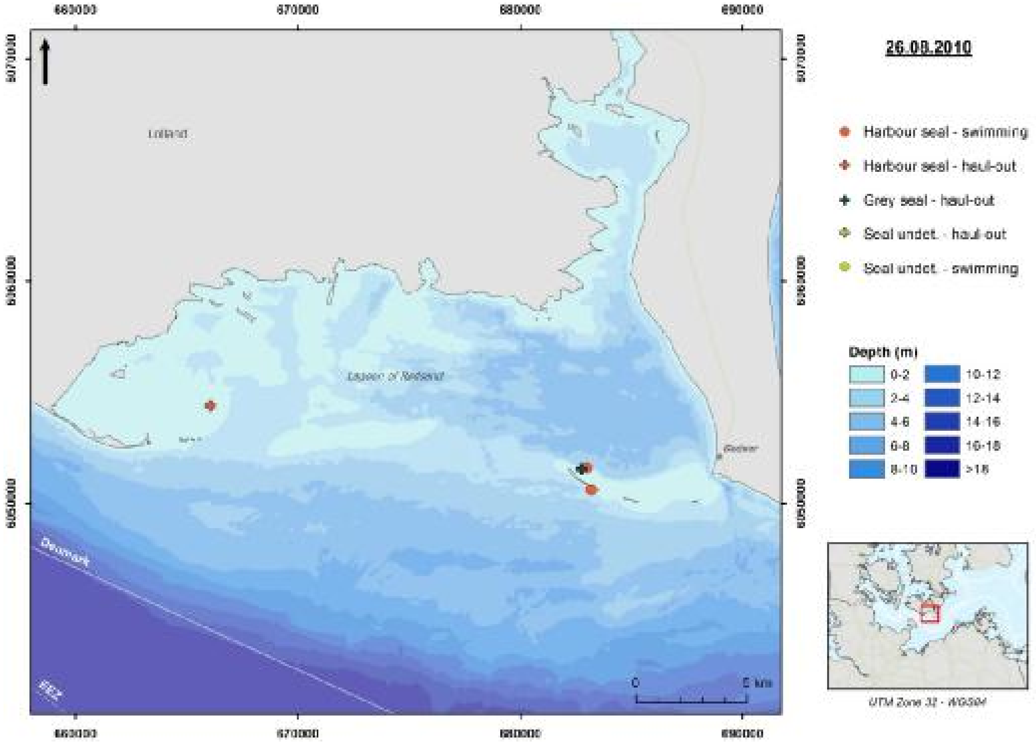

Figure 7.6-13 Locations of seal groups counted during aerial survey, August 2010

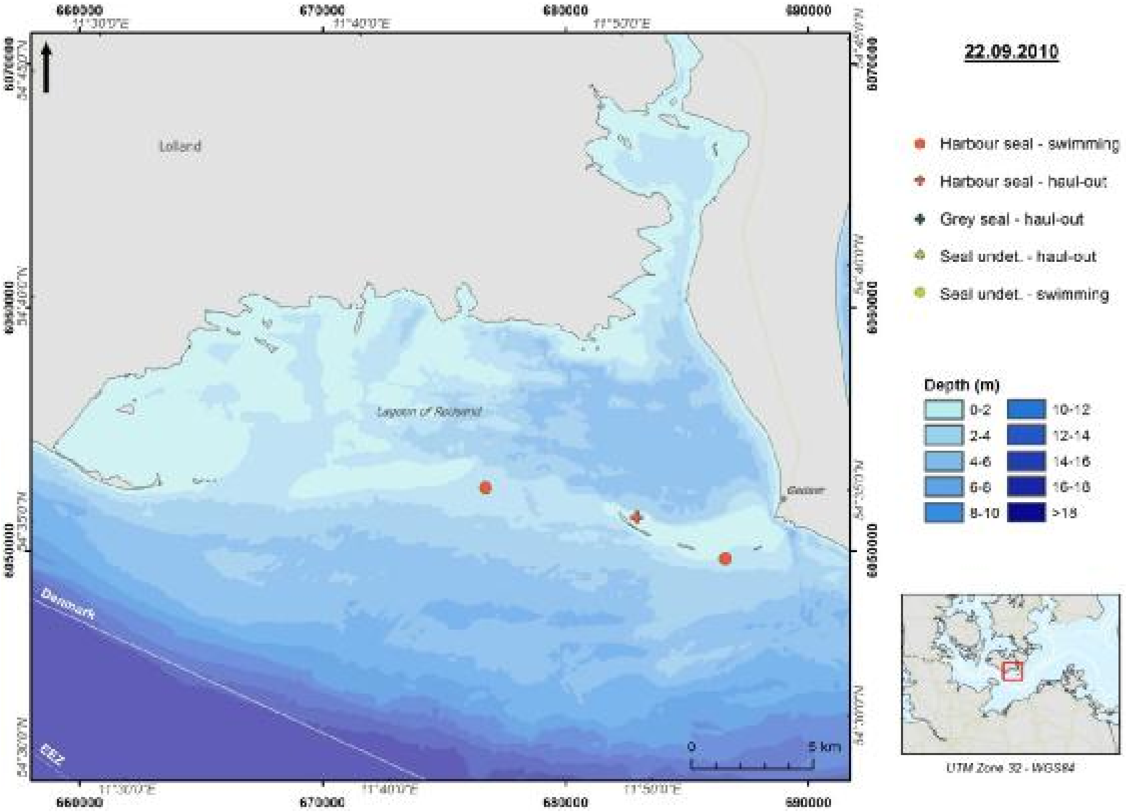

Figure 7.6-14 Locations of seal groups counted during aerial survey, September 2010

7.7. Appendix 7: Seal Telemetry

7.7.1. Monthly subsets of tagging data for inference of feeding areas

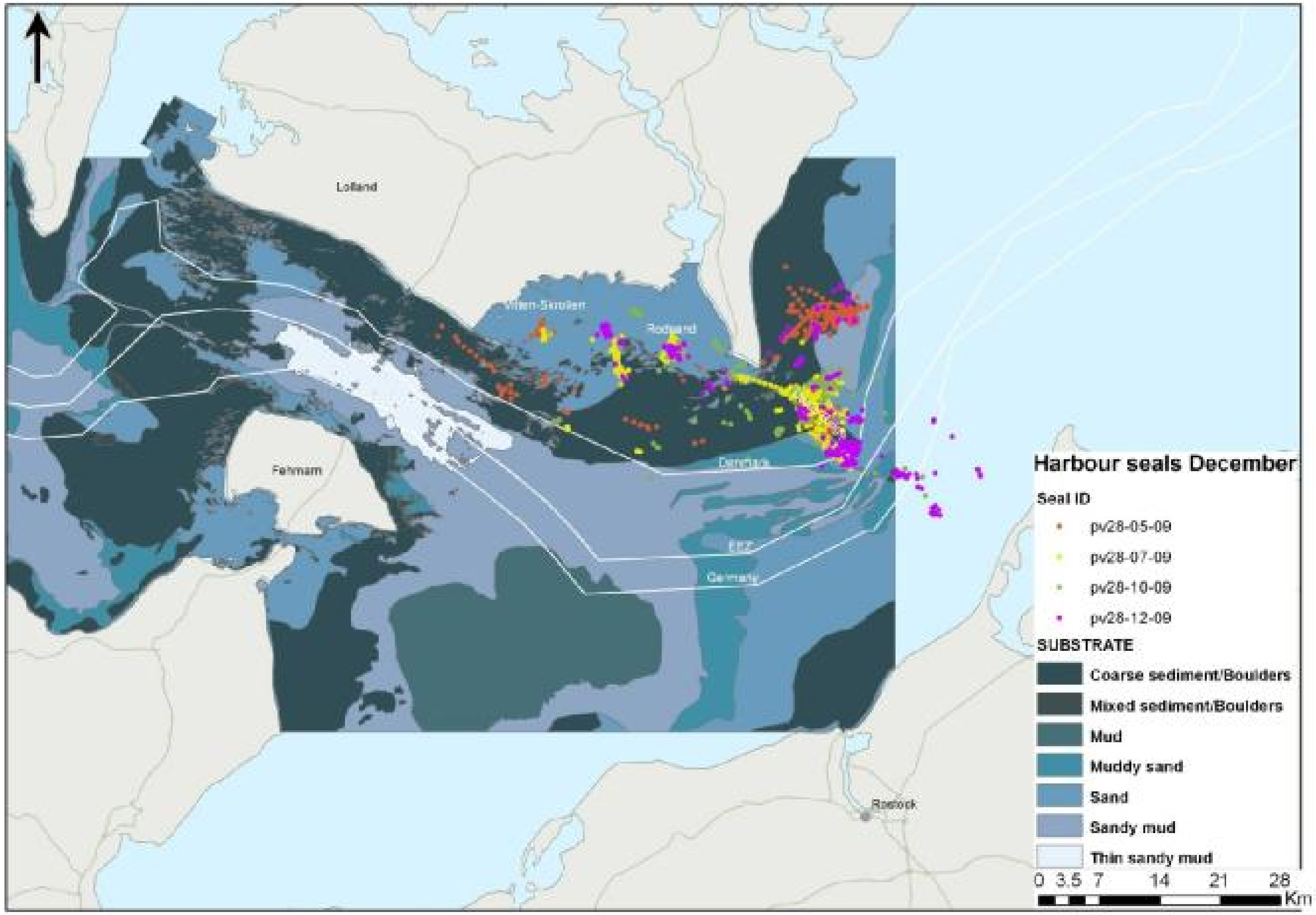

Figure 7.7-1 Map of slow travel rate locations of harbour seals for the month of December 2009, colour-coded by seal, overlaid on substrate type.

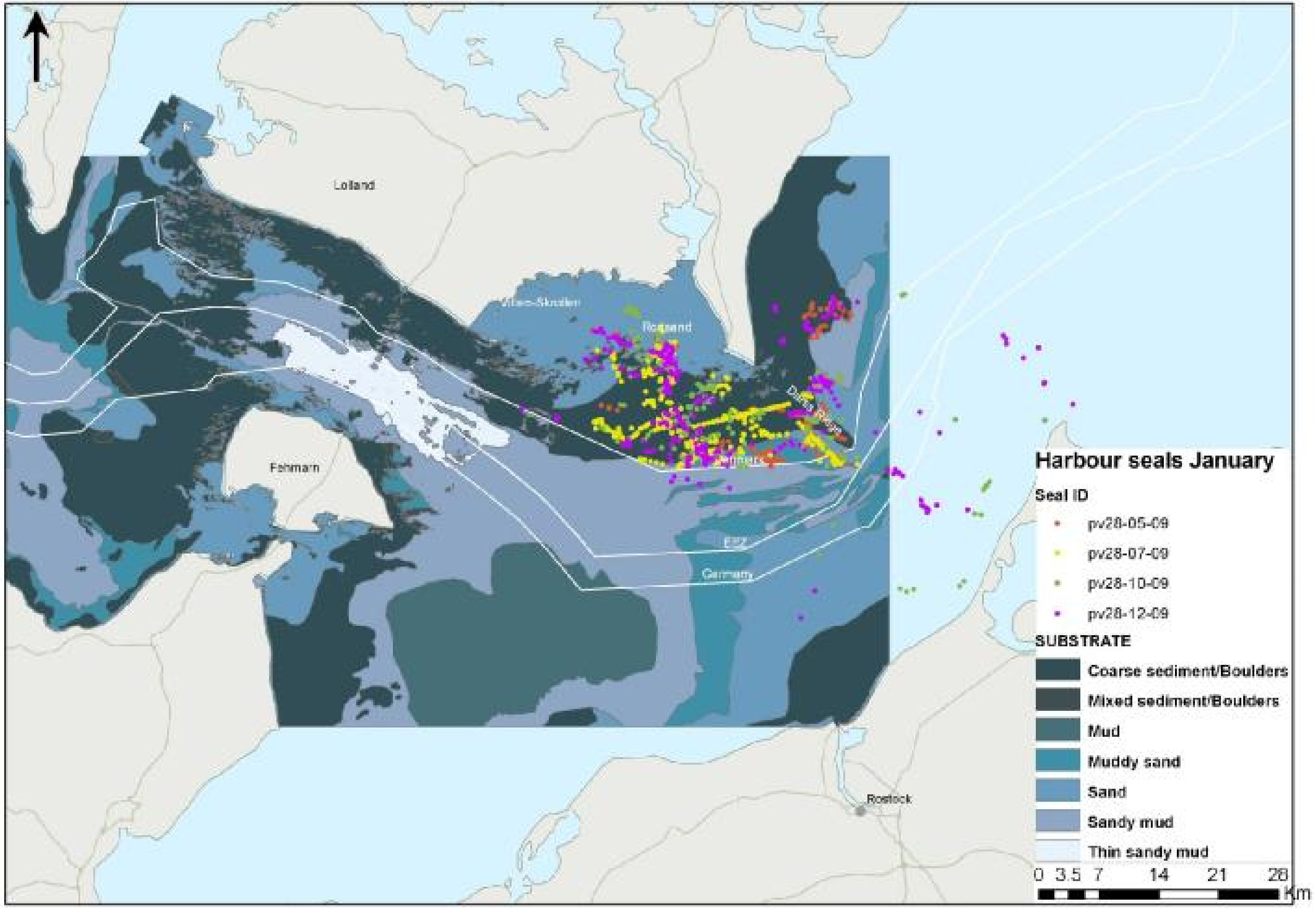

Figure 7.7-2 Map of slow travel rate locations of harbour seals for the month of January 2010, colour-coded by seal, overlaid on substrate type.

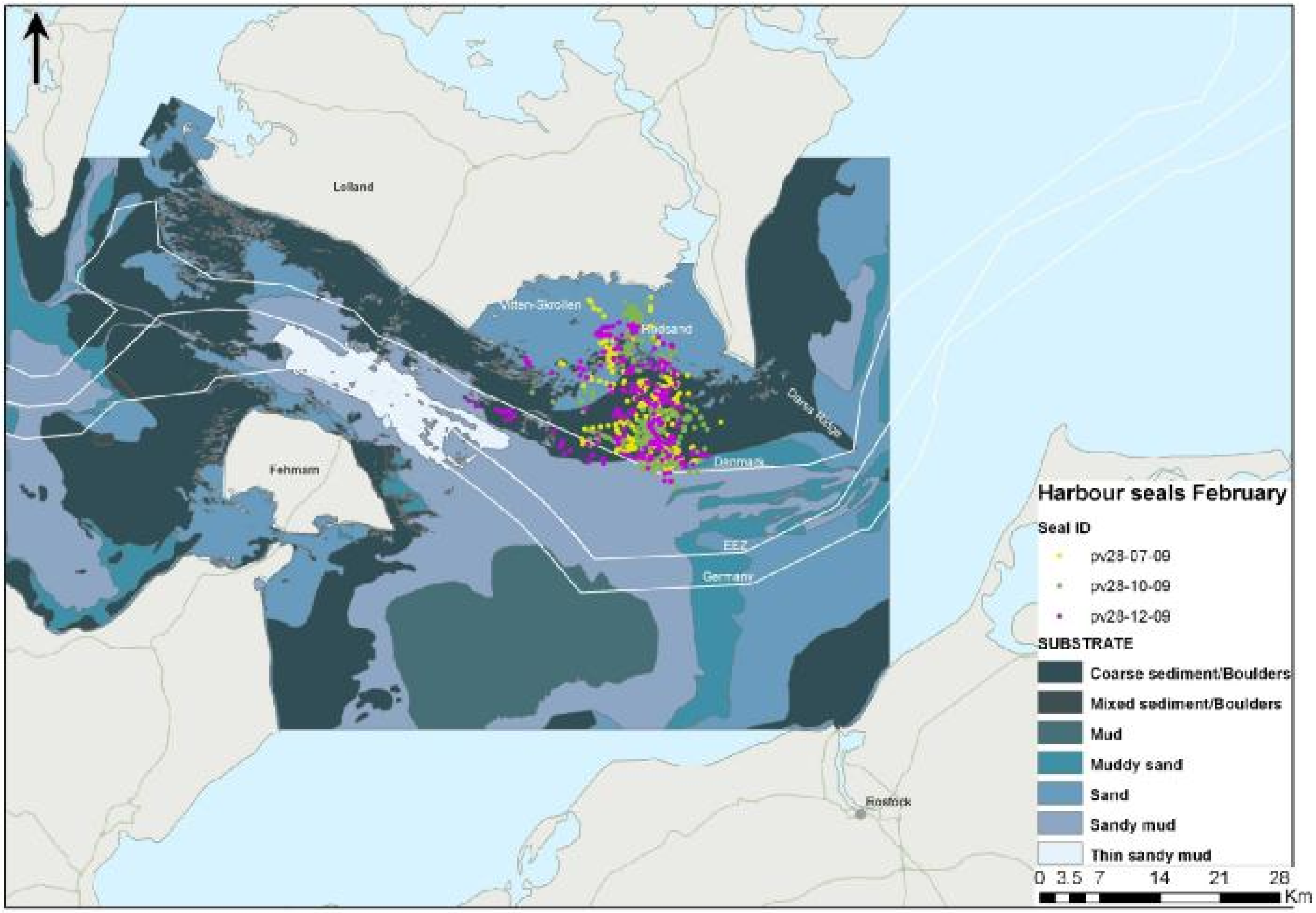

Figure 7.7-3 Map of slow travel rate locations of harbour seals for the month of February 2010, colour-coded by seal, overlaid on substrate type.

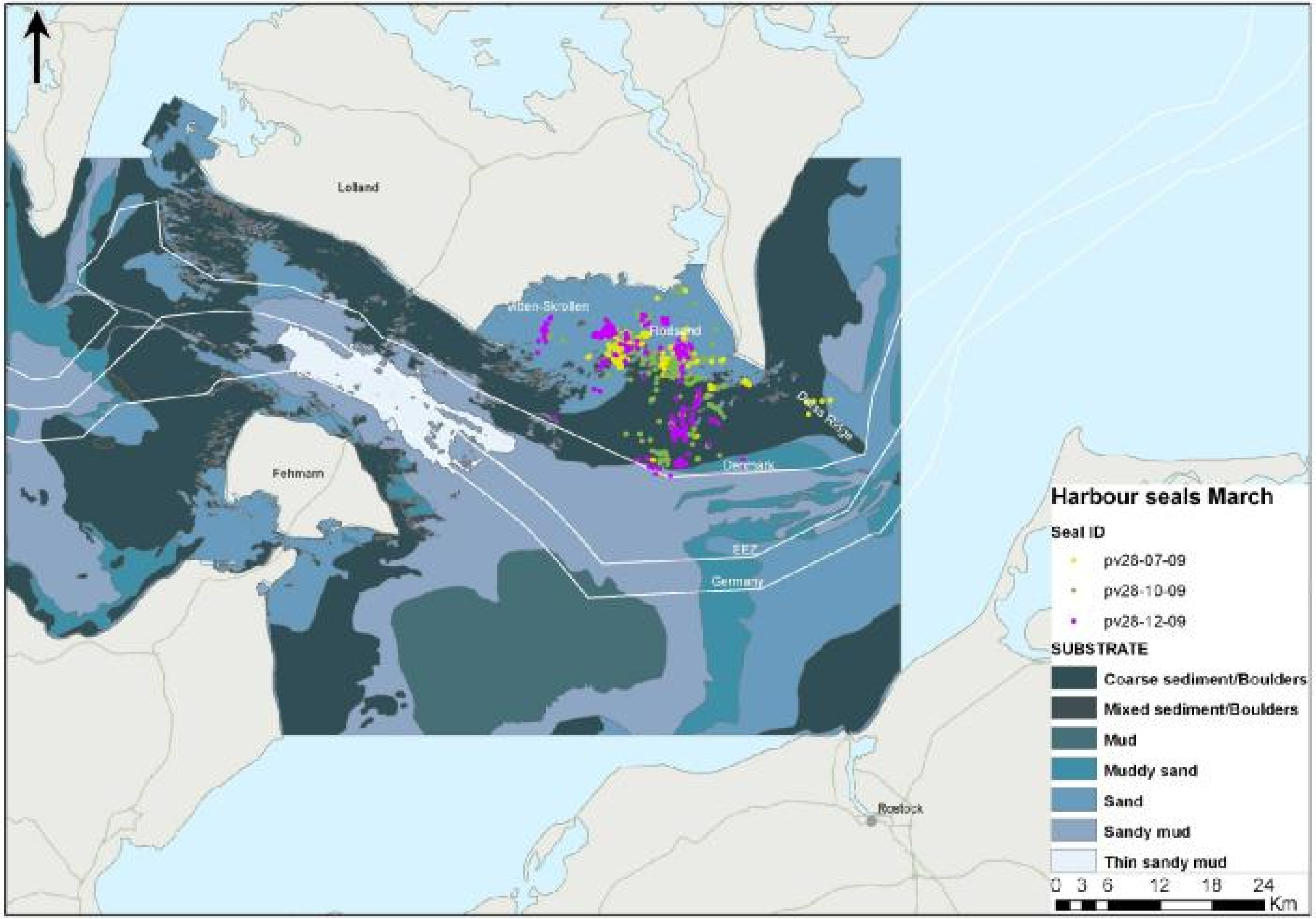

Figure 7.7-4 Map of slow travel rate locations of harbour seals for the month of March 2010, colour-coded by seal, overlaid on substrate type.

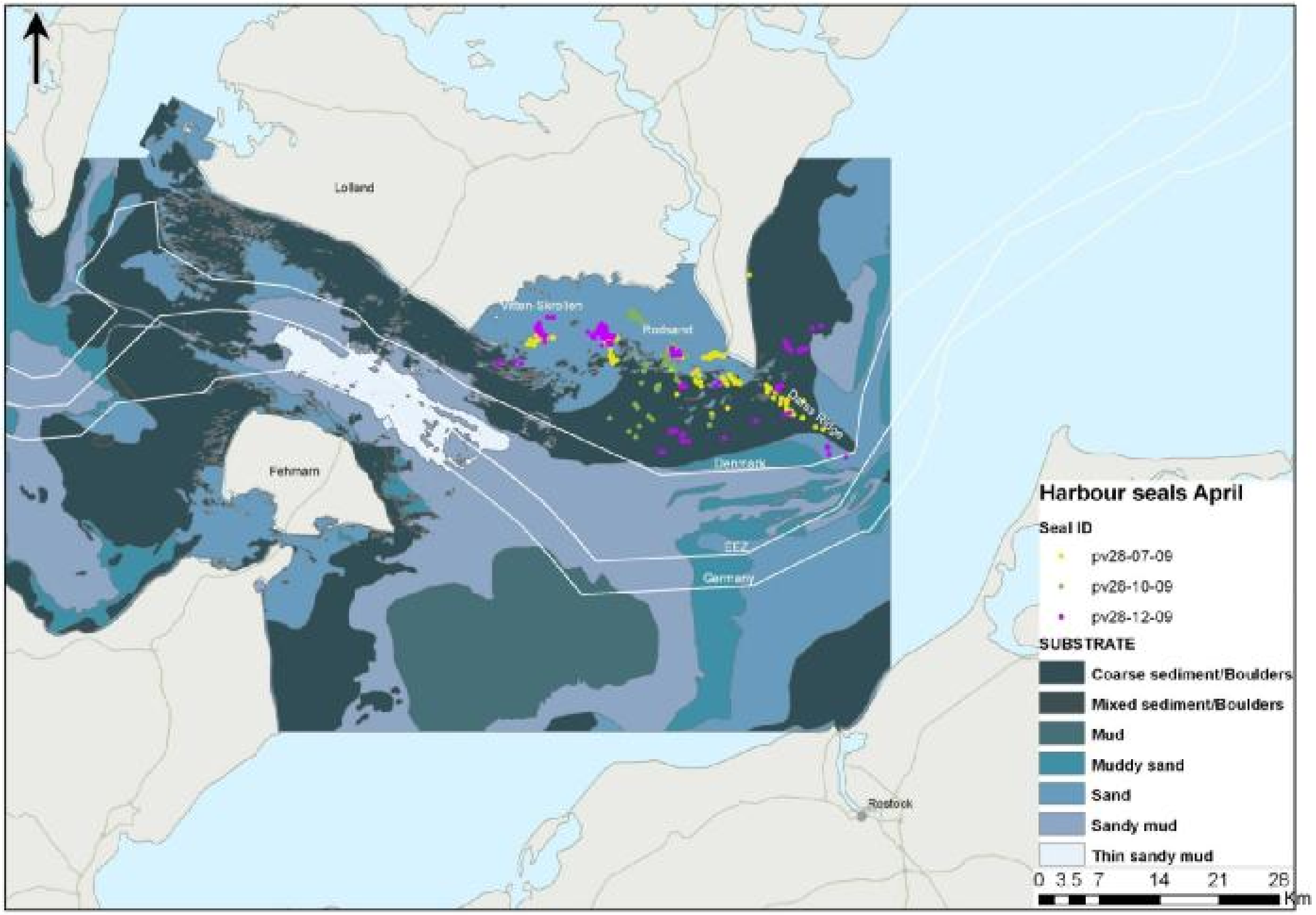

Figure 7.7-5 **Map of slow travel rate locations of harbour seals for the month of April 2010, colour-coded by seal, overlaid on substrate type.**

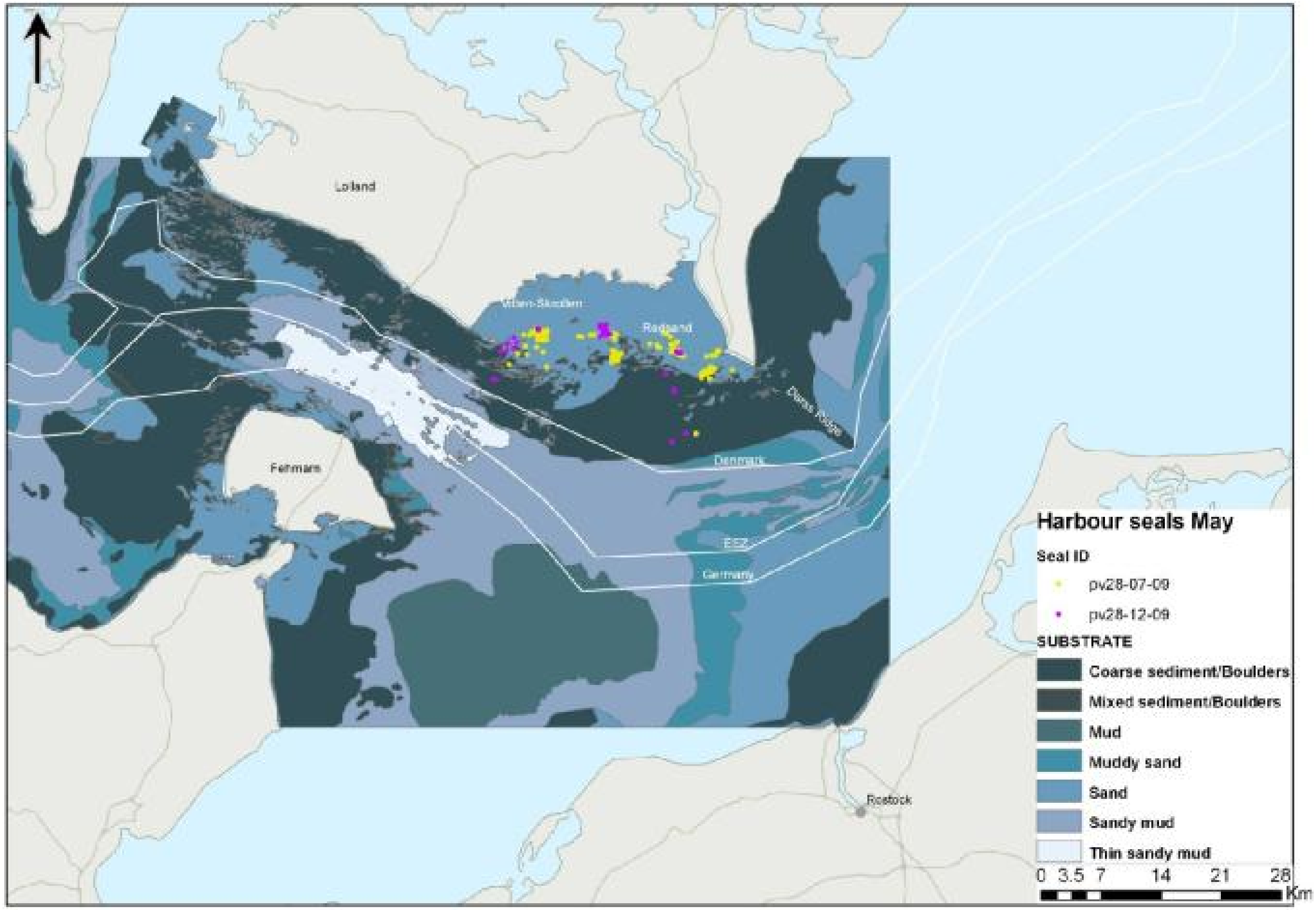

Figure 7.7-6 Map of slow travel rate locations of harbour seals for the month of May 2010, colour-coded by seal, overlaid on substrate type.

7.7.2. Usage Model Selection

In models with just distance and two candidate covariates (Model structures 1-3), depth was consistently important: of the ten random samples of the original data, depth was included in the best model eight times, and of all the models with the lowest ubre scores (5% quantile, n=220), depth was included 85% of the time. There were two model structures that were clearly better than others: depth * distance to land and depth * bottom temperature interactions. They occurred in the best 5% in every run, and on average, ranked as the second or third best model in the set. These models were followed by **depth + bottom current speed** (not an interaction), and **depth * surface temperature interaction**. Both occurred in the best set of models 9/10 times, but on average, did not rank quite as highly.

There was strong support for 5-covarite models with an interaction term in the first sample of data. A third of all the 270 5-covariate models with an interaction were included in the best 1%. There was no support for models with two interaction terms.

The best 1% of models in the sample included 141 different structures, each of which were then re-fitted with 20 new random samples of the data. The set included one model with just two candidate covariates, 32 models with three, and 108 models with four candidate covariates. The set included 11 types of interactions, while 31 models didn't have any (Table 7.7-1). All candidate covariates were included in at least 6 different models; depth and bottom current speed were included almost in every model (140 and 131 models, respectively).

Table 7.7-1 Interaction terms in the explored 141 models that were ranked across 20 resamples of data.

interaction term	frequency
depth * distLand	23
depth * T_bot	22
depth * T_surf	21
CS_surf * CS_bot	19
depth * CG_bot	19
CG_bot * S_bot	1
depth * vort_surf	1
depth * vort_bot	1
depth * grain	1
W_bot * grain	1
depth * strat_strength	1
no interactions	**31**
Total	**141**

The highest-ranking models are listed in Table 7.7-2. Almost every model with depth * distance to land, depth * bottom temperature and depth * surface temperature interactions (n=66) ranked higher than any other model. Three-covariate models also ranked high when distance to land was included, or both of the temperatures. The highest ranking 3-covariate model was depth * distance to land + bottom current speed.

Table 7.7-2 **The best ranking model structures across the 20 datasets, given tried 141 models (See Table 7.7-1). Ubre is the information criteria score of the model in the original sample from the data. This original sample was used to select the 141 models from a much larger set. Models were ranked within each new data set according to their ubre score. The lower ubre score, the better the compromise of model complexity and model fit *in that data*. Minimum and median ranks are shown for each model. f(best) is the number of times that the model was selected as the best (lowest ubre score) model in the dataset. f(5%) is the number of times the model ranked in the 5% of the ubre scores. The table includes all models that occurred in the best 5% more than once, and whose median rank was less than 40**

Id	univariate 1	univariate 2	interaction	ubre	Min (rank)	Median (rank)	f (best)	f (5 %)
1	CS_bot	T_surf	depth * T_bot	-0.5770729	1	15	1	9
2	T_bot		depth * T_surf	-0.5716495	2	32.5	0	9
3	CS_bot	T_bot	depth * T_surf	-0.5794397	1	23	5	8
4	T_surf		depth * T_bot	-0.5674185	1	24.5	2	8
5	CS_bot	D_bot	depth * distLand	-0.574867	1	15	1	6
6	CS_bot	T_bot	depth * distLand	-0.5771748	1	19.5	1	6
7	CS_bot	CG_bot	depth * distLand	-0.5827833	1	30	1	6
8	CS_bot	CG_surf	depth * distLand	-0.5762228	1	15	2	5
9	CS_bot	W_bot	depth * distLand	-0.57689	1	20	1	4
10	CS_bot	grain	depth * distLand	-0.5768849	3	20	0	4
11	CS_bot	S_bot	depth * distLand	-0.5746738	2	22	0	4
12	CS_bot	CG_surf	depth * T_bot	-0.5780979	1	35	1	4
13	CS_bot	T_surf	depth * distLand	-0.5753696	3	35.5	0	4
14	T_bot		depth * distLand	-0.5670761	2	25	0	3
15	CS_bot	W_surf	depth * distLand	-0.5725886	2	29.5	0	3
16	CS_bot	ship	depth * distLand	-0.5750586	1	31	1	3
17	CS_bot	W_10_bot	depth * distLand	-0.5744471	1	22.5	1	2
18	CS_bot	CS_surf	depth * distLand	-0.5785741	2	23	0	2
19	CS_bot	CG_bot	depth * T_surf	-0.5825806	6	31	0	2
20	CS_bot	CG_surf	depth * T_surf	-0.5776201	3	35.5	0	2
21	CS_bot	vort_surf	depth * distLand	-0.5782472	3	35.5	0	2

It seemed that distance to land was important in the models due to the headland east of the haul-out sites, and the models' ability to fit this as a highly non-linear response. Animals passed this headland close to land, perhaps as a shortcut to reaching the foraging grounds to the east. We believe there was no affinity to land per se, especially in a coastal area where seals are unlikely to use land for navigation. We, therefore, decided to consider only the following models:

Presence ~ s(dist) + s(CS_bot) + te(depth, T_bot) + t(T_surf)
Model a.

Presence ~ s(dist) + te(depth, T_bot) + t(T_surf)
Model b.

Given distance to haul-out site, one of the three interactions and current speed, there was little difference between models including or not including a fifth covariate (Table 7.7-2). We would have expected bottom salinity/density and sediment grain size to be more important. Bottom current speed may have captured the variability in grain size. Similarly the two temperatures together probably captured more of the variability in water column features than bottom salinity/density.

Both of the models were fitted to each individual departing from each of the haul-out site. The ubre score of each model was improved by including the bottom current speed (Table 7.7-3). We therefore constructed the usage maps using Model a.

To interpret predictions from Model a, it was fitted to a larger data set (n=6000). The dataset was sampled so that sampling of the presence points was weighted by the time lag between subsequent locations. This way, we could predict with more precision while minimising serial correlation. Nevertheless, the prediction intervals should be interpreted with caution.

Table 7.7-3 Models a. and b. fitted to each individual (REF) departing from each haul-out site (RDS – Rødsand, VSK – Vitten-Skrollen) in the usage model. Sample size (N) and explained deviance % are provided for each model. D(ubre) is the improvement of the ubre score of the model when CS_bot is included. Estimated degrees of freedom (edf, measure of the wiggliness of the spline) are shown for each fitted term, and a p-value for their support in the model (Wald test)

model	haul-out	REF	N	D(ubre)	expl dev %	dist		depth *T_bot		T_surf		CS_bot	
						edf	p	edf	p	edf	p	edf	p
b	RDS	pv28-05-09	721		99.3	2.0	0.16	8.5	0.72	8.6	0.76		
b	RDS	pv28-07-09	6654		72.2	2.0	0.00	11.6	0.00	8.7	0.00		
b	RDS	pv28-10-09	10834		61.2	1.7	0.00	23.7	0.00	9.0	0.00		
b	RDS	pv28-12-09	7094		56.9	1.9	0.00	23.1	0.00	8.8	0.00		
b	VSK	pv28-05-09	1688		75.6	2.0	0.00	10.5	0.00	5.7	0.21		
b	VSK	pv28-07-09	2845		78.5	1.8	0.00	15.0	0.00	8.1	0.00		
b	VSK	pv28-12-09	5042		57.7	2.0	0.00	23.0	0.00	8.5	0.00		
a	RDS	pv28-05-09	721	0.0012785	100.0	1.6	0.96	11.7	1.00	5.1	1.00	2.5	1.00
a	RDS	pv28-07-09	6654	0.0018888	72.5	2.0	0.00	11.6	0.00	8.8	0.00	3.3	0.00
a	RDS	pv28-10-09	10834	0.0118407	62.6	1.9	0.00	23.7	0.00	9.0	0.00	6.4	0.00
a	RDS	pv28-12-09	7094	0.0012907	57.1	1.9	0.00	23.1	0.00	8.7	0.00	5.1	0.01
a	VSK	pv28-05-09	1688	0.0045828	76.2	2.0	0.00	10.2	0.00	5.8	0.07	1.0	0.00
a	VSK	pv28-07-09	2845	0.0004794	79.9	1.8	0.00	16.5	0.00	8.2	0.00	4.8	0.21
a	VSK	pv28-12-09	5042	0.0041566	58.6	2.0	0.00	22.9	0.00	8.4	0.00	5.3	0.00

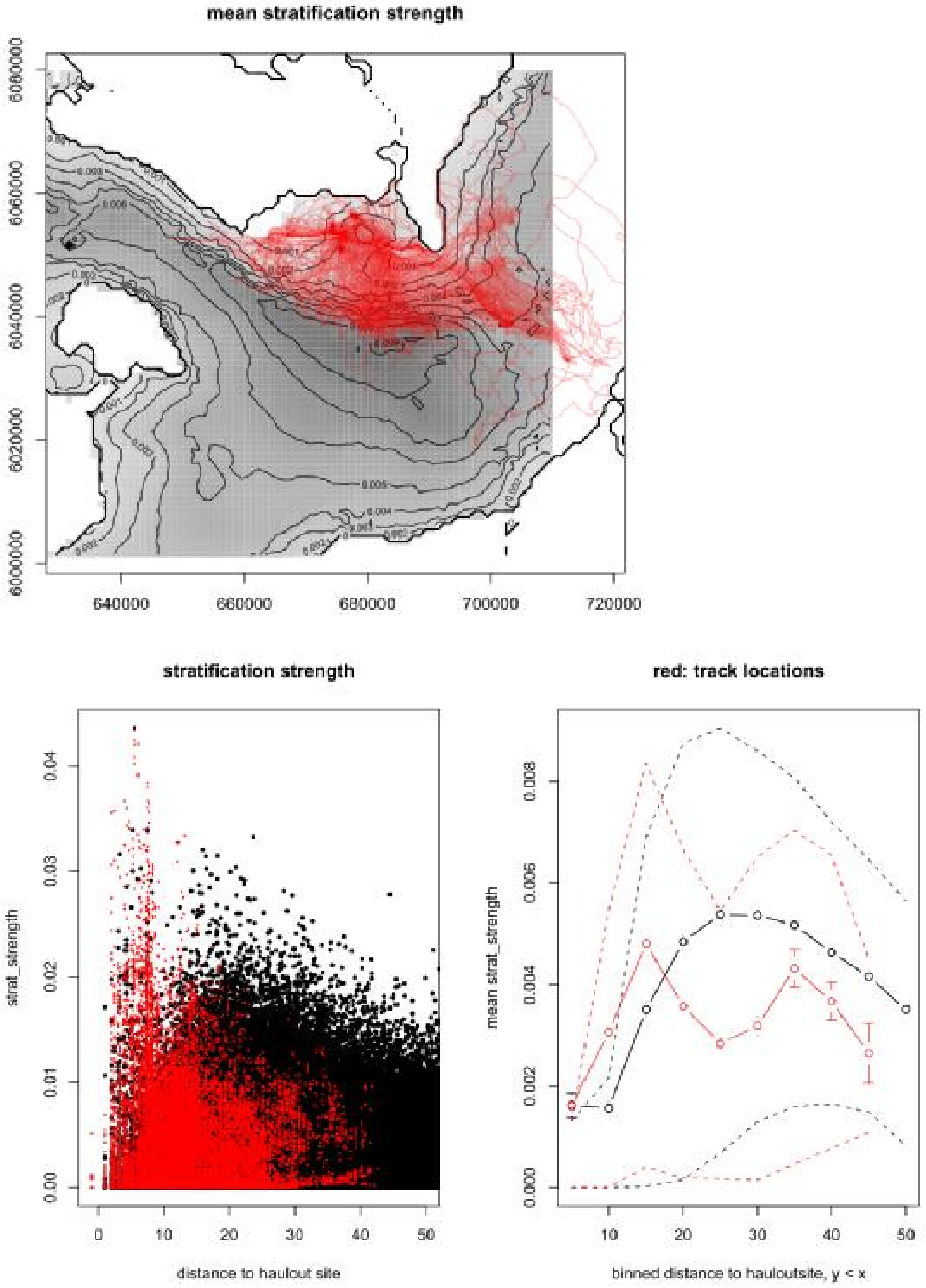

Figure 7.7-7 **Map of mean stratification strength and stratification as a function of distance to the haul-out sites. Dashed lines show 60 % quantile of the data, vertical lines are 5% error bars for the means.**

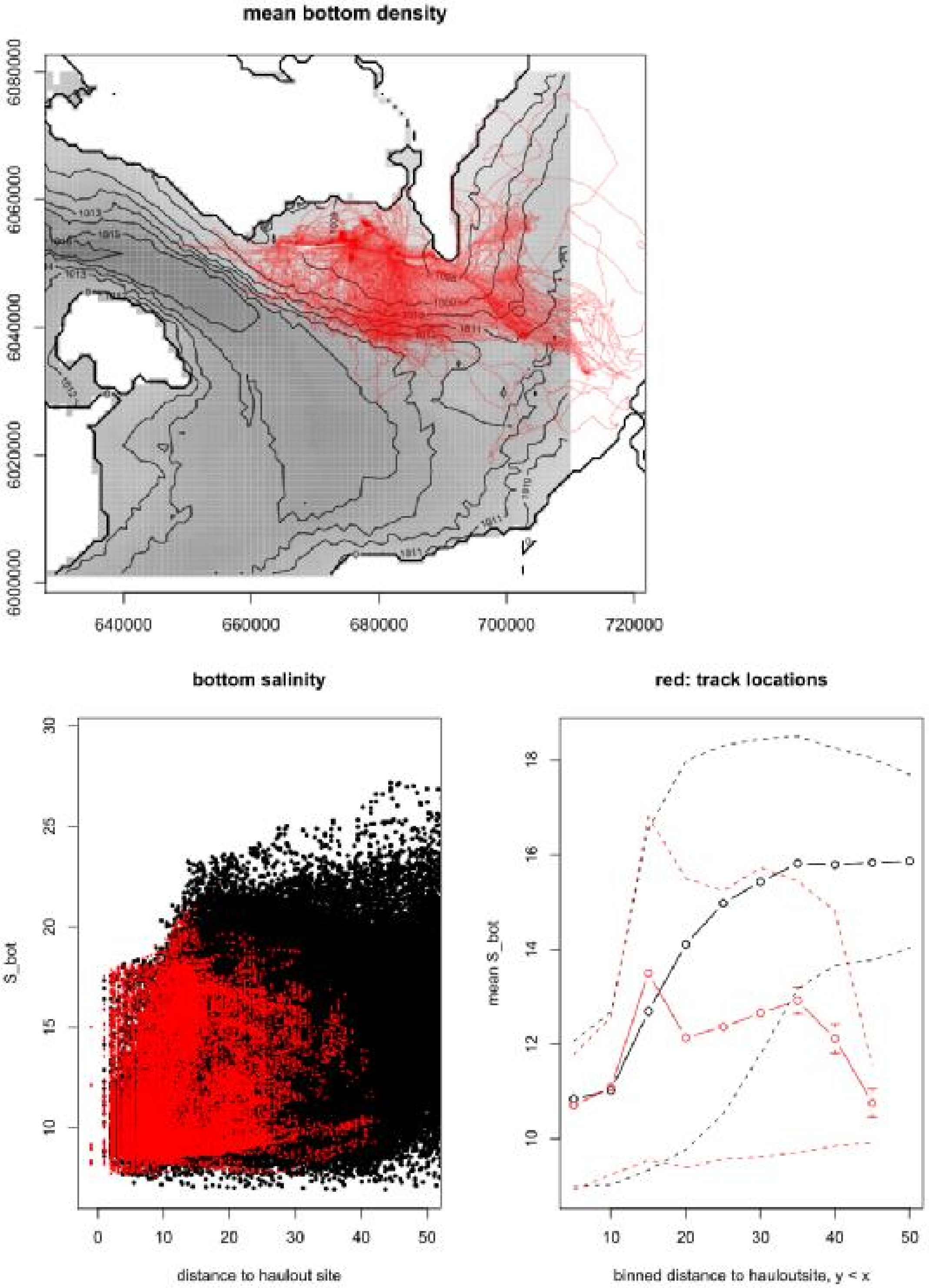

Figure 7.7-8 Map of mean bottom density and salinity as a function of distance to the haul-out sites. Dashed lines show 60 % quantile of the data, vertical lines are 5% error bars for the means.

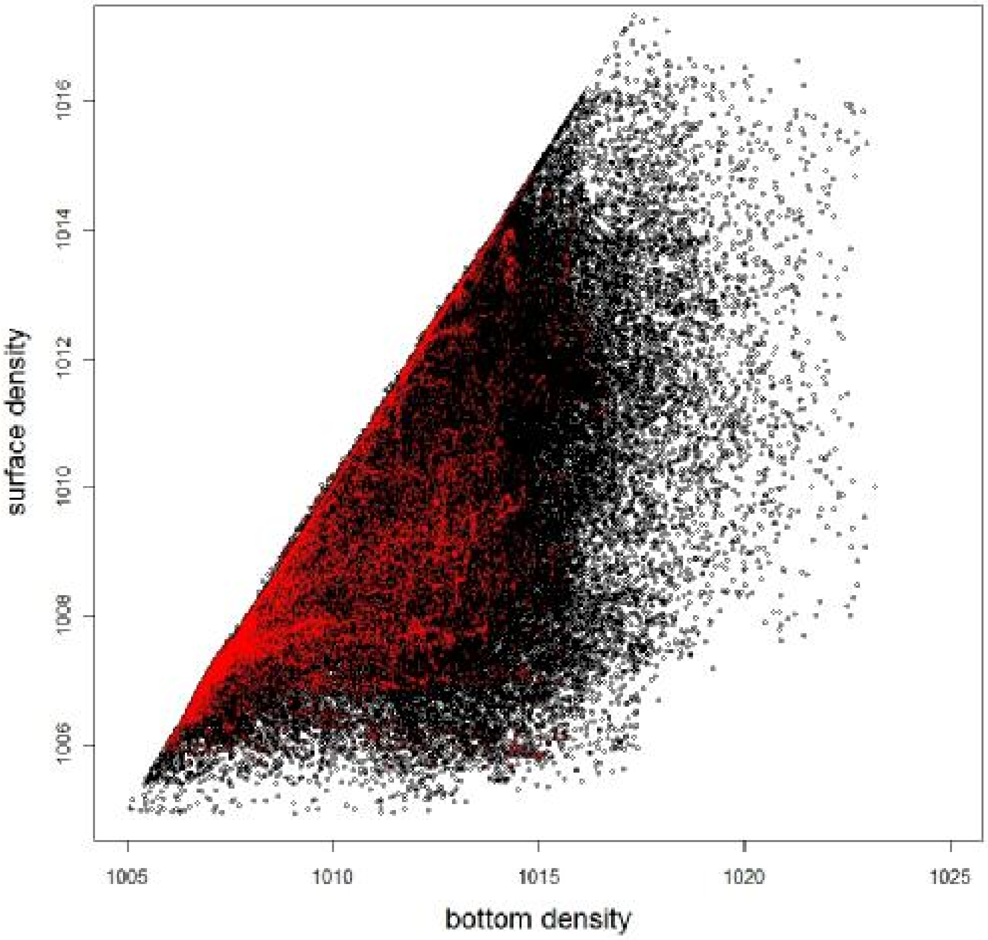

Figure 7.7-9 Surface density as a function bottom density. Red dots shows presence, black absence points.

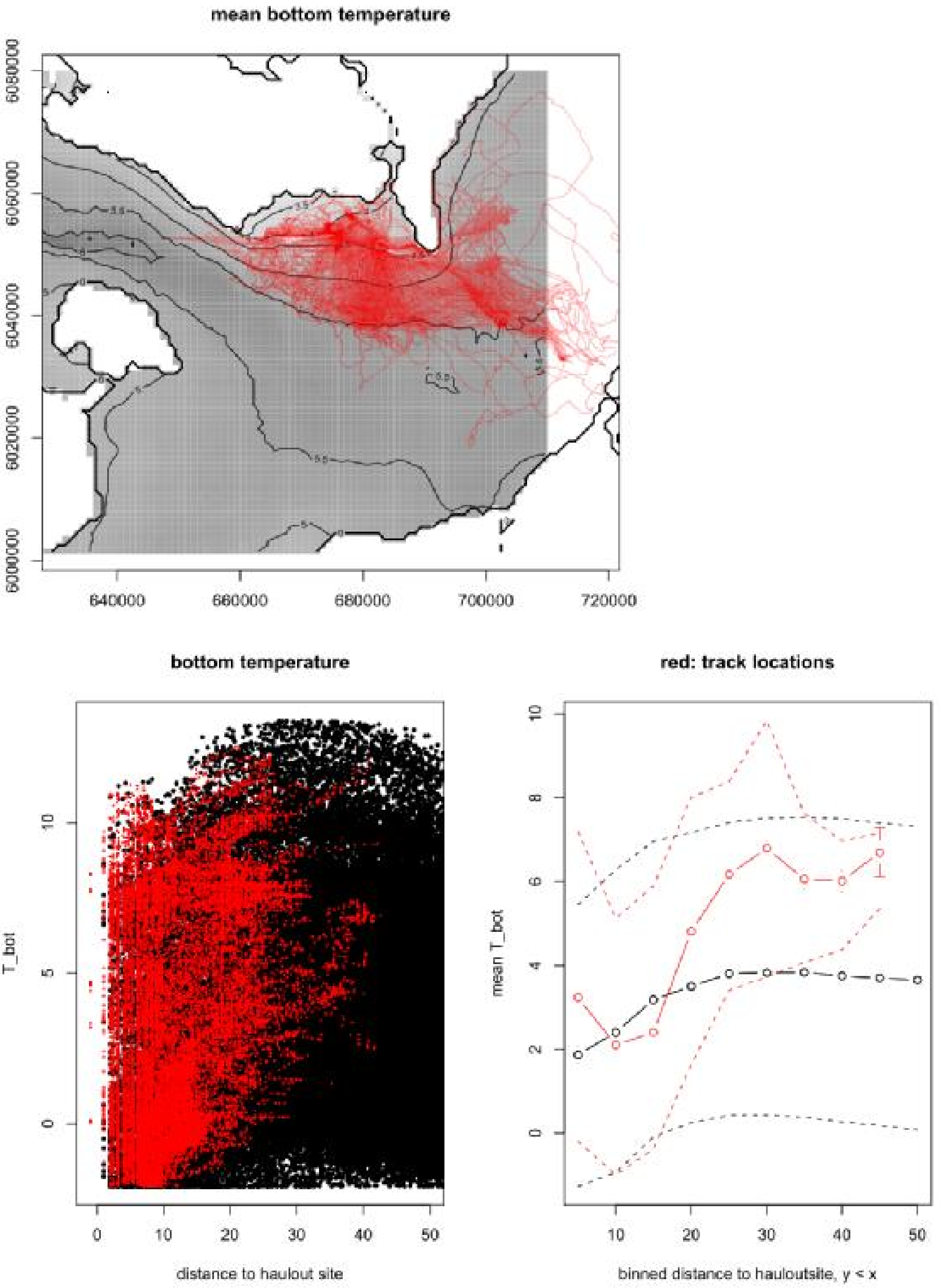

Figure 7.7-10 Map of mean bottom temperature, and temperature as a function of distance to the haul-out site. Dashed lines show 60 % quantile of the data, vertical lines are 5% error bars for the means.

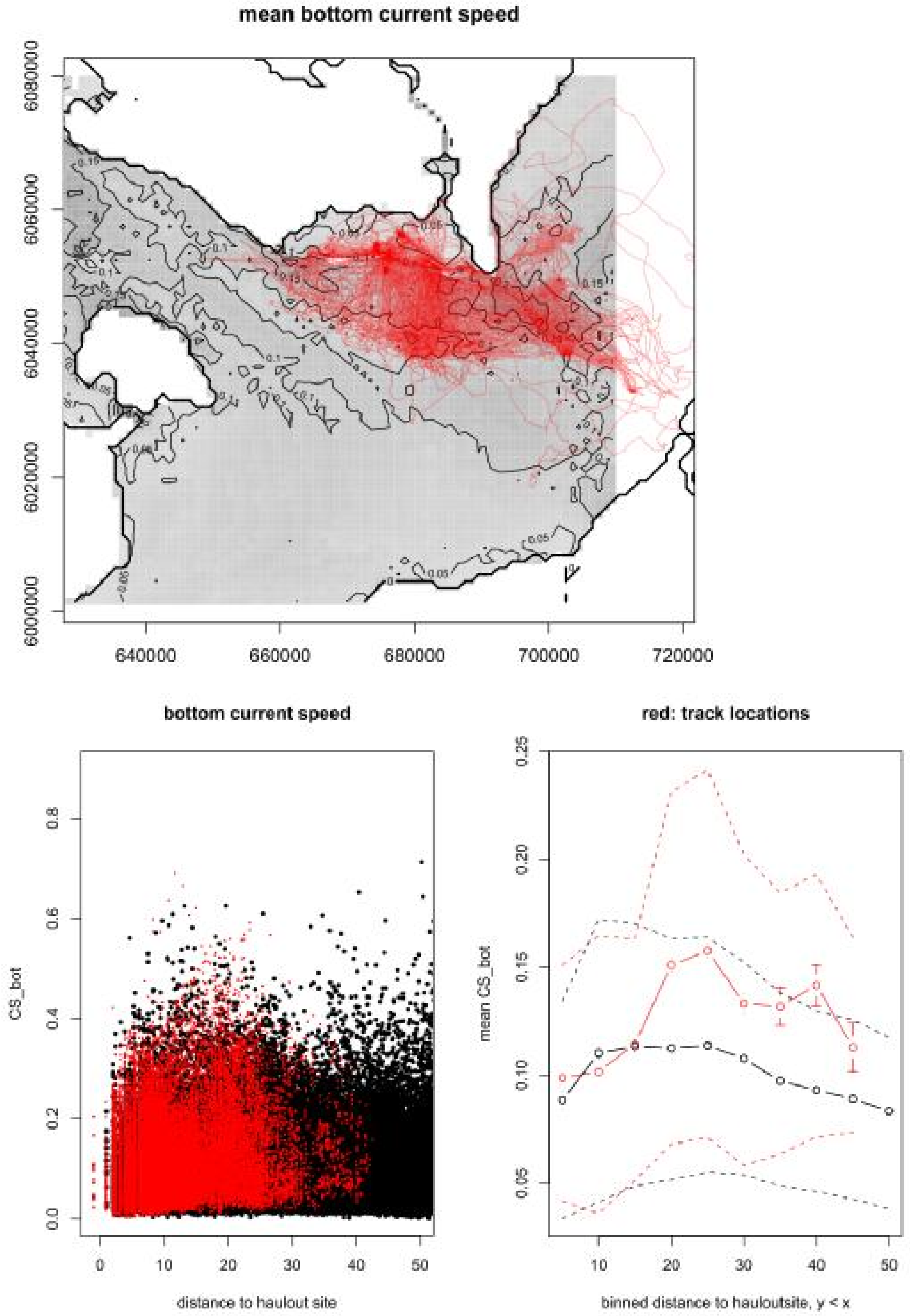

Figure 7.7-11 Map of mean bottom current speed, and bottom current speed as a function of distance to the haul-out site. Dashed lines show 60 % quantile of the data, vertical lines are 5% error bars for the means.

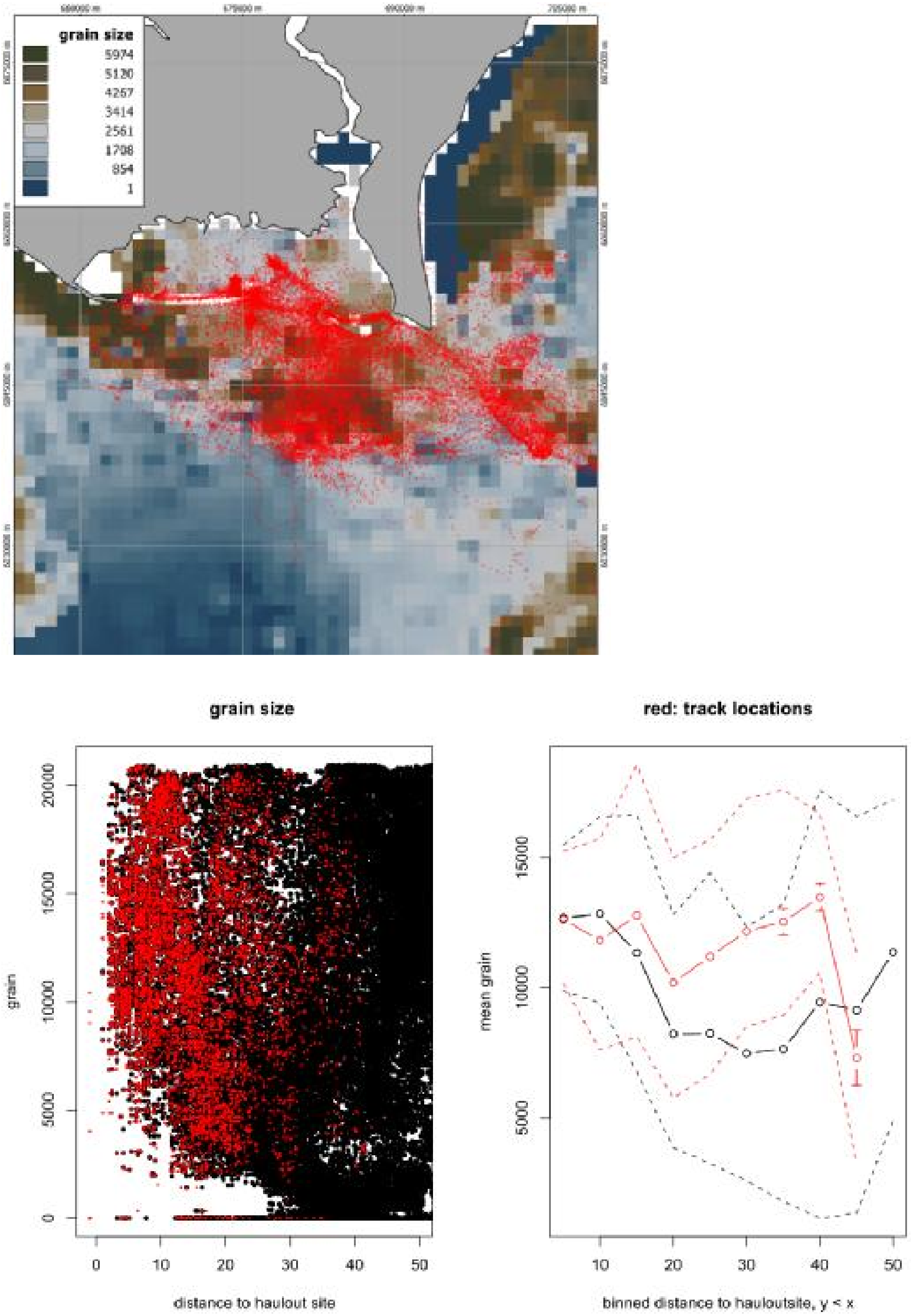

Figure 7.7-12 Map of mean grain size, and grain size as a function of distance to the haul-out site. Dashed lines show 60 % quantile of the data, vertical lines are 5% error bars for the means.

7.7.3. Historic Seal Tag data

During 2001-2002, NERI deployed 10 tags on harbour and grey seals in the the Fehmarnbelt region. The tags were Argos spot tags and were deployed on four harbour seals and six grey seals from Rødsand. The location data were smoothed using a Kalman filter. These data add further suport to the findings of the FMM studies; primarily that grey seals travel more widely from the haul-out where as the distribuiton of harbour seals is more localised to the haul-out.

Table 7.7-4 Details of the seals tagged by NERI between 2001 and 2002. The tags were all Argos Spot tags

Ref	Species	Sex	Age	Mass (kg)	Length (cm)	Tagging date	Final date
10337b	Pv	M	subadult	54	121	21/04/2001	22/06/2001
10335	Pv	F	adult	100	148	22/04/2001	15/06/2001
17562	Pv	M	yearling	25	90	24/09/2001	27/02/2002
17773	Pv	M	subadult	43.5	107	12/04/2002	27/06/2002
10337a	Hg	M	subadult	49	130	16/11/2000	27/11/2000
24286	Hg	M	subadult	71	135	17/11/2000	12/03/2001
10334	Hg	F	subadult	66	133	20/04/2001	14/05/2001
17567	Hg	M	adult	110	162	18/09/2001	13/05/2002
17759	Hg	F	adult	110	152	18/09/2001	29/04/2002
17765	Hg	F	adult	74	150	20/03/2002	27/04/2002

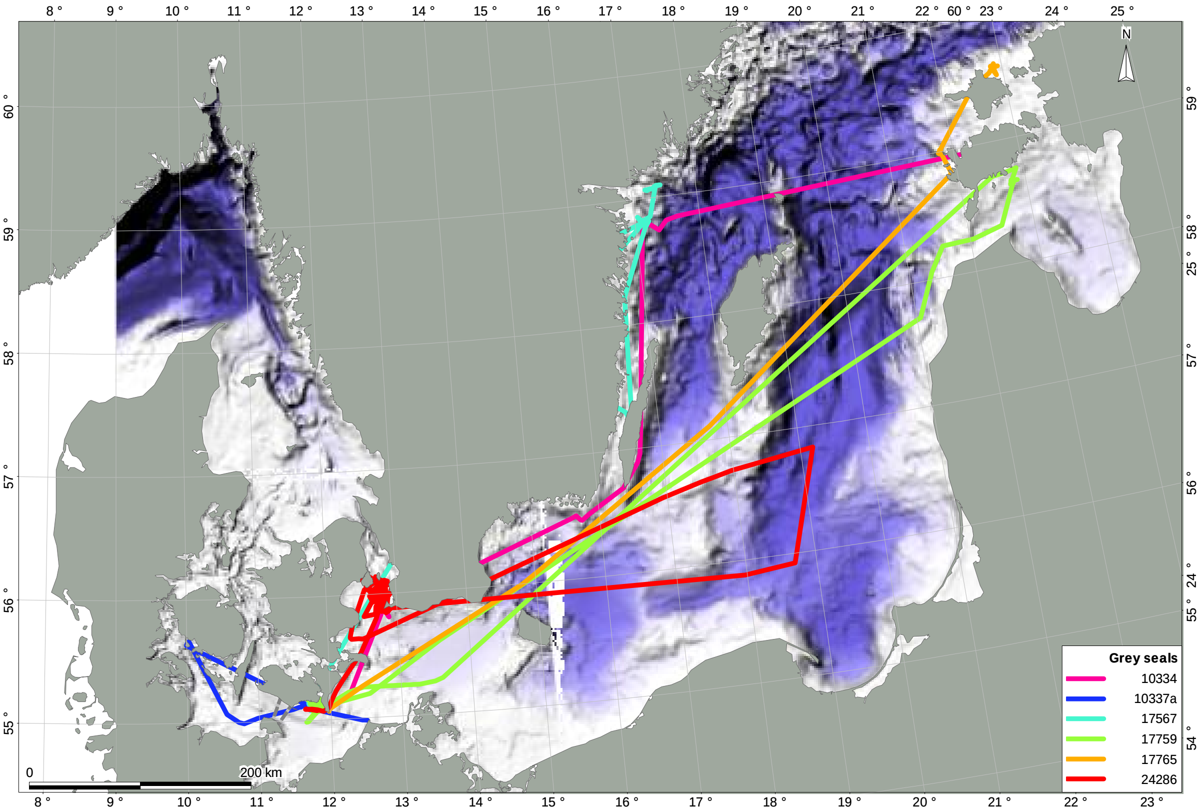

Figure 7.7-13 Tracks of six grey seals tagged with Argos spot tags between 2001-2002 in the Danish Straits.

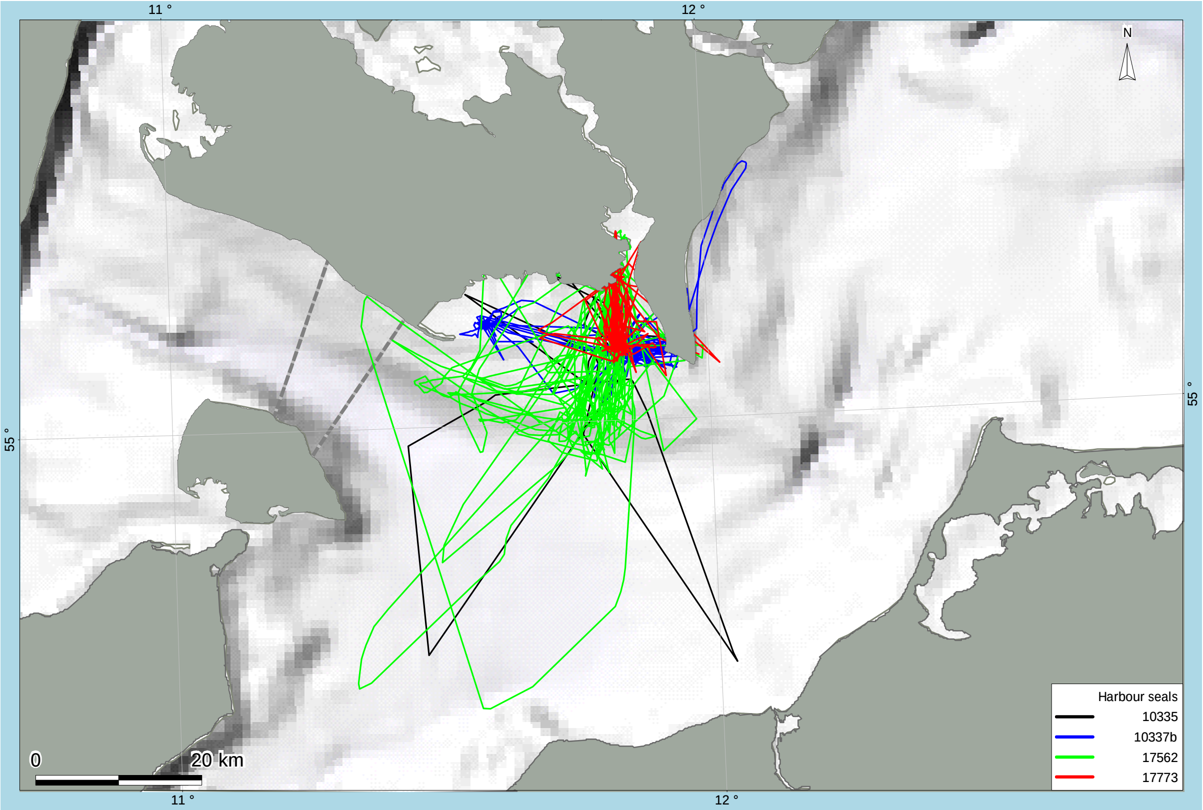

Figure 7.7-14. Tracks of four harbour seals tagged with Argos Spot tags in the Danish Straits, 2001-2002.

7.7.4. Ancillary data on harbour and grey seal movements through the Fehmarnbelt.

In 2010 the UK Crown Estate commissioned the Sea Mammal Research Unit and the National Environment Research Council (Prof Rune Dietz) to extend the seal studies in the Fehmarnbelt region. The aim of this study was to provide higher resolution location telemetry data to investigate the effects of operating wind farms on the movements of the local harbour and grey seals. The Crown Estate has kindly agreed to this extra data being made available to the Fehmarnbelt Fixed Link baseline studies. The data adds new insight into the usage within the area of the proposed fixed link. We present, and briefly describe, the tracks in their raw form rather than integrating them into our existing usage model.

Five grey seals and one harbour seal were captured and tagged at the Rødsand haul-out (Table 7.7-5). The tracks of those four tagged with GPS/GSM tags are shown in Figure 7.7-15 and Figure 7.7-16.

Two important points emerge which augment the main body of the Report.

1. All three grey seals undertook movement to the west, through the region of the proposed fixed link. Hg-04-01's passage was brief – within a day. However passages of the other two GPS/GSM tagged grey seals were more extensive and provided connectivity with a network of haul-out sites up to 100 km to the north-west.
2. The sub-adult harbour seal (Pv-02-10) moved through the region of the proposed fixed link seven times over a period of four months. Its travels were extensive – up to 180 km to the north and west. In the body of the report we provide tracks from only one sub-adult harbour seal – and it also showed similar large scale movement. This adds weight to the suggestion that it is a characteristic of sub-adults in their exploratory phase – in contrast to the more restricted movement patterns of adult harbour seals. Thus sub-adult harbour seals may have higher usage in the area of the proposed fixed link.

Table 7.7-5 Deployment details and tagging longevity. Tag type: A=Argos satellite, G=GPS/GSM.[1] Data still being received at time of report writing

ref	species	sex	age	tag type	tagging date	final date	duration (day)
Hg-01-10	Hg	M	adult	G	08/10/2010	27/03/2011	170
Hg-04-10	Hg	M	juvenile	G	06/10/2010	29/03/2011	174
Hg-05-10	Hg	M	juvenile	G	07/10/2010	28/02/2011	144
Hg-37281-10	Hg	M	juvenile	A	08/10/2010	30/03/2011[1]	173
Hg-60266-10	Hg	M	adult	A	07/10/2010	30/03/2011[1]	174
Pv-02-10	Pv	F	juvenile	G	08/10/2010	07/02/2011	122

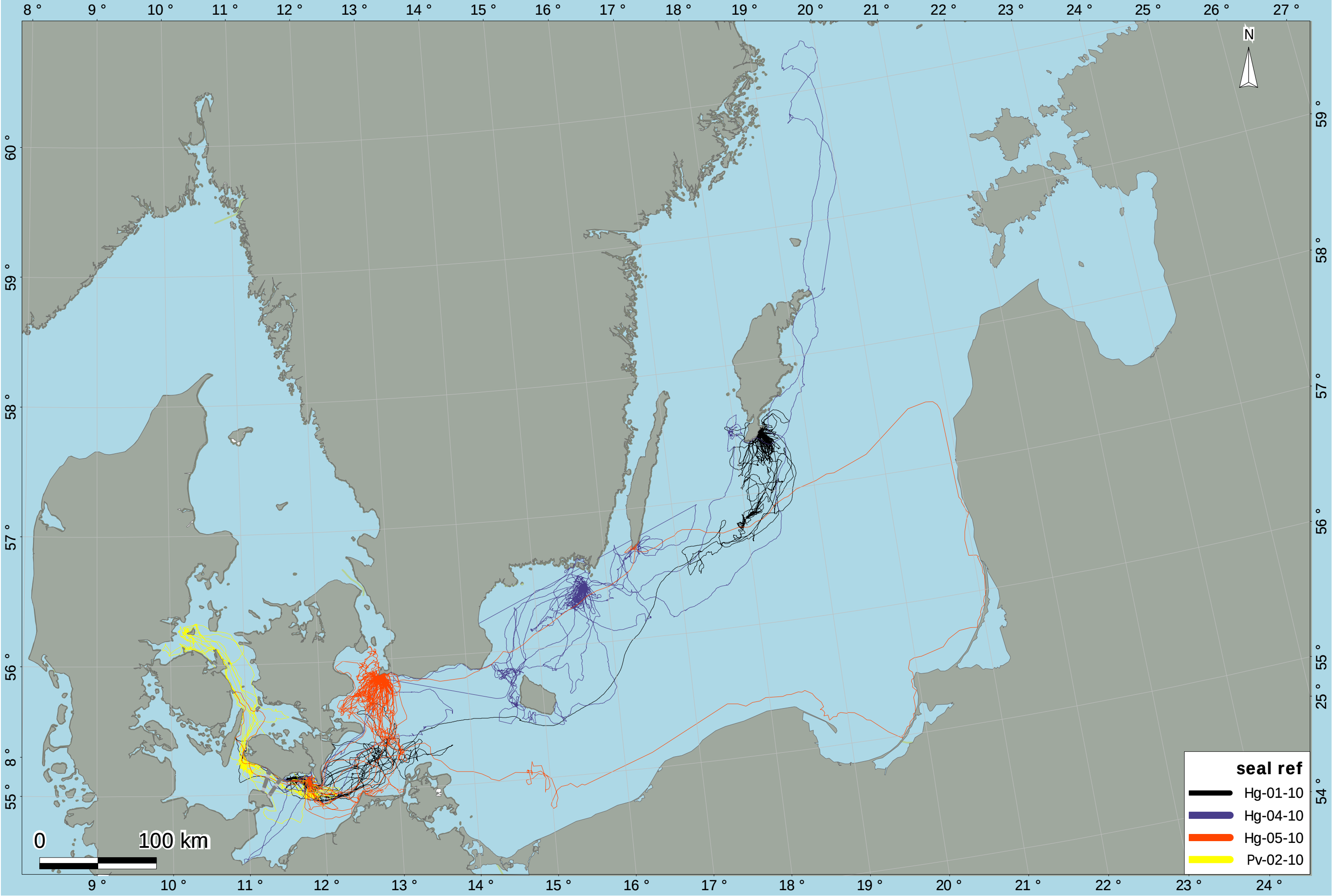

Figure 7.7-15 **Tracks of the four seals (three grey – Hg; one harbour – Pv) tagged with GPS/GSM tags in 2010. Data supplied by The Crown Estate.**

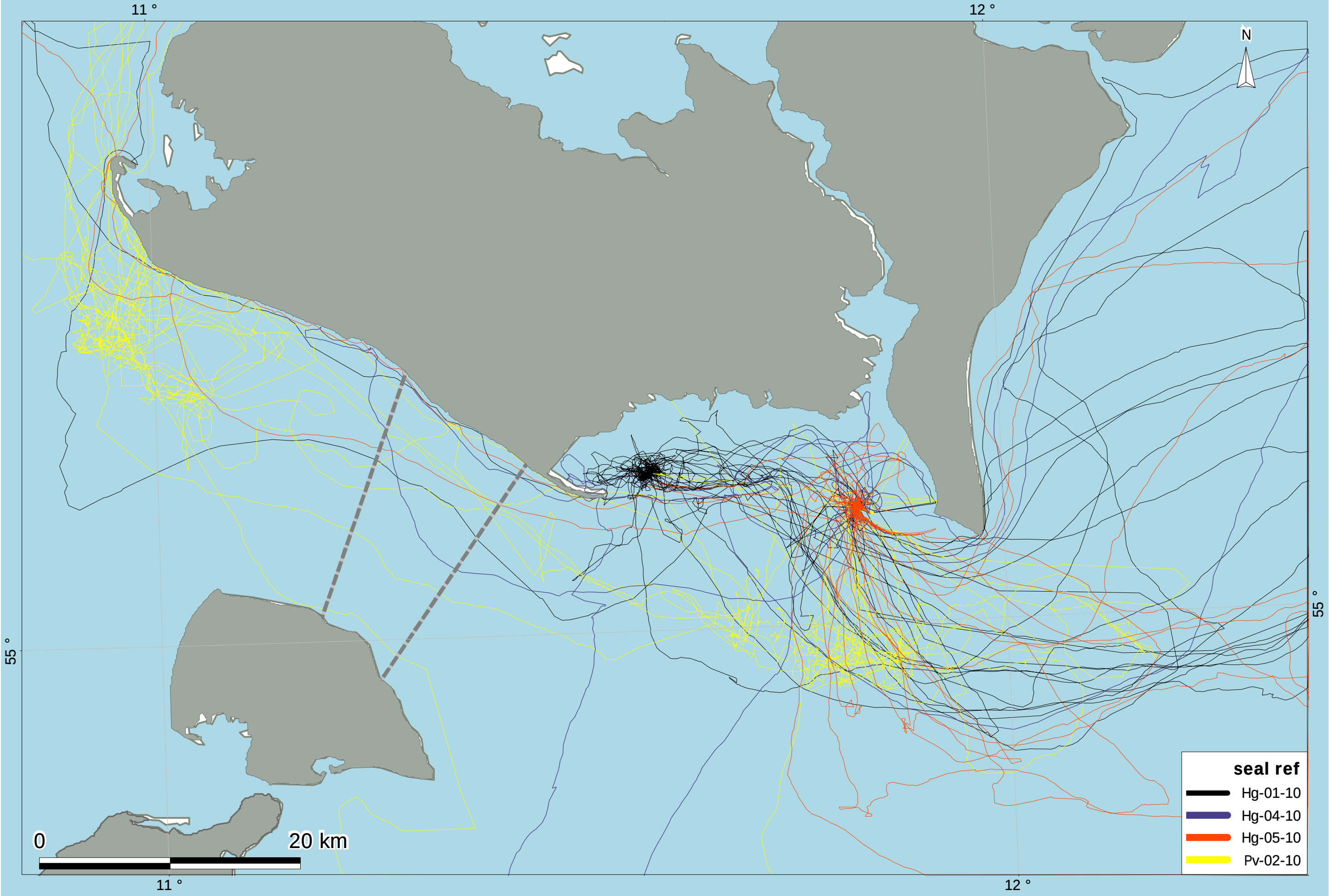

Figure 7.7-16 Tracks of the four seals (three grey – Hg; one harbour – Pv) tagged with GPS/GSM tags in 2010. Data supplied by The Crown Estate.

7.8. Appendix 8: Seal Health Studies tables

Table 7.8-1 Mass, length, girth and condition index (mass/length) of harbour and grey seals sampled at Rødsand haul-out site, October 2009

Species	Sex	Age Class	Mass (kg)	Length (cm)	Girth (cm)	Condition Index (kg/cm)
Harbour seal	M	Adult	113	153	123	0.739
Harbour seal	M	Adult	97	149	119	0.651
Harbour seal	M	Adult	90	137	117	0.657
Harbour seal	M	Adult	103	156	123	0.658
Harbour seal	F	Juvenile	32	104	83	0.305
Grey seal	M	Juvenile	49	117	94	0.416
Grey seal	F	Juvenile	48	112	89	0.424

Table 7.8-2 **Haematology parameters in harbour and grey seals sampled at Rødsand haul-out site, October 2009**

Species	Sex	Age Class	Total White Blood Cells (x 10^6/ml)	Polymorphonuclear cells (x 10^6/ml)	Lymphocytes (x 10^6/ml)	Monocytes (x 10^6/ml)	Eosinophils (x 10^6/ml)	Total IgG (mg/ml)
Harbour seal	M	Adult	6.11	2.87	2.15	0.26	0.83	40.24
Harbour seal	M	Adult	6.09	3.87	1.26	0.45	0.53	38.10
Harbour seal	M	Adult	8.2	5.74	1.44	0.68	0.34	38.28
Harbour seal	M	Adult	9.24	6.16	1.23	0.74	1.11	36.11
Harbour seal	F	Juvenile	10.56	5.68	1.94	1.01	1.94	42.10
Grey seal	M	Juvenile	10.12	6.41	2.30	0.40	1.00	41.96
Grey seal	F	Juvenile	9.90	5.17	2.83	0.86	1.48	35.62

Table 7.8-3 **Clinical chemistry parameters in harbour and grey seals sampled at Rødsand haul-out site, October 2009. Published range [1]Greig et al., 2010; [2]Hall, 1998**

Species	Sex	Age Class	Glucose (mmol/L)	Cholesterol (mmol/L)	ALP (U/L)	Urea (mmol/L)	Triglycerides (mmol/L)	Albumin (µmol/L)	Total Protein (g/L)
Published range[1]			4.77-8.94	-	4-88	-	0.43-2.77	379-515	70-95
Harbour seal	M	Adult	**9.88**	5.75	**150**	13.78	1.32	**588**	**62**
Harbour seal	M	Adult	5.60	3.76	**200**	11.81	1.41	**549**	**61**
Harbour seal	M	Adult	**9.17**	2.21	**100**	11.76	1.52	**607**	**65**
Harbour seal	M	Adult	7.96	5.25	**150**	17.81	1.21	**613**	**62**
Harbour seal	F	Juvenile	8.60	3.23	**150**	12.71	1.77	**611**	**64**
Published range[2]			5.2-10.15	-	-	-	-	197-636	48-109
Grey seal	M	Juvenile	7.67	5.62	375	8.36	2.79	551	62
Grey seal	F	Juvenile	**10.97**	6.52	50	9.58	2.25	614	60

Species	Sex	Age Class	AST (U/L)	ALT (U/L)	Total Bilirubin (µmol/L)	Creatinine (mmol/L)	Globulin (g/L)	Iron (µmol/L)
Published range[1]			59-326	22-123	3-31	0.044-0.097	43-67	10-56
Harbour seal	M	Adult	157	60	2	**0.12**	51	40
Harbour seal	M	Adult	54	58	3	**0.13**	61	54
Harbour seal	M	Adult	151	63	3	**0.13**	58	35
Harbour seal	M	Adult	113	61	3	**0.14**	60	22
Harbour seal	F	Juvenile	97	61	3	**0.20**	54	**63**
Published range[2]			-	-	-	-	23-88	-
Grey seal	M	Juvenile	173	63	2	0.11	45	13
Grey seal	F	Juvenile	185	63	4	0.31	60	59

Table 7.8-4 **CDV-VNT titres in harbour and grey seals sampled at Rødsand haul-out site, October 2009. Titres of <5 are seronegative**

Species	Sex	Age Class	CDV-VNT titre
Harbour seal	M	Adult	56
Harbour seal	M	Adult	20
Harbour seal	M	Adult	<5
Harbour seal	M	Adult	113
Harbour seal	F	Juvenile	<5
Grey seal	M	Juvenile	<5
Grey seal	F	Juvenile	<5

Table 7.8-5 **Cortisol concentrations in harbour and grey seals sampled at Rødsand haul-out site, October 2009**

Species	Sex	Age Class	Cortisol (nmol/L)
Harbour seal	M	Adult	847
Harbour seal	M	Adult	2234
Harbour seal	M	Adult	480
Harbour seal	M	Adult	434
Harbour seal	F	Juvenile	586
Grey seal	M	Juvenile	998
Grey seal	F	Juvenile	915

Table 7.8-6 **Polyaromatic hydrocarbons (PAHs) in harbour and grey seals sampled at Rødsand haul-out site, October 2009 (<LOD, below limit of detection)**

Species	Sex	Age Class	PAHs (ppb)
Harbour seal	M	Adult	0.8
Harbour seal	M	Adult	1.2
Harbour seal	M	Adult	<LOD
Harbour seal	M	Adult	<LOD
Harbour seal	F	Juvenile	<LOD
Grey seal	M	Juvenile	<LOD
Grey seal	F	Juvenile	<LOD

Table 7.8-7 Heavy metals in seal plasma samples (mg/kg)

Species	Sex	Age Class	Cr	Ni	Cu	Zn	As	Cd	Pb	Se	Hg	Mn	Fe
Harbour seal	M	Adult	<0.01	<0.02	0.83	<1.11	0.04	<0.01	<0.01	0.46	<0.01	<0.04	2.7
Harbour seal	M	Adult	<0.01	<0.02	0.66	<1.11	<0.01	<0.01	<0.01	0.43	<0.01	<0.04	1.8
Harbour seal	M	Adult	<0.01	<0.02	0.74	<1.1	<0.01	<0.01	<0.01	0.46	<0.01	<0.04	2.0
Harbour seal	M	Adult	<0.01	<0.02	0.68	<1.11	0.01	<0.01	<0.01	0.46	<0.01	<0.04	2.1
Harbour seal	F	Juvenile	<0.01	<0.02	0.67	<1.09	<0.01	<0.01	<0.01	0.46	<0.01	<0.04	2.1
Grey seal	M	Juvenile	<0.01	<0.02	0.76	<1.12	0.05	<0.01	<0.01	0.47	<0.01	<0.04	1.7
Grey seal	F	Juvenile	<0.01	<0.02	0.91	<1.11	0.2	<0.01	<0.01	0.47	<0.01	<0.04	1.5

Table 7.8-8 **Fish otolith measurements, digestion coefficients, otolith length (OL) or otolith width (OW) to fish length (FL) regression equation coefficients, and final estimated fish lengths in faecal samples collected from Rødsand haul-out site. [1]Otoliths were graded by degree of digestion and grade-specific correction factors (digestion coefficients, DC) were applied. Regression relationships used were all from Leopold et al., 2001 except those indicated ** which were taken from Härkönen 1986**

Seal Species	Otolith identification	OL (mm)	OW(mm)	DC[1]	OL or OW to FL regression equation	FL (cm)
Harbour	Cod	6.72	2.85	1.56	-6.635+(3.493*OL)	30.0
Harbour	Cod	6.50	2.81	1.56	-6.635+(3.493*OL)	28.8
Harbour	Cod	6.41	2.65	1.56	-6.635+(3.493*OL)	28.3
Harbour	Cod	6.18	2.55	1.56	-6.635+(3.493*OL)	27.0
Harbour	Cod	5.78	2.39	1.56	-6.635+(3.493*OL)	24.8
Harbour	Herring	3.18	1.20	1.32		
Harbour	Herring	2.80	1.77	1.32		
Harbour	Herring	2.11	1.09	1.32		
Harbour	Whiting	7.96	2.69	1.50		
Harbour	Black Goby	2.35	1.80	1.00	(-8.927+(42.037*OL))/10**	6.7
Harbour	Black Goby	2.22	2.18	1.00	(-8.927+(42.037*OL))/10**	8.3
Harbour	Long Spined Sea Scorpion	3.44	1.85			
Grey	Cod	10.92		1.56	-6.635+(3.493*OL)	52.9
Grey	Cod	11.82		1.56	-6.635+(3.493*OL)	57.8
Grey	Cod	11.63		1.56	-6.635+(3.493*OL)	56.7
Grey	Cod	7.7		1.56	-6.635+(3.493*OL)	35.3
Grey	Cod	13.32		1.56	-6.635+(3.493*OL)	65.9
Grey	Cod	11.08		1.56	-6.635+(3.493*OL)	53.7
Grey	Cod	11.52		1.56	-6.635+(3.493*OL)	56.1
Grey	Cod	11.74		1.56	-6.635+(3.493*OL)	57.3
Grey	Cod	7.69		1.56	-6.635+(3.493*OL)	35.3
Grey	Herring					
Grey	Herring					
Grey	Herring					
Grey	Lavaret	7.29		1.00	(2.724+(48.6*OL))/10**	35.7
Grey	Whiting					
Unknown	Cod	12.48		1.56	-6.635+(3.493*OL)	61.4
Unknown	Cod	7.03		1.56	-6.635+(3.493*OL)	31.7
Unknown	Herring					
Unknown	Herring	1.94		1.00	-6.359+(15.507*OW)	27.0
Unknown	Herring	1.96		1.00	-6.359+(15.507*OW)	27.4
Unknown	Whiting	5.53		1.50	0.81+(1.726*OL)	15.1
Unknown	Whiting	5.14		1.50	0.81+(1.726*OL)	14.1
Unknown	Whiting	7.62		1.50	0.81+(1.726*OL)	20.5

Seal Species	**Otolith identification**	**OL (mm)**	**OW(mm)**	**DC^1**	**OL or OW to FL regression equation**	**FL (cm)**
Unknown	Four bearded Rockling	4.51		1.25	-4.61+(7.065*OL)	35.2
Unknown	Four bearded Rockling	4.52		1.25	-4.61+(7.065*OL)	35.3
Unknown	Sandeel					
Unknown	Sandeel					
Unknown	Sandeel					
Unknown	Sandeel					
Unknown	Sandeel					
Unknown	Sandeel					
Unknown	Sandeel					
Unknown	Sandeel					
Unknown	Sandeel					
Unknown	Sandeel					